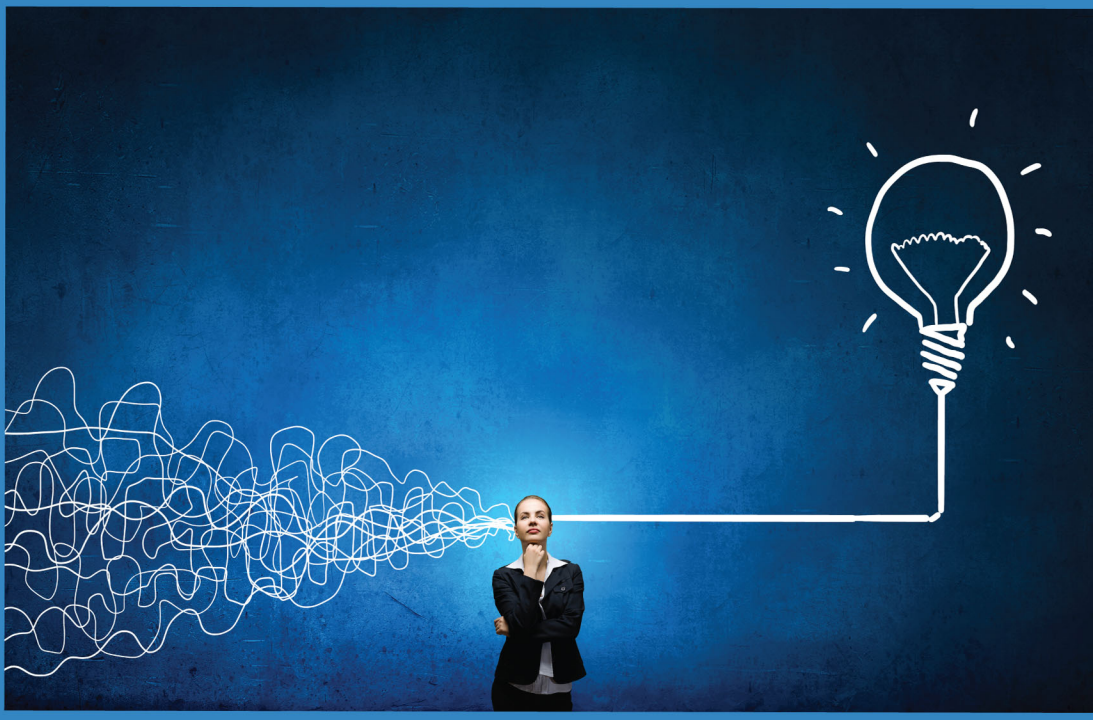
Automated Problem Solving and Decision Making:
Key Trends



Edited by: **C. R. Larsen**

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e-book Edition 2021

ISBN: 978-1-98465-323-9 (e-book)

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In Collaboration with Intelliz Press. Originally Published in printed book format by Intelliz Press with ISBN 978-1-68251-788-8

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PREFACE

The day-to-day work of business professionals requires solving problems (or assessing opportunities) and making decisions. Decision making is a core activity for professional regulators. However, high-impact regulatory decisions are often made in an uncertain environment affected by resource constraints, individual biases and time pressures. Regulators can draw on a range of tools and techniques to strengthen their organisational decision making processes to address these challenges. The decision making process of many operations are dependent on analyzing very large data sets, previous decisions and their results. The information generated from the large data sets are used as an input for making decisions. Since the decisions to be taken in day to day operations are expanding, the time taken for manual decision making is also expanding. In order to reduce the time, cost and to increase the efficiency and accuracy, which are the most important things for customer satisfaction, many organisations are adopting the automated decision making systems.

Consequently, the purpose of this book is to introduce you to methods and techniques that will help you solve problems and make decisions. This book presents insights about the technologies used for automated decision making systems and the areas in which automated decisions systems works more efficiently and accurately. The Automated decision making systems are mainly used in business analytics and informatics. The decision making systems can be automated by applying certain business rules which are generated and operated by business analytics. The decisions taken by the automated decision making systems are part of the business informatics. This book provides the wide—ranging coverage to the challenges and perspectives of decision making from a computational perspective. This book will serve as valuable tool for directors, policy staff and operations staff, as well as to researchers and practitioners working within the field of organisational decision making. It is also of relevance to other regulatory bodies with an interest in the findings and conclusions from the work.

CHAPTER 1

A MULTI-OBJECTIVE DECISION-MAKING APPROACH TO THE JOURNAL SUBMISSION PROBLEM

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ABSTRACT

When researchers complete a manuscript, they need to choose a journal to which they will submit the study. This decision requires to navigate trade-offs between multiple objectives. One objective is to share the new knowledge as widely as possible. Citation counts can serve as a

proxy to quantify this objective. A second objective is to minimize the time commitment put into sharing the research, which may be estimated by the total time from initial submission to final decision. A third objective is to minimize the number of rejections and resubmissions. Thus, researchers often consider the trade-offs between the objectives of (i) maximizing citations, (ii) minimizing time-to-decision, and (iii) minimizing the number of resubmissions. To complicate matters further, this is a decision with multiple, potentially conflicting, decision-maker rationalities. Co-authors might have different preferences, for example about publishing fast versus maximizing citations. These diverging preferences can lead to conflicting trade-offs between objectives. Here, we apply a multi-objective decision analytical framework to identify the Pareto-front between these objectives and determine the set of journal submission pathways that balance these objectives for three stages of a researcher's career. We find multiple strategies that researchers might pursue, depending on how they value minimizing risk and effort relative to maximizing citations. The sequences that maximize expected citations within each strategy are generally similar, regardless of time horizon. We find that the "conditional impact factor"—impact factor times acceptance rate—is a suitable heuristic method for ranking journals, to strike a balance between minimizing effort objectives and maximizing citation count. Finally, we examine potential co-author tension resulting from differing rationalities by mapping out each researcher's preferred Pareto front and identifying compromise submission strategies. The explicit representation of trade-offs, especially when multiple decision-makers (co-authors) have different preferences, facilitates negotiations and can support the decision process.

INTRODUCTION

Researchers often face the decision problem of where to submit a manuscript. In addition to potential professional benefits, the quick publication of papers where they are likely to be widely read improves the public good obtained by the generation and dissemination of scientific knowledge.

Some authors and institutions focus on the impact factor of the journals in

which a researcher publishes as a measure of the reach of the researcher's work [1,2]. This is motivated by the fact that a journal's impact factor is intended to correlate with the average number of times per year a paper in a given journal is cited [3]. The use of impact factors is often criticized, however. For example, impact factor is a journal-level metric, not author-level, so their usefulness for evaluating the productivity of an individual researcher is limited [2,4]. Additionally, impact factors fail to take into account numerous non-citation considerations in determining an author's scientific reach (such as social media activity, media interest, page and article views, influence in policy documents and general interest outside the core scientific community) [4,5]. Impact factors also tend to overemphasize a small number of highly-cited papers [6] and they do not compare well across disciplines due to different field characteristics such as size and publication rates [1,6–9]. Nevertheless, impact factors are often viewed as a rough estimate of the expected number of times an article in a given journal will be cited in other peer-reviewed work in a one-year period. We—noting the caveats listed above—follow the example set by previous work and use impact factor as an estimate of how influential a paper is likely to be when published in a particular journal [10]. We discuss this assumption further in Methods.

However, researchers may not only select journals to maximize the potential impact of a publication. Researchers may also seek to minimize the time length of the review process (as well as the frustrations and extra time commitments stemming from multiple revisions and resubmissions), helping to ensure that new knowledge reaches its audience as quickly as possible. The "journal submission decision" problem was introduced by ref. [11] and more recently formalized and expanded along these lines [10]. In this framework, the researcher(s) must select a sequence of journals to which to submit the manuscript. This submission decision problem features multiple objectives, including: (i) the expected number of citations the article to-be-submitted will accumulate over a given time horizon (ii) the expected number of (rejections and) resubmissions; and (iii) the expected length of time from submission to acceptance [10]. The submission decision problem was expanded by ref. [12], who incorporated a representation of the uncertainties and complications inherent in the process of ranking journals beyond impact factor.

Complex decision problems often feature *deep*,

or *Knightian*, *uncertainties*, in which decision-makers cannot agree on the set of possible outcomes, the consequences of those outcomes, and/or the associated probability distributions [13–15], as well as *multiple decision-maker rationalities* [16]. For example, the trade-offs between objectives for co-authors on the same manuscript may not always be aligned due to the co-authors' different career stages. The co-authors may also have conflicting prior assumptions regarding the probability that their manuscript will be "scooped" (that is, a journal article of similar scope is published prior to their manuscript being accepted for publication, potentially reducing the novelty and impact of the manuscript). This perceived "scooping" probability is an example of a deeply uncertain parameter even for the single-author case, as it is mostly based on (often diverging) subjective estimates. Furthermore, differing objectives and prior assumptions between authors illustrate the importance and difficulty of balancing multiple decision-maker rationalities. Previous analyses of the submission decision problem have illustrated the development of optimal submission strategies for a single researcher, but has been silent on the issues of (i) finding strategies to compromise between the interests of multiple decision-makers and (ii) the impacts of deeply uncertain factors in the decision problem [10,12,17].

Here, we expand upon previous studies and offers a formal method to navigate the concerns that result from deep uncertainty and multiple decision-maker rationalities. We employ a Many-Objective Robust Decision-Making (MORDM) approach, using a set of tools designed to inform decision-making through transparency [18]. Decision-making in cases of deep uncertainty can be informed by explicit and transparent representation of the trade-offs. This representation can then help to identify solutions that are acceptable to the different decision-makers that often have diverging preferences [19]. We evaluate the impacts of deeply uncertain factors (e.g., perceived scooping probability). We focus on introducing the MORDM methodology to the journal submission decision problem and demonstrating how to discover and navigate the tensions brought on by deep uncertainty. A full Many-Objective *Robust* Decision-Making approach would include a "stress test" of the proposed submission strategies to discover scenarios in which the strategies might perform poorly. This is beyond the scope

of this study, although we note that recent work has proposed and demonstrated a framework for endogenizing the "scenario discovery" within the MORDM approach [20]. We explicitly represent the trade-offs inherent in the submission decision process, and illustrate the impacts of deep uncertainties such as contrasting co-author views of the probability of their manuscript being scooped and the length of time needed to make revisions. This quantitative formulation of the journal submission decision problem, both in the present work and as it was originally formulated [10], is accompanied by many caveats, and should not be taken as a blanket endorsement of one journal or set of journals or a prescription of a particular submission sequence. However, we defer additional discussion of these caveats until the section Discussion and Caveats.

METHODS

Representing the Journal Submission Decision Problem

We adopt as a starting point the insightful model of the journal submission decision problem described in ref. [10]. In this model, a researcher has finished a manuscript and must decide to which journal to submit. This decision, when viewed as an optimization problem, can have many objectives. We focus here on three objectives: (i) maximize the expected number of citations the paper will accrue over a fixed time period; (ii) minimize the expected number of times the manuscript will be rejected (and consequently revised and resubmitted); and (iii) minimize the expected amount of time from initial submission to final acceptance (or rejection, in the event that the manuscript has been rejected from all journals to which it was submitted). The following problem formulation is based on ref. [10], with several modifications described below. We provide an overview of the problem set-up and key equations. A detailed mathematical construction of the model is provided in greater detail in Supplementary Text.

Let T represent the time horizon over which the researcher wishes to maximize citations. T might be the duration of a postdoctoral appointment

(say, three years) for a junior researcher who is interested in applying for tenure-track jobs. Alternatively, T could represent the time until a final decision is made regarding tenure (say, seven years), or the projected remainder of a tenured researcher's career (say, 20 years).

The impact factor (IF) of a journal is calculated as

$$\mathrm{IF} = \frac{Q}{M}, \tag{1}$$

where Q is the number of citations in the current year to items published in the journal the previous two years and M is the number of items published in the journal during the same two years [3]. Let q_i represent the number of citations in the current year to items published in the previous two years for publication $i = 1, 2, \ldots, M$ in the journal in question, where i enumerates the items published in the journal over the previous two years. Then Eq (1) becomes

$$\mathrm{IF} = \frac{1}{M}\sum_{i=1}^{M} q_i, \tag{2}$$

which is the mean number of citations in the current year for an item published in the journal during the past two years. In light of the lack of journal-specific data regarding a probability distribution for the number of citations per article per year, we use the impact factor as a point estimate for the expected value (in the mean sense) of the number of citations per year for an article published in that journal. Furthermore, we make the assumption that the impact factor remains constant over the time period considered, which is almost certainly not the case in reality.

Let an enumeration of journals be indexed by j, and suppose the authors of a manuscript only intend to submit to N journals total. Suppose the authors intend to submit the manuscript, in order, to journal $j = 1, 2, \ldots, N$. Let α_j, λ_j, and τ_j denote the acceptance rate, expected number of citations for an article in the journal over the course of a year, and the expected time from submission to publication for journal j, respectively. Let s denote the probability (per day) of an article being scooped and t_R denote the time (in days) required to make revisions and resubmit a manuscript. Following previous work, we adopt the assumption that a manuscript that has been "scooped" is essentially worthless and receives

no citations, and that the probability of being scooped is constant in time [10]. As in previous work [10], the perceived probability of scooping (s) is a function of the preferences and perceptions of the individual decision-makers. Different fields, research topics, and decision-maker perceptions will suggest higher or lower values for s are appropriate for different applications. Decision-makers may want to examine the cumulative probability of scooping, $(1\text{-}s)^t$ (where t is time in days), to decide what values of s are realistic for their application. The total probability of a manuscript being rejected from all N journals in a submission sequence is

$$p_r = 1 - \sum_{j=1}^{N} \alpha_j \prod_{k=1}^{j-1} (1 - \alpha_k)(1 - s)^{\tau_k + t_R}. \quad \textbf{(3)}$$

Thus, the total probability of acceptance at a journal in the submission sequence is $1\text{-}p_r$. We include this in the results as a quantity to help navigate trade-offs, but do not include it explicitly as an objective because the acceptance rate for each journal is included in the other objectives. The expected number of citations for the manuscript is then

$$C = \sum_{j=1}^{N} \alpha_j \lambda_j [T - (\sum_{i=1}^{j} \tau_i) - (j-1)t_R]^+ \prod_{k=1}^{j-1} (1 - \alpha_k)(1 - s)^{\tau_k + t_R} + p_r * 0, \quad \textbf{(4)}$$

where the superscript + on the term in square brackets in Eq (4) implies that negative values should be replaced with zero. The p_r*0 term in Eq (4) accounts for the fact that a manuscript which has been rejected N times earns zero citations. In practice, authors may submit such a manuscript to journals with subsequently higher acceptance rates to reduce the probability of overall rejection, rather than worrying about citations.

There are several simplifying assumptions in the formulation of Eq (4). First, the impact factor of each journal is assumed to be constant over the time horizon. Second, the "impact" of a paper is time-invariant: the rate of citations does not change with time. Finally, as a consequence of the available data, we assume that the time a paper is under review at a particular journal is precisely the mean time for that journal.

The expected total number of submissions of a manuscript is

$$R = \sum_{j=1}^{j_{max}} j\,\alpha_j \prod_{k=1}^{j-1}[(1-\alpha_k)(1-s)^{\tau_k+t_R}] + j_{max}\left(1-\sum_{j=1}^{j_{max}}\alpha_j \prod_{k=1}^{j-1}[(1-\alpha_k)(1-s)^{\tau_k+t_R}]\right), \quad (5)$$

where j_{max} is the expected maximum number of submissions within the time horizon T along a given submission sequence. That is, j_{max} is the largest index j along the submission sequence such that the following expression is true.

$$T - \sum_{i=1}^{j}\tau_i - (j-1)t_R > 0 \quad (6)$$

The formulation of Eq (5) differs from that in ref. [10], in that we limit the maximum number of submissions based on the expected revision and review time of the proposed journal submission sequence instead of using a Heaviside function to assign zero probability to submission numbers exceeding the time limit.

The expected total time spent under review along a given journal submission sequence is

$$P = \sum_{j=1}^{j_{max}}\alpha_j\left(\sum_{i=1}^{j}\tau_i + (j-1)t_R\right)\prod_{k=1}^{j-1}[(1-\alpha_k)(1-s)^{\tau_k+t_R}] + \min\left(T, \sum_{i=1}^{j_{max}}\tau_i + (j_{max}-1)t_R\right)\left(1-\sum_{j=1}^{j_{max}}\alpha_j\prod_{k=1}^{j-1}[(1-\alpha_k)(1-s)^{\tau_k+t_R}]\right). \quad (7)$$

This can be interpreted as the expected time until the final decision, which occurs at one of three points: (i) acceptance by one of the N journals, (ii) rejection by all N journals, or (iii) expiration of the time horizon before the manuscript could be accepted. This time includes the manuscript revision time t_R between each resubmission. If the time horizon T expires before the review process can be completed at all N journals along the submission sequence, then the final decision occurs at time T. The parameters s, t_R, and T are considered uncertain factors that depend on the perspectives and preferences of the authors of the manuscript. The quantities α_j, λ_j, and τ_j are properties of the journals to which the manuscript might be submitted.

Data

The model of Eqs (4), (5) and (7) requires the mean acceptance rate (α_j), impact factor (λ_j), and mean time from submission to final decision (τ_j) for each potential journal the researchers might submit to. We use the data set from ref. [10], which permits a transparent comparison of methodologies

from that work and the results presented here. This data set contains the required information for a set of 61 journals that either specialize in Ecology or are general journals that publish ecological research. The data set spans a wide range across the impact factor spectrum and is available from ref. [10] (see S1 Table in [10]).

In the original formulation [10], Eq (4) is normalized to ensure that the probability of being accepted to a particular journal forms a probability distribution. This normalization implicitly assumes that the manuscript will be accepted to one of the journals along the sequence (i.e., pr = 0). When all 61 journals in the data set are included in each submission sequence, this is a reasonable assumption; the probability of being rejected from all 61 journals is about 2x10-13 (neglecting scooping). Here, we consider only journal submission sequences of length N = 5. This parameter choice reflects the authors' experience that many researchers try to limit the number of revisions and resubmissions. As a (convenient) side effect, this choice also keeps the computational demands within a reasonable scale. With this assumption, there is a non-negligible chance that a manuscript will be rejected from all five journals in a given submission sequence.

XLRM FRAMEWORK

The "XLRM" framework is a simple approach to synthesize the formulation of a decision analysis [21] (Fig 1). This framework casts the decision problem in terms of external factors that the decision-maker must take into account in the decision process (X), levers the decision-maker may manipulate that constitute the actual "decision" (L), the system relationships (R), and the performance metrics on which the optimality of the decision is based (M).

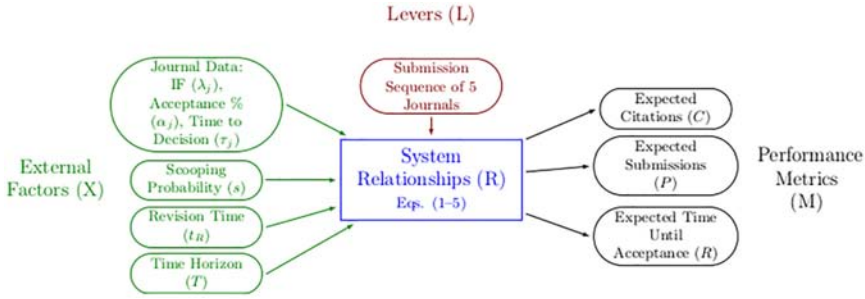


Figure 1. *XLRM framework***.**

Illustration of the external factors (X), levers the decision-maker can manipulate to affect the outcome (L), the modeling relationships (R) and the performance metrics (M) in the formulation of the journal submission decision problem [10].

https://doi.org/10.1371/journal.pone.0178874.g001

In our formulation of the journal submission decision problem, the external factors consist of the journal-specific data (acceptance rates (α_j), impact factors (λ_j), and time-to-decision (τ_j)), the scooping probability (s), the time horizon (T) over which the decision-maker wishes to accrue citations, and the time needed to make manuscript revisions (t_R). The scooping probability, time needed to make revisions, and time horizon are uncertain factors that may vary from researcher to researcher. The decision lever in this problem is the chosen ordered sequence of N journals to which to submit the manuscript. The performance metrics are the three objectives of maximizing citations, minimizing time in review, and minimizing the number of submissions (Eqs 4, 5 and 7, respectively).

Multi-objective Decision-Making

Choosing a strategy in the face of multiple objectives often requires the navigation of trade-offs among the objectives. In other words, different solutions may perform better than others with respect to particular objectives. For these types of problems, decision-makers are often interested in characterizing the entire set of solutions that are *non-dominated*—that is, for which no other solution performs better across all objectives (an improvement in one objective requires a deterioration in

another) [22]. Non-dominated solutions are also called *Pareto-optimal*, and the set of objective values corresponding to Pareto-optimal solutions is the *Pareto front* [22]. The identification of the Pareto front prior to decision-making allows decision-makers to explore preferred solutions based on an understanding of the relevant trade-offs. This form of optimization is known as *a posteriori* decision-making (as opposed to *a priori* decision-making, in which preferences are specified prior to the optimization process) [23].

For even relatively simple problems, it can be computationally intractable to enumerate all possible solutions to find the "true" Pareto front. In this relatively stylized example, there are over 700 million possible permutations of five journals out of the total set of 61 journals; direct identification of the exact Pareto front would involve simulating all of these permutations and comparing their objective values. While technically still feasible (but arguably cumbersome) in this case, we apply a method to identify high-quality approximations of the Pareto front. One class of these computational methods are Multi-Objective Evolutionary Algorithms (MOEAs) [23,24]. These algorithms utilize a population-based search to identify an approximate Pareto front. For this work, we use the NSGA-II (Non-Dominated Sorting Genetic Algorithm-II) MOEA, which uses the Pareto-dominance relation to search the lever space for Pareto-approximate solutions [25]. We examine the number of function evaluations required by the MOEA employed here as well as the Metropolis algorithm used by ref. [10] in order to discover the approximate Pareto front.

In the face of deep uncertainties, MOEAs can be combined with methods from robust decision-making to form the Multi-Objective Robust Decision-Making (MORDM) framework [18,24,26]. Solutions from the Pareto front are tested against various states of the world to identify regions of the parameter space where the solution performs "poorly," as defined by the decision-maker. While we do not fully utilize the power of the MORDM framework here, our analysis can be extended to examine how select submission sequences cope with uncertain time horizons, revision times, and scooping probabilities. To illustrate this in a limited fashion, we demonstrate the consequences of multiple decision-maker rationalities, where different decision-makers have different beliefs or preferences. In particular, we consider the case of a collaborative paper

between a junior author (for example, a Ph.D. student) and a senior author (say, this Ph.D. student's advisor). We determine the approximate Pareto front for each co-author based on their preferred time horizon. A more complex approach, which we do not employ here but is an interesting avenue for future study, is to include both researchers' objectives explicitly in the same multi-objective optimization formulation.

RESULTS

Performance Comparison

First, we compare the approximate Pareto front from the original Metropolis algorithm-based method [10] with the MOEA-based method outlined here in Methods for a varying number of function evaluations (Fig 2).

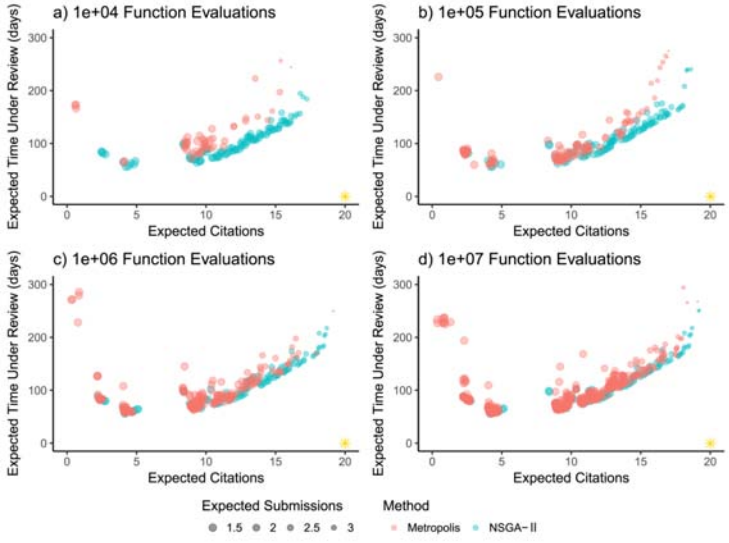


Figure 2. Performance comparison. The approximate Pareto front between expected citations (horizontal axis), expected time under review (vertical axis) and expected number of submissions (size of points), as discovered by the Metropolis algorithm (red points) or NSGA-II MOEA (blue points) for (a) 10^4,

(b) 10^5, (c) 10^6 and (d) 10^7 function evaluations. The model was run with T = 3 years, s = 0.001 and t_R = 30 days. The gold star in the lower-right corner represents the target direction for the represented objectives.

https://doi.org/10.1371/journal.pone.0178874.g002

For these experiments, we use a time horizon of T = 3 years, a scooping probability s = 0.001, and revision time t_R = 30 days. The NSGA-II algorithm finds the basic shape of the approximate Pareto front within 10^4 function evaluations (Fig 2A). By contrast, the Metropolis algorithm requires about 10^7 function evaluations to converge to a similar approximate front. Even with 10^7 function evaluations, several solutions on the Metropolis front are dominated by solutions on the NSGA-II front, suggesting that the NSGA-II algorithm outperforms the Metropolis algorithm in this case.

Visualization and Navigation of Multi-Objective Trade-Offs

The overall geometry of the approximate Pareto front is mostly invariant with respect to the time horizon (Fig 3). This is because the expected total time under review along the approximate Pareto front remains between about 50 to 250 days for the 3-, 7- and 20-year time horizons. This leaves more time for citation accumulation than is spent under review, even for the relatively short 3-year horizon. Similarly, the expected number of submissions (Fig 3, dot size) ranges from just over one to under four submissions, also regardless of the time horizon. However, the maximum number of expected citations scales approximately with the number of years in the researcher's time horizon. The Pareto-approximate sequences appear in clusters roughly organized by the first journal in the sequence. Sequences with low-submission counts, review time, and expected citation sequences typically begin with *Polar Record*. Sequences with high citation counts typically begin with *Ecology Letters*. Finally, submission sequences with moderate citation counts, time in review, and numbers of submissions begin with either *PLOS ONE* or *Molecular Ecology Resources*, depending on the balance between the "effort" metrics of review time and submissions versus the citation count. Note that despite this tendency for the approximate Pareto front to be organized by the first journal, the subsequent journals in each approximately Pareto-optimal submission sequence can vary substantially, illustrating the importance

of examining the entire sequence. For these results, we use the MOEA-based approach with 10^7 function evaluations, scooping probability s = 0.001 and revision time t_R = 30 days, unless otherwise stated.

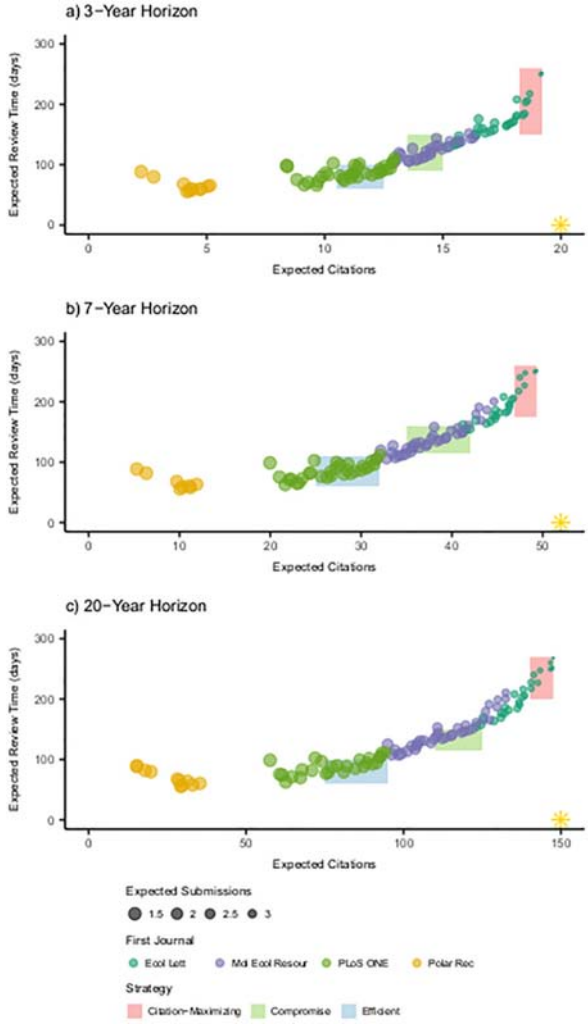


Figure 3. Pareto-approximate solutions. Approximate Pareto fronts for the (a) junior researcher (T = 3 years), (b) tenure-seeking researcher (T = 7 years) and (c) tenured researcher (T = 20 years). The shaded boxes depict the three strategies: Efficient (blue shaded box), Compromise (green shaded box) and Citation-Maximizing (red shaded box). The gold stars in the lower-right corner represent the target direction for the represented objectives.

https://doi.org/10.1371/journal.pone.0178874.g003

Journal Submission Strategies

We find three distinct regions that represent different strategies a researcher could follow in submitting a manuscript (Fig 3). We select the boundaries between these regions to roughly correspond to the position of the inflection points on the citation count versus time under review Pareto front. The three strategies are: (i) the "Efficient Strategy" (no fewer than 50% of the maximum expected citations and less than 100 days expected under review); (ii) the "Compromise Strategy" (at least 67–70% of the maximum expected citations and no more than 150 days under review); and (iii) the "Citation-Maximizing Strategy" (at least 95% of the maximum expected citations). The shaded boxes in Fig 3A, 3B and 3C depict these strategies for junior ($T = 3$ years), tenure-seeking ($T = 7$ years), and tenured ($T = 20$ years) researchers.

The Efficient Strategy aims to balance the effort the researcher must dedicate to revisions and resubmissions, while pushing the expected citation count as high as possible before the upwards inflection in expected time under review (seen in Fig 3A at about 13 citations). The Efficient Strategy typically requires half the time under review of a Citation-Maximizing Strategy. The Compromise Strategy also avoids the steep increase in expected review time that accompanies a Citation-Maximizing Strategy. The expected number of submissions is less than two for all Pareto-approximate submission sequences following an Efficient Strategy, and less than three for the Compromise Strategy. The increased number of submissions and long review time relative to a 3-year time horizon may make the Citation-Maximizing Strategy less attractive than Efficient or Compromise to the junior researcher, in light of the small number of additional citations to be gained within their time horizon relative to alternative strategies. The longer time horizons of the senior researchers provide the flexibility to pursue higher citation counts, particularly as the potential benefits from more expected citations is larger than for the junior researcher (Table 1). This effect is highlighted by examining expected citations per year for each researcher (expected citation count normalized by the time horizon; Table 1).

Table 1. Submission sequences to maximize citations under each strategy.

	Time horizon	**Submission sequence**	**Expected citations**	**Expected submissions**	**Expected time under review**	**Acceptance probability**
Citation-Maximizing Strategy	3 years	1. *Ecol Lett* 2. *Science* 3. *Mol Ecol Resour* 4. *Ecol Monogr* 5. *PLOS ONE*	6.4 y^{-1}	3.8	251.7 days	0.728
	7 years	1. *Ecol Lett* 2. *Science* 3. *Ecol Monogr* 4. *Mol Ecol Resour* 5. *PLOS ONE*	7.0 y^{-1}	3.8	251.7 days	0.728
	20 years	1. *Ecol Lett* 2. *Science* 3. *ISME J* 4. *Mol Ecol Resour* 5. *PLOS ONE*	7.4 y^{-1}	3.8	268.0 days	0.716

Compromise Strategy	3 years	1. *Ecol Lett* 2. *Mol Ecol Resour* 3. *PLOS ONE* 4. *Biotropica* 5. *Evol Ecol*	5.5 y^{-1}	2.9	149.0 days	0.840
	7 years	1. *Mol Ecol Resour* 2. *Ecol Lett* 3. *Ecol Monogr* 4. *PLOS ONE* 5. *J Evol Biol*	5.9 y^{-1}	2.9	149.5 days	0.833
	20 years	1. *Mol Ecol Resour* 2. *Ecol Lett* 3. *Ecol Monogr* 4. *PLOS ONE* 5. *Biotropica*	6.0 y^{-1}	2.9	148.1 days	0.841
Efficient Strategy	3 years	1. *PLOS ONE* 2. *Ecol Lett* 3. *Mol Ecol Resour* 4. *ISME J* 5. *Ecol Monogr*	4.3 y^{-1}	1.9	94.2 days	0.873
	7 years	1. *PLOS ONE* 2. *Ecol Lett* 3. *Ecol Monogr* 4. *ISME J* 5. *Mol Ecol Resour*	4.5 y^{-1}	2.0	95.7 days	0.871
	20 years	1. *PLOS ONE* 2. *Ecol Lett* 3. *Mol Ecol Resour* 4. *ISME J* 5. *Ecol Monogr*	4.6 y^{-1}	1.9	94.2 days	0.873

https://doi.org/10.1371/journal.pone.0178874.t001

We identify submission sequences for each researcher that maximize the number of citations under each of the three submission strategies (Table 1). These sequences generally feature the same set of journals, though there are some differences in the order in which they appear. It is perhaps surprising that the sequences that maximize citations within each strategy are quite similar across time horizons: aside from the Compromise Strategy, the first two journals in each set of sequences are identical, and the remaining journals are rearranged or are replaced by journals with similar characteristics. The overall Citation-Maximizing Strategies for all three researchers start by submitting to *Ecology Letters*, then to *Science*, and *PLOS ONE* last. That *Ecology Letters* appears before *Science* is likely a result of the higher acceptance rate and faster review time of the former. The Compromise Sequence is also quite similar, though it appears to be more optimal for the researcher with a 3-year horizon to submit to the higher-impact factor *Ecology Letters* before *Molecular Ecology Resources*, while the researchers with longer horizons should submit to *Molecular Ecology Resources* first. Numerically, this is likely related to *PLOS ONE*, with a high acceptance rate and fast review time, being the third journal in the 3-year horizon sequence rather than the fourth. We stress that the sequences presented in Table 1 neglect the effects of varying manuscript quality and content. These considerations may be examined, for example, by reducing the pool of journals to only those where the manuscript is appropriate based on content and quality.

Explicit Representation of Trade-Offs

There are strong trade-offs between the citations objective and each of the two effort objectives, depending on the submission strategy pursued (Fig 4). These trade-offs follow approximately the same shape, where the only difference is that longer researcher time horizons allow for proportionally higher maximum citation counts. In the parallel axis plots shown in Fig 4, each line corresponds to a different journal submission sequence found to be Pareto-approximate for that researcher. Trade-offs between objectives are represented as intersections between solutions from one objective's axis to the next. This illustrates how a high performance along one objective (near the top of that objective's axis) might come at the

cost of low performance along another objective (near the bottom of the other objective's axis). In our three-objective formulation of the journal submission decision problem, the three-dimensional approximate Pareto fronts of Fig 3 are readily interpretable. In higher dimensions, however, a graphical representation of all objectives becomes more complex. For example, we might also consider publication costs as an additional objective to minimize, resulting in a four-dimensional Pareto surface.

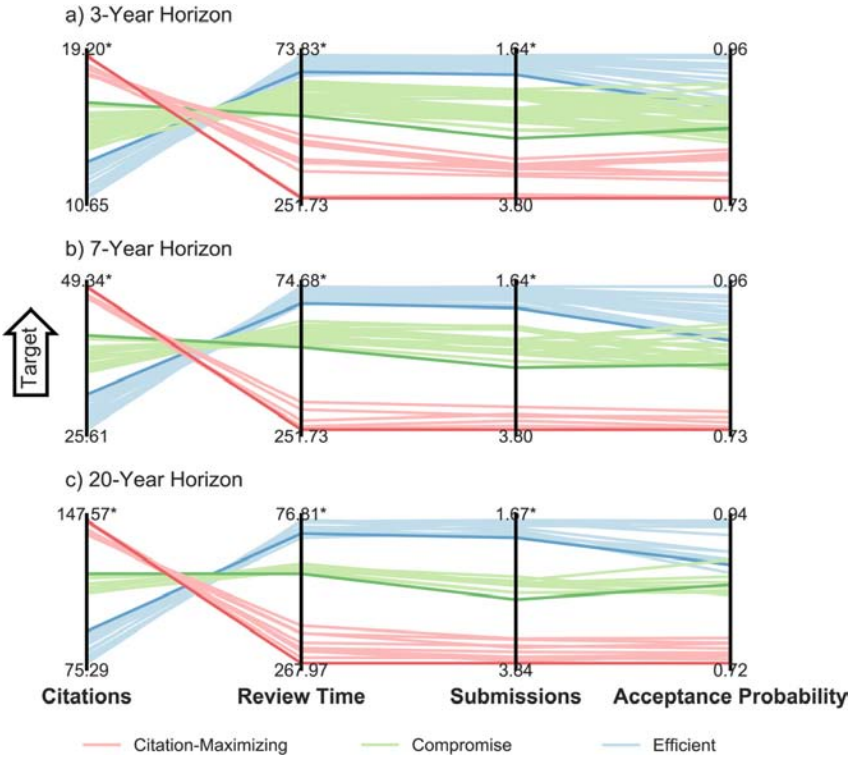


Figure 4. Visualizing multi-objective trade-offs. Parallel axis plots for the (a) junior researcher ($T = 3$ years), (b) tenure-seeking researcher ($T = 7$ years) and (c) tenured researcher ($T = 20$ years). Each vertical axis represents one of the three objectives, with the best simulated values at the top. Each horizontally-oriented shaded region represents a different journal submission strategy and bounds the range of Pareto-approximate solutions for that strategy. Red follows Citation-Maximizing Strategies, blue follows Efficient Strategies (moderate citations and fast publication) and green follows Compromise Strategies. The bold solutions denote the maximum-citation sequence within each strategy.

https://doi.org/10.1371/journal.pone.0178874.g004

For all three researchers, Efficient and Citation-Maximizing submission sequences that perform well on expected citations (i.e., near the top of the axis) tend to perform poorly in expected number of submissions and time in review, and vice versa. This demonstrates a strong trade-off between the expected number of submissions (and time in review) and the expected number of citations (Fig 4, central and left-most axes). There is little trade-off between the "effort objectives" of expected total time under review and expected number of submissions (Fig 4, center two axes). As expected, Citation-Maximizing Strategies have the lowest total probability of acceptance, while Efficient Strategies tend to have the highest. That there are some Efficient Strategies with lower total acceptance probabilities than some Compromise Strategies, with no analogous trade-offs on the citation axis, may indicate that those Efficient solutions should be ranked lower than the higher-acceptance probability Compromise solutions, though this depends on the preferences of the researcher with regard to the effort objectives.

A Heuristic Rule to Develop a Compromise Strategy

It may be counterintuitive that *Science*, the journal with the highest impact factor in the data set (31), does not appear as the first submission option for any of the Citation-Maximizing sequences depicted in Figs 3 and 4. Indeed, the strategy of submitting to a high-impact factor journal first, then subsequently lower impact factor journals as a manuscript is rejected, is commonly used in practice [27]. To understand why this strategy might be suboptimal, we order the journals in the data set according to their impact factor multiplied by their acceptance rate (which we call the "conditional impact factor"). Then the top five journals are: *PLOS ONE* (2.82), *Molecular Ecology Resources* (2.60), *Ecology Letters* (2.23), *Ecological Monographs* (2.18), *Science* (2.17). This metric expresses the expected number of citations per year for an article published in a particular journal, conditioned on the probability that the article will be accepted for publication in that journal. Conditional impact factors may be more appropriate for finding compromise solutions than the raw impact factors because this metric considers the fact that a manuscript that has been rejected accrues zero citations. The three journals with the highest conditional impact factors are the first submission journals for the majority of Pareto-approximate sequences in Fig 3, and *Ecological*

Monographs and *Science* are common later options for submission. Of course, pursuing a submission strategy wherein a manuscript rejected from lower-impact factor journals is subsequently submitted to higher-impact factor journals is counterintuitive to most researchers (including the authors), but has been observed by the authors in some cases. One can interpret these results as an indication of the importance of publishing rapidly (fast review times and high acceptance rates) relative to publishing widely (high impact factor). Thus, one heuristic approach for finding submission sequences might be to select from the journals with the highest conditional impact factor, with specific choices made to reflect preferences concerning increased raw impact factors versus increased acceptance rates (for example, opting to begin with *Molecular Ecology Resources* instead of *PLOS ONE* to increase expected citations at the cost of increased review time).

Multiple Decision-Maker Rationalities lead to Tensions

Consider a multiple author manuscript with a junior author ($T = 3$ years) and a senior author with tenure ($T = 20$ years). The junior author might be a graduate student seeking to publish a chapter from her dissertation, and her top priority is to strengthen her position on the job market. Meanwhile, her advisor may want to bolster the overall impact by publishing in a high-impact factor journal. These different time horizons are an example of multiple decision-maker rationalities [16], which may yield different Pareto-optimal solutions for each author. Our analysis shows, however, that the overall strategies are comparable across researchers. This is due to the similar geometries of the Pareto fronts with respect to the time horizon T. These strategies present options to still publish on a relatively short time horizon (no more than five months)–rapidly enough from an author's job applications perspective–but can still substantially increase the citation count for the senior author relative to an Efficient Strategy (Fig 3C).

Now consider the case of a graduate student who is approaching her Ph.D. defense, with a research focus that is at the forefront of her field that is also quite crowded. This graduate student may assume a relatively high scooping probability $s = 0.005$. In contrast, her tenured advisor may differ in this assessment and, based on his publishing experience, adopts

a probability of being scooped of $s = 0.001$. Moreover, the junior author may be more pessimistic about the amount of time required for revisions than the senior author. She assumes that each revision can be expected to take $t_R = 45$ days, while her advisor assumes $t_R = 30$ days.

The higher perceived probability of scooping (and thus accumulating zero citations) compresses her range of possible citation counts (Fig 5); the maximum expected citation rate for the junior author is reduced from 6.4 citations per year (Table 1) to about 4.3 citations per year (13 citations total). Thus, while the junior author could still be aggressive about citation-seeking, the resulting Citation-Maximizing sequences carry with them a high perceived risk (of scooping or long review times) with a relatively low increase in reward (citations per year) compared to sequences that might be classified as Efficient or Compromise solutions. For example, using the review time cutoffs applied previously, the maximum expected citations available under an Efficient solution (no more than 100 days under review) is about 10, while under a Compromise solution (no more than 150 days under review), the maximum expected citations is only slightly higher (10.7).

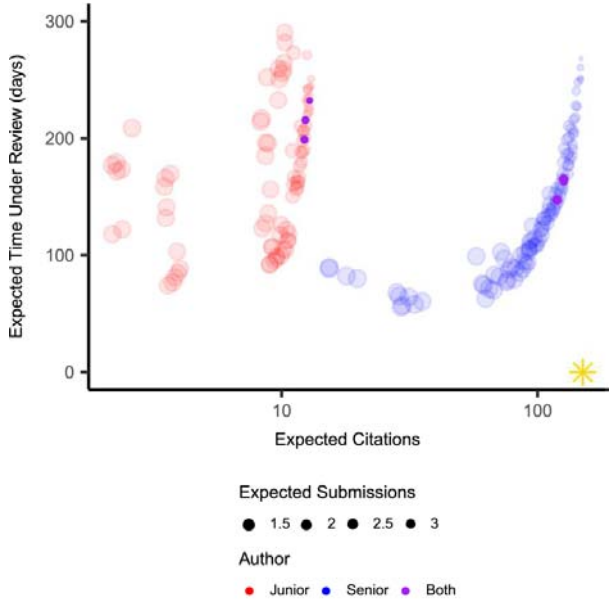


Figure 5. Multiple rationalities can lead to co-author tension. Pareto-approximate solutions for a scooping-averse junior researcher ($T = 3$ years, $s =$

0.005, $t_R = 45$ days) in red and a less scooping-averse senior researcher ($T = 20$ years, $s = 0.001$, $t_R = 30$ days) in blue. The x-axis (expected citations) is plotted on a log scale to highlight the different ranges of expected citations. The gold star in the lower-right corner indicates the target direction for the displayed objectives.

https://doi.org/10.1371/journal.pone.0178874.g005

These different rationalities require discussion and compromise between the two decision-makers, so that the senior author's desire for maximum exposure can be reconciled with the junior author's aversion to being scooped. One approach is to look for common Pareto-approximate submission sequences, though these may not always exist, requiring deviation from the approximate Pareto front for one or more decision-makers. In this case, three sequences are non-dominated for both researchers. These sequences and the values for each objective for each researcher are given in Table 2, and are depicted in purple in Fig 5. The shared sequences are generally similar, with the first two journals being some combination of *Ecology Letters* and *Molecular Ecology Resources*, the third journal being *Ecological Monographs*, and *PLOS ONE* occurring towards the end.

Table 2. Solutions that are Pareto-approximate for two authors.

Submission sequence	Expected citations		Expected submissions		Expected time under review	
	Junior author	Senior author	Junior author	Senior author	Junior author	Senior author
1. *Ecol Lett* 2. *Mol Ecol Resour* 3. *Ecol Monogr* 4. *PLOS ONE* 5. *Biotropica*	4.3 y^{-1}	6.4 y^{-1}	3.7	3.1	233 days	164 days
1. *Mol Ecol Resour* 2. *Ecol Lett* 3. *Ecol Monogr* 4. *ISME J* 5. *PLOS ONE*	4.2 y^{-1}	6.4 y^{-1}	3.3	3.0	216 days	166 days
1. *Mol Ecol Resour* 2. *Ecol Lett* 3. *Ecol Monogr* 4. *PLOS ONE* 5. *Biotropica*						

https://doi.org/10.1371/journal.pone.0178874.t002

These solutions come close to maximizing the expected citations for the junior researcher, while the senior author can expect more than 75% of the maximum citations he could obtain (indeed, the third sequence in Table 1 is classified as a Compromise solution by our previous analysis). The junior author's concern about revision time and scooping leads to longer expected review times for her. Thus, from her perspective, these solutions may not be as ideal as solutions with fewer expected citations but substantially less time under review and fewer submissions. While the senior author may be reasonably confident of success in publishing the manuscript in one of the journals (the acceptance probability from his viewpoint is over 81% for all three common solutions), the junior author may be more concerned about receiving five rejections (the maximum acceptance probability from her perspective is about 58%). However, these solutions can serve as a starting point for negotiations between the two collaborators.

From the perspective of the conditional impact factor heuristic described earlier, the solutions presented in Table 2 follow a similar ordering. The first three journals consist of three of the top four (excepting *PLOS ONE*) conditional impact factors, and *PLOS ONE* is included as the fourth or fifth journal in each of these compromise sequences. The positioning of *Molecular Ecology Resources* over *Ecology Letters* for two of the three sequences despite the latter's higher conditional impact factor reflects the decreased aggression in citation-seeking required due to the junior author's risk-averse preferences regarding revision time and scooping probability. If the junior author were more optimistic, we would expect to see *Ecology Letters* appear first more frequently.

It may not always be the case that these compromise solutions occur across all of the collaborators' Pareto-approximate sets, particularly as the number of coauthors increases. It may also be the case that the compromise solutions still perform relatively poorly for certain co-authors (for example, the junior author in our example may not be satisfied with overall acceptance probabilities below 60%). In this case, methods such as the Analytic Hierarchy Process [28] may be used to formulate new objectives that combine the preferences of each stakeholder. Another approach is to combine an MOEA optimization for a "typical" set of

parameter values with methods from robust decision-making to explore the robustness of sequences to differing combinations of parameter values. The combination of multi-objective optimization and robustness analysis forms the so-called Multi-Objective Robust Decision-Making (MORDM) framework (17,23,25).

Discussion and Caveats

The analyses of submission decision problem, as the objectives are formulated here and in ref. [10], are adorned with many caveats. For example, we assume that all manuscripts have equal probability of acceptance at a given journal. Others have parameterized the acceptance probability as a function of the manuscript quality [29]. This is arguably more realistic, but requires a subjective judgment that will differ for each manuscript. Due to the subjectivity of assessing manuscript quality, it may be more appropriate to treat this as an uncertain parameter in a robustness analysis, as described earlier. Additionally, not all manuscripts are appropriate for all publication outlets. The considerations of manuscript quality and content could be incorporated by reducing the pool of journals to only those in which the manuscript in question could reasonably be published [10]. Different co-author values for manuscript quality could also be factored into this analysis through author-specific scale factors (between 0 and 1) that modulate the expected acceptance rate in Eqs (2), (3) and (5). An optimistic author would set this scale factor to one and a pessimistic author would set this factor less than one.

We do not intend to explicitly recommend that a researcher should follow some of the Pareto-approximate sequences (e.g., from Tables 1 and 2). For example, some of the citation-maximizing sequences submit to higher-impact factor journals after submitting to lower-impact factor journals, which may seem counterintuitive to some researchers. Indeed, we have observed that the Pareto-approximate sequences, even those that are aimed at maximizing expected citations, tend to be ordered more by conditional impact factors than the raw journal impact factors. Furthermore, the impact factor, acceptance rate, and time-to-decision data set is from 2012 and is specific to Ecology [10], so decisions regarding contemporary strategies for journal submission require consideration of the *characteristics* of the journals along the pathways recommended

here. Additionally, researchers may decide to submit their manuscripts to journals in a sequence based on qualitative considerations such as prestige [11], even though these sequences may appear sub-optimal with regard to the quantitative metrics employed here. While some of these considerations may be quantified and incorporated into the optimization procedure, researchers will likely need to make subjective judgments regarding other factors after optimization.

The results presented here are intended to illustrate a framework for understanding the trade-offs and the balancing of competing decision-makers' interests that are inherent in the journal submission decision problem. These methods show how a general understanding of the trade-offs can provide insight into non-obvious ways to generate journal submission sequences that balance researchers' values (such as in Table 2), and illustrate the value in *a posteriori* decision-making procedures such as those used in this work. Generating submission sequences tailored to the preferences of a specific set of co-authors likely requires manual inspection of the Pareto-approximate solutions presented here, even within a strategy set consistent with the co-authors' values. For example, the maximum-citation sequences in Table 1 begin with *Ecology Letters* (impact factor 18) and proceed to *Science* (impact factor 31), if rejected. This counter-intuitive behavior is driven by the fact that the time-to-decision for *Science* in the data set is 84 days, with a low acceptance probability of 7%. On the other hand, the time-to-decision for *Ecology Letters* is 33 days with a 12.4% probability of acceptance [10]. A "desk rejection" by the editor at *Science*, however, is considerably faster (about one week). Finally, our study–as well as ref. [10]–is silent on the question of whose time is allocated to making the revisions (t_R) and whose efforts go into the resubmissions. These can be important considerations when honing submission sequences to decision-makers' particular goals.

The analysis presented here is a limited version of the robust decision-making analysis present in the full MORDM framework (16,19,21). Under this analytic framework, after finding the approximate Pareto front for expected values of uncertain parameter values (such as revision time and scooping probability), selected solutions are tested against a variety of states of the world to determine under what combinations of parameters they perform acceptably well or unacceptably poorly. This full analysis, which is beyond the scope of this didactic example, can more

fully inform decision-makers about the risks they may face if they have made incorrect assumptions about the "true" parameter values [20]. The authors intend to illustrate this analytic method in a subsequent work.

CONCLUSIONS

We use a multi-objective optimization analysis to explicitly illustrate the trade-offs inherent in deciding on which journal(s) to send a manuscript. Our results expand upon previous work by representing the tension brought on by multiple rationalities surrounding co-author values such as time horizon and perceived probability of being scooped. This analysis serves as an introduction to the more rigorous robust decision-making framework which often accompanies this method of decision analysis. We implement an open source and freely available multi-objective optimization framework and demonstrate the relative efficiency of our approach over that of previous work (Fig 2). We show that optimal solutions may be partitioned into different classes of strategies, though here we focus on three, which we call Efficient, Citation-Maximizing and Compromise. Citation-Maximizing Strategies are attractive for senior researchers but may be less suitable to junior researcher. This is because the junior researcher's time horizon is not sufficiently long to accrue a substantially larger number of citations as compared to an Efficient or Compromise Strategy. Furthermore, Citation-Maximizing Strategies also require more time under review and carry a higher risk of rejection from all journals. We find that the conditional impact factor is a useful heuristic metric to generate Compromise and Efficient submission sequences. Moreover, we find that this method of analysis can inform multiple researchers with different interests, assumptions, and perspectives and can help find starting points for negotiations about submission strategies.

ACKNOWLEDGMENTS

We gratefully acknowledge Caitlin Spence, Julianne Quinn, Rob Lempert, and Bella Forest for invaluable inputs. This study was partially supported by the Penn State Center for Climate Risk Management. Any conclusions or recommendations expressed in this material are those of the authors

and do not necessarily reflect the views of the funding agencies. Any errors and opinions are, of course, those of the authors.

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CHAPTER 2

DISTRIBUTED LEDGER TECHNOLOGY FOR FULLY AUTOMATED CONGESTION MANAGEMENT

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ABSTRACT

Congestion management in distribution grids is an important task for distribution grid operators, both from a financial and a technological perspective. Whereas large generation units and large controllable loads might in general be controllable in a manual way, this is no option for small distributed generators and loads. With flexibility control in multiple owner scenarios, documentation, transparency and automation are of crucial importance. In this work, we present a fully automated congestion

management approach based on a combination of distributed ledger technology and distributed algorithms in an agent-based architectural approach. We present a case study focused on the visualization of the concept and discuss the advantages and possible challenges for this approach. Whereas distributed ledger technology has been introduced for peer-to-peer energy trading within the last years, no similar approach has been presented yet for stable distribution grid management.

Keywords: Congestion management, Distributed energy scheduling, Blockchain, Distributed ledger technology, Agent-based control

INTRODUCTION

Distributed and renewable or highly efficient energy resources (DER) such as wind energy converters, photovoltaics, combined-heat and power plants as well as battery storage systems are important building blocks for the transition of the global energy system. DER have seen a significant rise in the share of the electric power generation of Germany, Austria and Switzerland over the last decades, thus helping both to reduce green house gas emissions and to substitute nuclear power plants. While hydropower plants are an important renewable energy resource especially in Austria and Switzerland (Eidgenössisches Departement für Umwelt 2018; Haas et al. 2018), many DER are or will be integrated at medium or low voltage levels. Thus, the increasing share of DER in the power system are a major challenge especially regarding the reliable operation of distribution grids. Traditionally, distribution grids were designed for peak loads, and not for DER peak generation. This may lead to several congestion problems, i. e. voltage band violations and thermal stress on power lines and transformers. A pragmatical, but from a macroeconomic point of view rather unsatisfying and inefficient solution to distribution grid congestions are feed-in management of DER (German: Einspeisemanagement, short: EISMAN) and power grid extensions.

As the costs of building new lines and transformers or reinforcing existing grid assets until 2032 may sum up to 20 - 50 billion Euro (E-Bridge et al. 2018), the German Association of Power and Water Economy (German: Bundesverband der Energie- und Wasserwirtschaft, BDEW) has proposed the usage of distributed flexibility for power grid operations.

The so-called *traffic light concept* (German: Ampelkonzept) proposes three distinct phases that are tightly coupled to the operational state of a power grid (BDEW Bundesverband der Energie- und Wasserwirtschaft e. V. 2017). In the green phase, the operational state is feasible within the limits defined by (DIN 2010), and all DER may feed-in without restrictions. In contrast, in the red phase the operational state is critical, and the distribution grid operator (DSO) limits or totally shuts down the feed-in from DER as necessary in order to reach a feasible operational state. The third, yellow phase is a novel concept for the transition between normal operation (green phase) and congestion management measures (red phase). Here, flexible units such as battery storages, electric vehicles or other controllable loads may be economically incentivized by the DSO to change their consumption or feed-in. However, the traffic light concept does not propose a specific implementation of the yellow phase, and the first pilot projects evaluating different approaches such as a centralized flexibility platform (Innogy SE 2018) or cellular concepts (Smart Grids-Plattform Baden-Württemberg e.V 2018) have just recently finished. These approaches come with several drawbacks: First, they may require an elaborate, highly scalable and very reliable centralized communication and service platform. Second, individual contracts with owners and/or operators of DER may have to be signed, thus limiting the acquisition of flexibility to larger DER such as biogas plants. Third, an additional information processing system is needed in order to transparently track the provision of flexibility for reimbursement purposes.

In this paper, we therefore propose a fully automated congestion management system for distribution grid operation based on distributed ledger technology and intelligent agents by presenting a case study for an exemplary simplified scenario. We combine an off-chain negotiation process with an on-chain documentation of the contracted negotiation results to reduce mining overhead and storage requirements.

The rest of this paper is structured as follows: First, we give an overview on the problem of congestion management in distribution grids (“Congestion management in distribution grids” section). After that we introduce the methodological background of the chosen approach, namely agent-based flexibility control (“Agent-based flexibility control” section) and distributed ledger technology (“Distributed ledger technology” section). In “Case study: fully automated distribution grid congestion management”

section, the case study is presented in detail, including a presentation of the chosen process for congestion management, the design decisions and the results of the case study in terms of the visualization of the implemented concept. We conclude with a discussion on the usefulness of the chosen concept and open question including future work.

CONGESTION MANAGEMENT IN DISTRIBUTION GRIDS

In the northwestern part of Germany, large amounts of renewable energy resources, especially wind power plants, are already integrated into the power grid. Therefore, grid congestions are a rather typical situation, and feed-in management measures are increasingly necessary to maintain the distribution grids stability. Figure 1 shows the progression of feed-in management incidents in the grid area of the German DSO EWE from 2009 to 2016 including data for Q1 and Q2 2017.

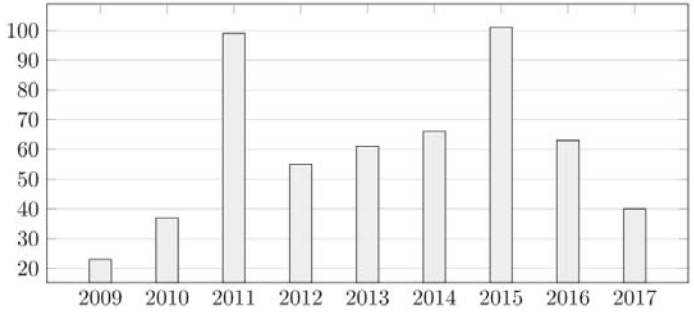


Figure 1. Number of feed-in management incidents in the distribution grid area of EWE (2017: data for Q1 and Q2 only). Source: EWE AG

According to the German grid regulation authority (Bundesnetzagentur, short: BNetzA), feed-in management is a "specially regulated grid safety measure to relieve grid bottlenecks" (Bundesnetzagentur für Elektrizität 2014). Regarding renewable energy resources, the BNetzA specifies that "in accordance with the special prerequisites and legal consequences of feed-in management, the responsible grid operator can also temporarily regulate the feed-in from renewable energy […] if the grid capacities are not sufficient to transport the total electricity generated" (Bundesnetzagentur

für Elektrizität 2014). Using feed-in management to regulate feed-in from renewable energy entails monetary compensation: "If renewable energy […] is regulated by feed-in management, the plant operator has a claim to compensation from its grid operator." (Bundesnetzagentur für Elektrizität 2014)

Whereas feed-in management can be regarded as a reactively used "ultima ratio" in the sense of the red phase of the grid traffic light concept, proactively using the flexibility of controllable loads (also known as demand response) and flexible DER can be a feasible option for congestion management. In order to implement an intelligent use of flexibility, however, two major obstacles have to be overcome: First, grid operation has to be proactive both regarding the forecasting of loads and renewable energy production, and regarding the usage of power flow calculations and state estimation for the prediction of congestions. Second, the activation of flexibility, the documentation of its actual provision and the monetary compensation have to be flexible, scalable and highly automated in order to tap this potential in a feasible, economically and organizationally efficient way. The first topic has been in the focus of several national and international research projects within the last years, whereas the second topic has not been fully addressed yet. In the following sections, intelligent agents and distributed ledgers are introduced as a potential means to solve the second problem.

AGENT-BASED FLEXIBILITY CONTROL

Software agents constitute autonomous software programs that can both sense and influence their environment. A set of (interacting) agents constitutes a multi-agent system (Wooldridge 2009). At the level of single agents, multi-agent systems (MAS) differ especially regarding their internal representation of knowledge the agents gain from their environment, the MAS architecture and the level of autonomy of the individual agents. Multi-agent systems allow for distributed problem solving as a technological realization of distributed algorithms especially in those fields, where the structure of the problem to be solved inhibits complete (i. e. optimal) approaches for reasons of complexity and/or time requirements. For these tasks, MAS can be used to implement heuristic

approaches. In the context of agent-based control in Smart Grids, a huge body of research emerged for both economic and technological optimization goals. First results have been published in the field of demand side management and market-based concepts (Kok et al. 2005). For economic virtual power plant control several concepts have been presented with hierarchical and fully distributed concepts (Anders et al. 2013; Nieße and Sonnenschein 2015). Demand-side management has been setup in research projects using agent-based concepts with high degrees of autonomy (Pournaras et al. 2014). In the last years, more concepts have been presented in the context of stable grid operation, like voltage stabilization (Elmitwally et al. 2015; Vaccaro et al. 2015), frequency control (Lehnhoff et al. 2011), and other Smart Grid applications (see (Vrba et al. 2014) for an overview on further agent-based Smart Grid applications).

All of the referenced approaches are usually evaluated using a scientific excerpt of a larger system view, and thus reducing the real-world problem to be solved e. g. regarding the attached processes or involved actors: Feasibility and algorithmic performance is usually the main focus of the presented work, thus showing that agent-based control schemes can be used to solve the specific tasks.

To analyze the applicability and economic viability of such an approach though, full process consideration is needed. Especially the process of accounting and billing is often neglected when new or adapted algorithms are presented. As an effect, the restricted actor and process view might lead to problems when presenting the concepts to possible application partners in the industry.

DISTRIBUTED LEDGER TECHNOLOGY

Distributed Ledger Technology (DLT) has gained a lot of interest recently. Going back to Satoshi Nakamotos Blockchain implementation Bitcoin (Nakamoto 2009), DLT combines peer-to-peer networks, cryptography and game theory to provide a distributed and immutable transaction storage. Bitcoin was designed as a currency system in which signed transactions are stored by combining a number of transactions in

a so-called block. The transactions are stored in structure called merkle tree (Merkle 1987) that supports the integrity of the contained data and provides an efficient way to check the validity of the contained data. Each block is secured using an additional hash function that is created for the data of the block header, which includes the root of the merkle tree, and must fulfill certain characteristics. Each block header has a reference to the hash value of the previous block. This ensures both the chronological order and the data integrity of the entire database. So-called miners are searching for the hash value of a new block. This search is associated with the provision of a certain amount of resources, at least in permissionless environments. Once found, the users agree whether the transactions and the block hash and therefore the blocks are valid or not (the so-called consensus). If the block is valid it is attached to the chain and the successful miner receives a reward. This list of chained blocks is public and can be verified by all peers. With this concept, blockchains solve the problem of distributed consensus (described e.g. in Lamport (1998)).

Relating to this principle, the blockchain technology has extended its use cases by integrating fully programmable functions, using graph-like structures instead of a single chain, or providing possibilities for access control (permissioned blockchains). This leads to the definition of DLT as a data register that establishes a verifiable consensus on the correctness of transactions and data in a decentralized peer-to-peer network, based on the calculation of hash values. This way, the DLT developed from being solely a technology for digital currencies, but can be used to store any kind of information, including executable computer code as smart contracts that are executed once certain defined conditions apply.

The heavily regulated energy sector is considered one of the key industries that will benefit from the distributed ledger technology. One of the first energy industry use case implemented was the local peer-to-peer trading of self-generated electricity from renewable energy sources in neighborhoods (microgrids). As so-called prosumers, the owners of solar systems are enabled to either consume their generated electricity themselves, sell it to their neighbors, or they can purchase electricity from other producers if the electricity generated by their own electricity supply is insufficient. The transaction handling is automated and enforced

using smart contracts. Examples for these use cases are the Brooklyn Microgrid in New York (Mengelkamp et al. 2018) or *Conjoule* in Germany (Conjoule GmbH 2018). The German TSO *TenneT* and the company *sonnen GmbH* are using networked battery storages that are installed in more than 6000 households (sonnen GmbH 2018). The purpose is to test to what extent emergency measures such as the shutdown of wind farms can be reduced in the event of bottlenecks in the transmission grid using the storage capacities of the distributed battery systems. The intelligent charging management adapts individually to the particular situation in the *TenneT* network. The distributed ledger technology offers the possibility to connect the distributed system and to store all transactions reproducible.

While the *TenneT* and *sonnen GmbH* project is solely focusing on battery storage systems, there has been no approach to handle all kind of flexibility options (load shifting, distributed storage, renewable energy sources, etc.) in a distribution grid. The concept presented in this work aims at the use flexibility options in a distribution grid to solve congestion issues in distribution grids. It combines agent technology and distributed ledger technology to have a fully automatic process from the identification of the congestion up to the settlement of the used flexibility.

Case study: fully automated distribution grid congestion management

To present the case study, we first will give details on the process that has been developed for a fully automated distribution grid management in "Process overview" section. After that, we present the system design by introducing the layered agent concept regarding chosen optimization heuristic, the blockchain technology and the incentivation scheme. In "Scenario setup" section we introduce the chosen setup regarding (controllable) loads and flexible generation units in a simplified congestion scenario.

"Agent-based schedule adaptation" and "Visualization" sections present the results of the case study, with the results of the agent based optimization first followed by the key artifact of the presented work, the graphical user interface of the presented application.

PROCESS OVERVIEW

The distributed, intelligent and fully automated congestion management we propose in this work comprises five interconnected process steps (cf. Fig. 2). We will present them briefly and give information on the technical realization in the upcoming sections.

1. **Prediction of congestions:** Based on forecasts for both loads and feed-in from DER, a DSO uses power flow analysis for the prediction of congestions, e. g. transformer overloads, in a given distributed grid. This is typically done day-ahead after the day-ahead market has cleared.

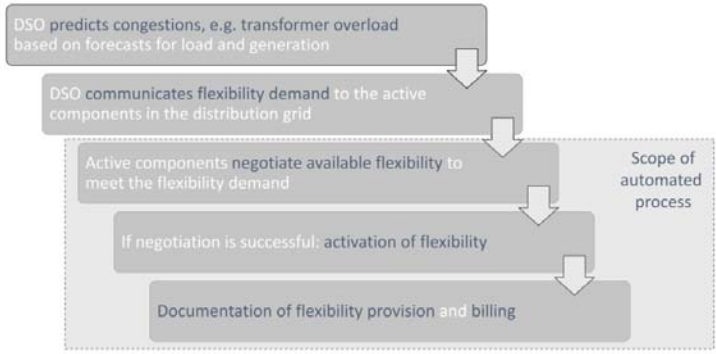


Figure 2. Overall process of automated distribution grid congestion management

2. **Communication of flexibility demand:** In order to solve the congestion, the DSO derives a flexibility demand and a financial incentive and communicates it to the active components, e. g. controllable loads, DER and battery storage systems, in the affected distribution grid.
3. **Negotiation of available flexibility:** Upon receiving a request for flexibility, the active components that are represented by intelligent agents in our system negotiate a response, i. e. the overall available flexibility they can provide for congestion management. Throughout this step, the agents can take into account the financial incentive given by the DSO, technical constraints of their respective active component and user preferences.
4. **Activation of flexibility:** A successful negotiation results in the

activation of the contracted flexibility. In this context, as the congestion itself is predicted for a future time interval, activation means that all active components change their schedules according to the flexibility they contributed during the negotiation.

5. **Documentation of flexibility provision and billing:** In order to be able to verify the fulfillment of a contracted flexibility, an active component's load and/or generation is continuously measured. Thus, the change in consumption and/or generation as promised in the updated schedules and the actual flexibility provision can be compared.

In this overall process, steps (1) and (2) are executed by the DSO. In Germany, research projects in the funding programs "SINTEG - Schaufenster Intelligente Energie" (Bundesministerium für Wirtschaft und Energie a) and "Zukunftsfähige Stromnetze" (Bundesministerium für Wirtschaft und Energie b) have put effort into the development of both improved state estimation methods and methods for the calculation of flexibility demand (Brüggemann et al. 2017; Frontier Economics Ltd 2017). In the following sections, we therefore focus on the system that implements steps (3) - (5) in a fully automated manner.

SYSTEM DESIGN

To illustrate the combination of agent-based congestion management avoidance and a blockchain-based automated transaction system, several design decisions had to be taken. In the following we will briefly recap these. As an important note, these design decisions have not yet been analyzed regarding the optimization of the overall process, but should illustrate the potential of such an automated concept for congestion management to practitioners.

For the task at hand, we needed a system design that allowed for the simulation of the following aspects:

- households comprising non-controllable or controllable loads and/or locally installed DER
- optimization agents controlling the flexible loads (like EV charging) and generating units, being able to negotiate the adaptation of the flexible loads with other agents in the system

- documentation agents realizing the documentation of both the flexibility offers and realization in a reliable way

To answer to these requirements, a three-level architecture has been set up (cf. Fig. 3): For each household, a simplified household simulation has been realized (lower layer for each component in Fig. 3). For this case study, a simple enumerated flexibility concept has been applied. Here, flexibility is the option to select a specific load profile—a schedule—from a set of different, feasible load profiles. This rather simple concept suffices for our case study, as we do not want to derive technical or economical performance indicators but demonstrate the feasibility of the overall concept. Of course, the flexibility model can and should be exchanged e.g. with sophisticated smart home models that can be integrated in sophisticated Smart Grid (co-)simulation frameworks.[Footnote1] The second and uppermost layer will be discussed in the following.

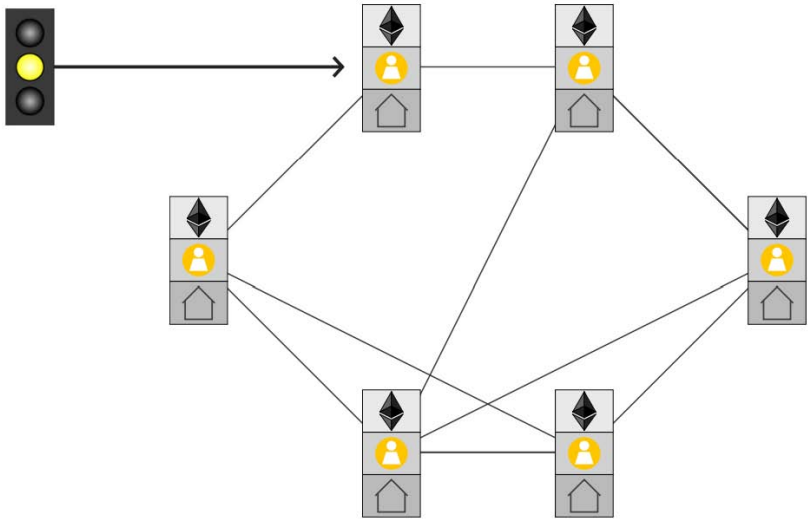


Figure 3. Overview on layered system architecture: Depending on a congestion warning (displayed as yellow traffic light), the agents cooperate using household simulation, cooperative agent layer and blockchain agent layer

Agent-based optimization heuristic The second layer represents the optimization agents. As has been discussed in "Agent-based flexibility control" section, many different concepts have been presented for agent-based control in smart grids. For the task at hand, a scheduling algorithm

is needed to let the agents answer to a requested change in their forecasted demand or generation profile. Within the area of algorithms supporting these kind of tasks, competitive and cooperative concepts have to be distinguished: While competitive concepts usually rely on a large amount of participants to realize an optimized price effect, cooperative concepts can be applied within regulated boundaries and locally restricted areas that comprise a reduced amount of participants. As the proposed process (cf. "Process overview" section) should realize a yellow traffic light phase, it is not yet defined, if pure market-based concepts would be appropriate. Within the responsibility of one DSO, cooperative concepts might be more appropriate.

For this case study, we chose a light-weight implementation of COHDA (combinatorial optimization heuristic for distributed agents (Hinrichs and Sonnenschein 2016)). From an algorithmic point of view, COHDA is an algorithmic level parallel heuristic (see e.g. (Talbi 2009) for a characterization of distributed algorithms). As a full presentation of COHDA would be out of scope of this presentation, we focus on the relevant characteristics:

COHDA has been developed for the task of scheduling controllable distributed energy units that show different levels of flexibility. Flexibility is modeled using the concepts of operation schedules with typically 15 min. values. For each DER, a software agent is implemented that is able to (a) determine the flexibility potential of a specific unit, (b) negotiate a behavior change (i. e. a different choice of schedule from its flexibility potential). For the work at hand, we added the ability of controlling simulation models by coupling the COHDA agents with the simplified household simulation. In the presented case study, the process step of agent-based optimization is performed off-chain, i. e. without storing the intermediate negotiation results in the blockchain – as they are not yet part of a contract, there is no need for permanently storing them. Thus, storage and mining overhead is reduced compared to other approaches (cf. "Distributed ledger technology" section). The agents are coupled with the blockchain layer in such a way that the load prognosis, the optimized (negotiated) schedule and measurement data are made available for the contract agents as defined in the next paragraph.

Blockchain layer To realize the documentation layer, we decided to implement an Ethereum-based blockchain (Gavin Wood) for the following reasons: First, the underlying technology can be easily implemented for small studies by setting up private blockchains. Second and most important, Ethereum implements the concept of smart contracts: Smart contracts are a special form of contracts realized as software code. Once a contract has been confirmed in the blockchain, it is continuously checked if defined preconditions have become valid. If so, resulting actions will be taken automatically, without further approvement, as these are part of the contract themselves. To realize this concept, Ethereum realizes two types of accounts: Externally owned accounts (EOAs) represent the cryptocurrency part. Contract accounts (CA) are connected to a specific EOA and store the smart contracts. If preconditions in a smart contract get valid, this might have effect on the balance stored in the EOA.

Contract design: Smart contracts are basically class objects with functions and member fields, so it is up to the programmer to define preconditions and the resulting actions. We designed our smart contract in a way that allows to store all data of one participant for one day. This means, our contract contains three fields, each able to store a time series of 96 values. Each of these fields are accessible by write and read functions. The write function is modified to allow only one single write call on each field to prevent subsequent changes. There are also some control fields to check preconditions and internal functions for further calculations. The contract is currently hard-coded in the client software, which is sufficient for a case study. The client software also contains the interface to the smart contract functions. One to three types of time series are stored over time for each contract:

- [b] First, each node starts its participation by deploying a copy of this contract filled with the initially predicted *baseline* schedule for the following day. This time series represents the *prognosis* for the components' behavior.
- [o] Next, in case of a change request initiated by the DSO, the agents start to negotiate. After this process has converged, the *optimized* schedule (i. e. the schedule that provides flexibility) is also stored in the specific contract.
- [m] After execution of the schedule, the *measured data* is send

to the contract as well. This last step also starts the calculation for the billing by comparing the measured data and the contracted schedule.

If an agent is not involved in a congestion prevention negotiation, only the first and last time series would be stored, thus resulting in the [bm]-state. For agents following the whole process, the contracts would take on the [bom]-state, storing forecasted values, negotiated schedules and measurement data.

The realization of an economic incentive is now directly realized using these contracts: When in [bom]-state, information on the forecasted, optimized and realized schedule is available in the blockchain. Using the concept of smart contracts, the billing is automatically started.

For the application of congestion management, a financial incentivation has to be realized to pay the participants for the offered and/or used flexibility. To illustrate this concept, we defined an exemplary currency called *Enercoin*. In the next paragraph, we briefly recap the incentivation scheme behind this currency.

Incentivation scheme To illustrate the economic aspects of distributed congestion management, a simplified incentivation scheme has been defined using an imaginary digital currency called Enercoins. This scheme should be understood as a first approach to realize the concept. Later studies can be performed to analyze a useful and economically feasible scheme.

In the following, we distinguish different flexibility behavior traits that can be shown by all participants of the congestion management process over time. They depend on internal and external factors, e. g. if flexibility has been offered and if it has been used to avoid congestion. The flexibility behavior traits can be summarized as follows:

- **FLEX_offer**: The component is able to offer flexibility.
- **FLEX_requested**: A flexibility offer been requested for the component.
- **FLEX_contract**: The component has been contracted a specific schedule from its flexibility potential.
- **FLEX_follow**: The component followed a contracted schedule.

The next behavior traits describe the effects if a component did not follow the contracted schedule. In these cases, the effect on the grid is reflected in the incentivation scheme, namely if a congestion has occurred as a possible effect of a schedule deviation, or if a schedule deviation reduced problems in the grid.[Footnote2] These effects are classified as deviation as follows:

- **DEV_grid-serving**: The deviation from the contracted schedule improved the stability of the grid.
- **DEV_destabilizing**: The deviation from the schedule lead to a more unstable situation.
- **DEV_congestion**: A congestion occurred that could not be avoided by the activation of flexibility potential.

Following these behavioral traits, the incentivation scheme as depicted in Table 1 has been defined and implemented in the case study.

Table 1. Incentivation scheme as chosen to reflect flexibility behavior and grid effects

Type	Flexibility behavior	Enercoins
1	FLEX_offer, FLEX_requested, FLEX_contract, FLEX_follow	+30
2	FLEX_offer, FLEX_requested, FLEX_follow	+11
3	FLEX_offer, FLEX_follow	+10
4	FLEX_offer, FLEX_requested, FLEX_contract, DEV_grid-serving	+1
5	FLEX_offer, FLEX_requested, DEV_grid-serving	+1
6	FLEX_offer	+0
7	*Non-controllable components*	+0
8	FLEX_offer, FLEX_requested, FLEX_contract, DEV_grid-destabilizing	-4
9	FLEX_offer, FLEX_requested, DEV_grid-destabilizing	-4
10	FLEX_offer, FLEX_requested, FLEX_contract, DEV_congestion	-9
11	FLEX_offer, FLEX_requested, DEV_congestion	-9

As an example, in type 1, the component offered flexibility (FLEX_offer), this flexibility has been requested and contracted, and later the

component followed the contracted schedule. The component earned 30 Enercoins within this process. In type 2, the component offered flexibility, this has been requested, but was not needed and thus not contracted. The component was given 10 Enercoins for the offered flexibility and for following the forecasted behavior. In type 3, the component could offer flexibility, but this was not needed to compensate. The component then followed the forecasted behavior.

Type 4 reflects schedule deviations: The component showed a deviation of the contracted schedule, but the deviation has been grid-serving, i. e. less congestion has been the effect: The deviation compensated for other deviations in the grid. Type 5 is similar, with the component's flexibility not being contracted in the process.

Type 6 and 7 reflect components that are either not involved in a negotiation (e.g. as not flexibility was needed) or components that are not able to offer flexibility.

Type 8 – 11 reflect instable grid situations that occurred despite the negotiation and contracting of flexibilities. Depending on the component's behavior regarding the forecasted or contracted schedule, -4 to -9 Enercoins result for the participant,

Simulation environment The layered architecture as presented in Fig. 3 has been realized within a laboratory environment, with each component realized as a separate virtual machine. With this approach, full separation of the different components has been realized, thus alleviating the communication of the concept to be realized in the field as a both fully automated and distributed concept for distributed congestion management. The agent layer has been realized using the Python-based agent framework aiomas[Footnote3]. For the blockchain realization, Ethereum has been used as already discussed in this section.

SCENARIO SETUP

For the case study, three types of households with different load profiles and varying flexibility have been modeled and integrated in a simplified exemplary grid (cf. Fig. 4). For each type of housefold a specific load profile was assumed which reflects the characteristics of the available facilities in each case. As we wanted to demonstrate the technical

feasibility of our system in the sense of a proof-of-concept, we did not aim at creating perfectly realistic load profiles, but rather archetypical ones that allow the demonstration of the overall process and easy recognition of the different household types. In all load profiles, positive values refer to consumption, whereas negative values refer to generation of electric power. The first type of household consists of controllable loads only. Therefore, the default load profile specified by the BDEW (BDEW Bundesverband der Energie- und Wasserwirtschaft e. V. 2000) as depicted in Fig. 5 was taken as a basis to illustrate this kind of household.

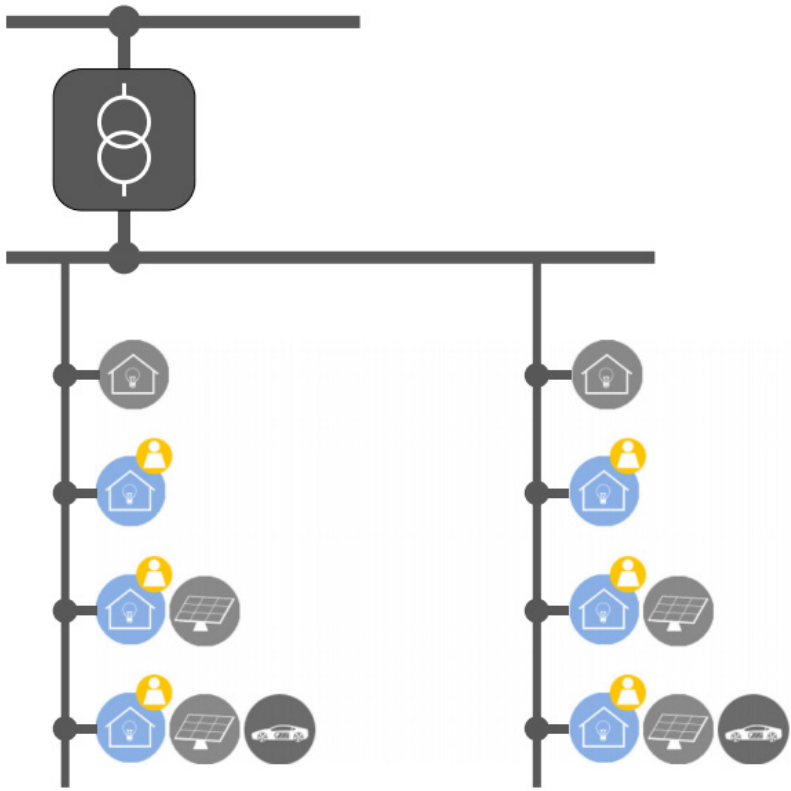


Figure 4. Showcase grid scenario: Non-controllable loads (grey houses) and controllable generation and load components (with agent symbol in yellow) connected to a transformer

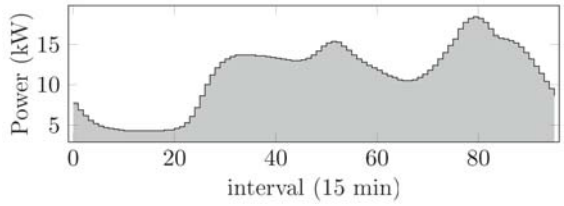


Figure 5. Exemplary schedule from the flexibility profile of a consumer-only household

In the second type of household feed-in from a photovoltaic plant is added to the load profile. In this case we assumed a sunny day for the simulation and therefore a high amount of feed-in of electrical power in the early afternoon. Figure 6 depicts this load profile, with the characteristic drop of the load curve far into the negative range where the feed-in from the photovoltaic system exceeds the local consumption.

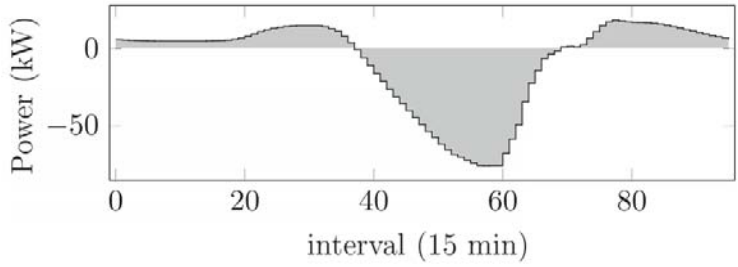


Figure 6. Exemplary schedule from the flexibility profile of a household with photovoltaics

In addition to the photovoltaic plant, the third type of household has an additional energy storage system installed, which is assumed to be an electric vehicle. This energy storage can be used for load shaping, e. g. consuming produced solar energy or reducing the peak load. As an additional constraint, it is assumed to be necessary to charge the electric vehicle for the next day, so that there will be a peak in consumption during the evening. This behavior is shown in Fig. 7.

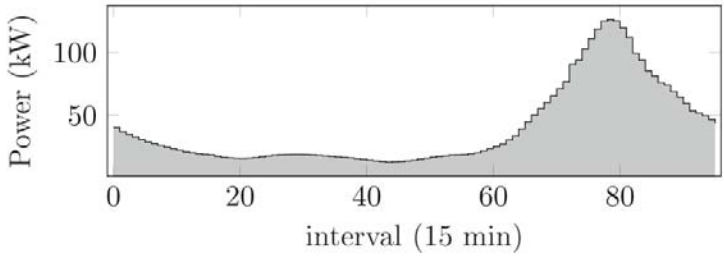


Figure 7. Exemplary schedule from the flexibility profile of a household with photovolatic and electric storage

As shown in Fig. 4, each of these types of household was deployed on two nodes in the scenario. Furthermore, every household needed a set of schedules representing the available flexibility that can be selected during the optimization process by the agents. Therefore, the basic load profiles in Figs. 5, 6 and 7 were subjected to Gaussian random noise in order to create a set of distinct schedules for each household. The non-controllable loads, also shown in Fig. 4, were represented by a variation of the default load profile.

All load profiles were aggregated in order to provide a global load prediction for the grid operator. This is depicted in Fig. 8. The total load and the proportion of the controllable households is shown. Additionally, the dotted line represents the feasible transformer peak power and indicates that a congestion was predicted, as the peak aggregated load surpassed this threshold. With this information, the optimization process was initiated with step (3) as defined in the overall process.

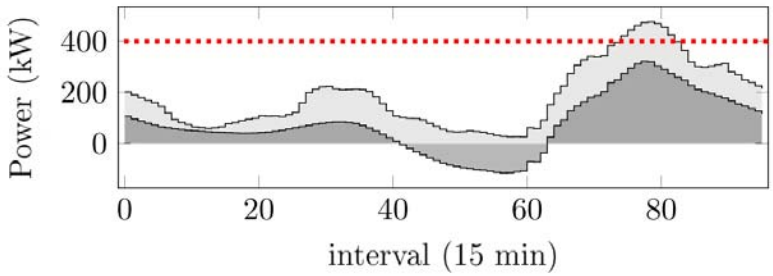


Figure 8. Predicted load with feasible transformer peak power. The darker area refer to non-controllable loads

AGENT-BASED SCHEDULE ADAPTATION

During the optimization process, each agent negotiated a new schedule for its household following the cooperative search as defined by the applied heuristic (cf. "System design" section). As an optimization goal, the avoidance of the congestion has been defined and communicated to the agents. In Fig. 9, the optimized load aggregated prognosis is depicted: In the relevant time intervals (70 - 85) the congestion has vanished from the prognosis as a result of new schedule choice of the involved agents.

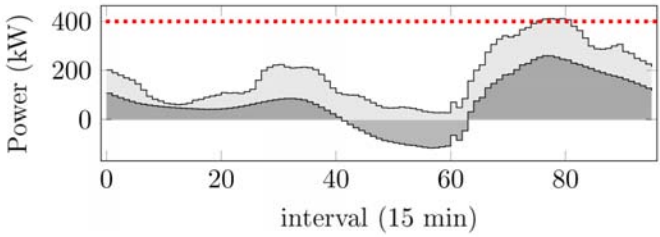


Figure 9. Resulting load prognosis after agent-based adaptation of feed-in and demand. The forecasted overload has been largely reduced. The darker area represents non-controllable loads

In the chosen setup, this process has been configured for day-ahead planning, so different aspects might lead to new congestions during execution of the chosen schedules. caused by e. g. different weather conditions. To visualize this aspect in the case study, a random noise has been added to the optimized schedules. For an in-depth analysis of the economic feasibility of the concept, a detailed household simulation is needed (cf. "Conclusion and further work" section).

VISUALIZATION

In order to show the fully automated functionality of the distributed congestion management system and make it more accessible to practitioners from energy utilities and DSOs, we developed a visualization of key information in the system. The visualization, as shown in Fig. 10, is divided intro three sections:

- **Blockchain area:** The *upper area* provides information about the

current state of both the application and the blockchain. The left symbol indicates the current state of this node: *Running* means that this node is connected and synchronized with the blockchain. Next, the state of the *contract agent* is shown which is responsible for submitting contracts to the blockchain. It should be noted that this agent is not connected to the MAS, but is only responsible for communication with the blockchain in the client software. The *block counter* tracks the current number of blocks in the chain. *Balance* represents the amount of so-called *Enercoins* gained so far by the respective node.



Figure 10. Graphical user interface of the application. The partner logos have been hidded for the reviewing process to ensure double-blindness

Participant area: The *center area* displays information accessible by each participant of the system. The tables on the left show all active nodes in the network, the number of contracts each one has published in the blockchain and all published contracts of the selected node. If a contract has been selected, the associated schedules are displayed in the center area. Different views are given for the baseline (i.e. the forecasted load / generation behavior), the optimized schedule after a negotiation and the measurement data. An additional view is integrated to depict the difference between contracted and measured behavior.

- **Aggregated transformer area:** The *lower area* has been

included for demonstration purposes. It represents the global view of the grid operator. The schedules of all nodes are aggregated. Additionally, uncontrollable loads are included in this view.

For the snapshot displayed in Fig. 10, we can see in the participant area that several nodes are involved in the current process. For the chosen participant, two contracts are listed. The first is in state [bom], whereas the second (for day 2017-06-30) is still in state [b]. From last runs, the participant earned 21 Enercoins as can be seen in the upper right corner in the blockchain area. For the contract 20170629 chosen for display (highlighted in the middle left contract table), the aggregated view on transformer level is displayed in the aggregated transformer area at the bottom of the visualization. The baseline is chosen for display in the aggregated view. It can be seen, that at about interval 75-82, a congestion is forecasted, as the aggregated load is not within the transformer's boundaries. Figure 4 displays the results after optimization. If the view *measured* would be chosen in the aggregated transformer area, these results would be displayed.

As can be seen, the visualization combines results from both energy system related and blockchain (i. e. incentivation-related) aspects. The transformer view is not needed to set up the fully distributed system, but needed to illustrate the potential of the system. Thus, this aggregated and thus centralized aspect is not part of the algorithmic setup, but used for visualization only.

CONCLUSION AND FURTHER WORK

In this work, we presented a fully automated congestion management system for distribution grid operation based on distributed ledger technology and intelligent agents. The intelligent agents are able to cooperate in order to negotiate schedule choices from their range of flexibility to avoid forecasted congestions on the transformer level. Contract agents were added to realize a fully distributed and automated documentation and billing process, thus closing the gap between control aspects and economic process fulfillment. To illustrate the concept, an simple incentivation scheme has been defined to show how different participant behavior can be used to incentive grid-serving behavior.

The focus of the work presented here has been on visualization and feasibility. Therefore, several simplifications have been chosen and discussed throughout the whole process. It can be seen though that with this case study, more detailed work on the definition of a fully distributed congestion management in the distribution grid can be performed. As an example, the simplified household model can be exchanged easily by adding a sophisticated smart home model.

Several open questions have been discussed while developing this case study and will now guide future work:

- **Incentivation scheme:** Would the presented incentivation scheme lead to an active participation? Does it realize congestion management at low cost?
- **Flexibility assessment:** What would be an appropriate method to assess the flexibility of the active participants?
- **Hardware implementation:** What would be an appropriate hardware to implement the chosen approach in the field? This will be connected with the chosen flexibility assessment as they might define requirements regarding storage and CPU.
- **Scalability:** While agent-based optimization concepts have been proven to fit large scale scenarios, this has to be evaluated for combined agent-optimization / blockchain systems. Depending on the use case, time requirements have to be taken into account.
- **Fraud mitigation:** There are several steps in the process where fraud would be possible: participants could e. g. pretend a grid-critical behavior in the first step of delivering a prognosis (state [b]) to evoke a situation where they can earn money by solving these grid issues. On the other hand it has to be ensured that the measured data really reflect the contracted schedule. For some of these aspects, existing concepts from the smart metering domain have to be taken into account.
- **Choice of blockchain technology:** In this case study, Ethereum has been used for ease of use and the feature of smart contracts. In a pilot implementation in the field, other DLT implementations have to be taken into account, e. g. HyperLedger might be an interesting alternative due to

the permission concept. The choice will have to guided by scalability and time requirements.

- **Data management:** We used the smart contracts and, therefore, the blockchain to store the time seres of the participant. This will most likely lead to a rapidly growing amount of data, which have to be stored at each participant. These aspects should be taken into account when choosing a suitable data management system.

As a general outcome of the work presented here, it can be concluded that the visualization has shown large benefits regarding the communication of both agent-based optimization and blockchain realization with practitioners from the distribution grid management domain. A pilot project will be defined where the open questions should be answered and a first implementation in the field will be realized.

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CHAPTER 3

TREND IN VIEWING QUANTITATIVE ANALYSIS AS A PRIMARY FUNCTION INVOLVING DECISION MAKING IN ORGANISATIONS

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ABSTRACT

This paper is to help view the trend in quantitative analysis as a primary function that involves decision making at every level in the organisation. The study involved the identification of recent trends in quantitative analysis, quantitative analysis as a primary function and its impact on decision making in the organisation. Quantitative analysis is an effective tool for statistical methods, e.g. big data analysis, machine learning, network analysis, operational analysis, etc. These analysis aids decision that is made within the confines of the organisation and its environment. The times are changing with a high rate of varieties in quantitative analytical trends. It has become imperative to follow these trends for enhanced decision making in today's contemporary organisation.

Keywords: Trend, Quantitative Analysis, Decision Making

INTRODUCTION

Decision-making process involves proper and efficient implementation of strategic plans and methods to achieve desired business objective [1]. According to Dunn [2], he posits that organisational challenges and problems are interdependent, subjective, artificial and dynamic. Challenges and problems can be rarely separated into independent, discrete and, mutually exclusive parts. Quantitative analysis (mathematical techniques) provides diversity of knowledge. A manager's level of education and technical know-how of quantitative methods will help to boost the decision-making process of the organisation.

The manager's concentration with respect to decision making is centred on quantitative approach which is utilised via mathematical expressions describing objectives, constraints and other relationships that exist around a problem [3] . Quantitative tools are vital prerequisites for solid and effective decision-making process. Managers, who make a decision, must enhance their decision-making skills, capabilities and competence by learning and understanding the various techniques that are involved (psycho-technical).

The psychological use of information embodied in decision-making method is sometimes intermingled with the practical and technical existence of data. How decisions are made in organisations to a large extent shows problem-solving skill of such organisation. There are quantitative measures to help us choose the best fit with respect to choices in the problems or challenges encountered. Quantitative measures such as network analysis, games theory, transportation model, optimisation, regression analysis, and correlation analysis aid adequate managerial decision making. No one goes into business with problems at the back of their mind and as much as they can, it should be avoided; though we do not envisage these problems in making some decisions to move the organisation forward we encounter some problems. Quantitative analysis is an effective managerial tool that often times is neglected, relegated and delegated: managers must understand that in order to make a decision that keeps the business flying, quantitative measures are a

prerequisite in carrying out certain function and making certain choices and decisions. These quantitative measures cover cost and profit analysis involving product costing, budgeting, purchasing, insurance, planning, remuneration, investments, and savings. Understand that proper application of relevant analytical tools can ensure an organisation's success when proper decisions are made. This paper is a theoretical review on the recent quantitative analytical trends involving decision making in any organisation and to add to existing knowledge

LITERATURE REVIEW

Concept of Quantitative Analysis

Quantitative analysis is numerically based; it is counted with findings that are generalizable. QA simplifies the reality in the effort to provide hard, objective, numeric data. According to [4] , quantitative analyses are very essential in managerial decision-making for efficient and effective use of available resources for the growth and development of an organisation. Quantitative analysis is a process of practical problem solving based on scientific rationality. It is an application of scientific method in the study of complex systems seeking to produce an understanding of problems and to develop a model to enable the consequences of decision to be investigated. Quantitative analysis is a number of techniques with a common scientific approach which includes:

1) Linear programming,
2) Queuing,
3) Inventory control,
4) Network analysis,
5) Correlation Analysis,
6) Regression Analysis, etc.

Linear Programming

Also known as Mathematical Optimization is a unique case of mathematical programming. It is a technique to obtain the most

advantageous outcome which is usually maximum profit or lowest cost of production, in a mathematical model whose needs are shown by linear relationships. Linear programming more formally can be said to be a method for the design and operation of a system or process to make it as good as possible in some defined sense which is usually linear objective function, conditioned to linear equality and linear inequality constraints [5] . Linear programming is a commonly accustomed field of optimization for many purposes. Several applicable issues in operations research can be stated as linear programming problems. Basic unique cases of linear programming, such as network flow issues are seen as important to have begotten much research on unique algorithms for their solution. Other types of optimization issues have a number of algorithms for finding solutions for linear programming problems as sub-problems. Main concepts of optimization theory such as duality, decomposition, convexity are also inspired by linear programming. Formation of Microeconomics earlier was heavily linked with linear programming and is recently used in company management, such as planning, production, transportation, technology and other issues. However, the recent management concerns are ever-changing, most companies would like to maximize profit or minimize cost with limited resources. Thus, many issues can be seen as linear programming [6] .

Inventory Control

This involves giving unchanged attention towards the Production, Sales, Maintenance, etc. with least stock. It is a mandatory aspect for the development and growth of company. Stores index is the core of a firm inventory control or stock control can be largely said as “the duty of inspecting a shop’s stock. More directly, inventory control may refer to: In operations management, logistics and supply chain management, the programmed software necessary for managing inventory. It involves stock control, regulating and maximizing one’s company inventory [7] . The main aim of inventory control is to highest profits with the least minimum inventory investment, without affecting customer satisfaction rate. It also involves having knowledge of where all your stock is and ensuring everything is accounted for at any given time.

Network Analysis

Is a set of unique analytical methods that are used in issues where it is mandatory to optimize and analyse a network of associated and anastomosed parts that have some connection between one another e.g. project management, where the parts are key activities of the project in the mutual time association. Another use of network analysis is in the field of transportation and logistics, where the components stand for the center and the dependencies are figuratively temporal or spatial. Network analysis techniques are focused on critical path optimizing or calculating between the elements [4] . These techniques are related to the notion of a network diagram, which is a perspective of the project as a diagram which introduces many links between the project activities.

Queuing Model

Mathematical examination of waiting lines or queues is the focus of queening model. Predictability of waiting time and queue lengths are one of the main goals of constructing a queuing model. Queuing theory is commonly seen as a branch of operations research due to the facts that results are most times used when making business decisions about the resources needed to provide a service [8] .

Regression Analysis

In statistical modeling, regression analysis is a set of statistical method for appraising the association among variables. It includes many processes for examining and modelling variously changeable, when the attention is on the association between a dependent variable and one or more predictors (independent variables). Concisely, regression analysis aids one understands how the particular value of the criterion variable (dependent variable) reacts when any one of the independent variables is changed, while the other independent variables are left unchanged [9]

Correlation Analysis

Correlation analysis is an approach of statistical assessment applied

to explain the potency of an association between two, numerically ascertained, continuous variables (e.g. height and weight). This specific type of analysis is important when a researcher needs to identify if there is a possible association between variables [9] . It is most times misunderstood that correlation analysis figures out cause and effect; in contrast, this is not the issue due to changeable that are not particularly present in the research that may have an effect on the results.

Concept Decision Making

Decision making is a fundamental management resource, especially in the face of complexity and dynamism requiring precision in decision making. The decision-making ability of every manager and those in spheres of leadership in organisations must be sharpened in order to face the challenges efficiently and effectively. Decision making is in business is a managerial function involving the best choice from an alternative pool of choices: Managers are referred to as decision makers. Decisions are said to be effective when it achieves zero defect, positively affecting the organisational goals and objectives [10] . In other to thrive in today's business world where the market is demand-driven and competition is high. Globalisation is putting so much pressure on management to make decisions. After the war, many of these team members continued their research on quantitative approaches to decisionmaking, leading to the growth and use of management science in non-military applications such as healthcare, manufacturing, engineering projects, transport and traffic studies, communication, business and educational administration. Decision making also involves choices among alternative courses of action as earlier defined but it also covers inaction and management is decision making though decisions made by managers sometimes in the organisation fail [11] [12] [13] . Effective decision making is an important part in maximizing effectiveness and efficiency at the workplace. Hence, decision-making became the heart of the management/administrative process [14] . Decision-making is an essential process in organizational effectiveness. Risk taking cannot be neglected or denied in decision making, for the everyday choices are made, it is accompanied with risk. Risk associated with personal decision making cannot be equated

with that of the organisation especially large organisations; the risk is enormous.

Organisations need to make good choices that will affect profitability, development and continuity, it imperative that they calculate and manage the risks associated with their choices using available statistical and highly sophisticated tools. Risks in years past were considered mostly in games but today, it has gone beyond the game for leisure; it can be viewed as a theory of games needful in making the right decision for well-calculated risks.

The decision-making process in an organisation is a decision of choice from two or more alternatives involving the optimum decision of the various alternatives. The decision making is divided into the problem identification stage and the problem-solving stage [15] .

Model of Decision Making Process

The above (Figure 1) diagrams depict the relationship and connectivity in the decision-making process required for organisations to thrive. Daft [15] explains it further.

a) The problem identification stage—according to Daft [16] , this stage involves having information about the environment and the organization itself in assessing her performance and to note areas of failure.

b) The problem-solving stage—this is the actual process of decision making. It involves the choice of action from alternative actions or strategies and its implementation. He categorized organizations' decisions as programmed and non-programmed. Programmed decisions are identified procedures to solution finding and resolving established problems and are iterative. The decision environments somewhat sure are usually termed to be structured. Notwithstanding, non-programmed decisions can be said to be uncertain or dangerous and do have unclear environment. Many of such non-programmed decisions imply carefully structured planning due to high intensity of competitiveness in decision environment and the unsure nature of the decision outcome [15] .

The business environment is in a realm of dynamism with rise in intricacy and unpredictability and still, the business manager is required to wallow through turbulent environment by decisions made by them.

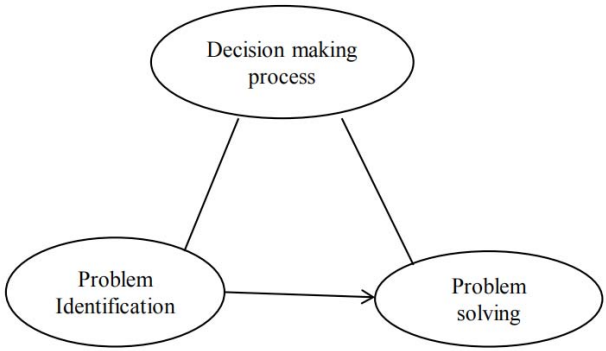


Figure 1: Model of decision making process. Source: Researchers Desk (2019).

Decision making as an action has shaped organisations and it is very symbolic to conclude that life is the sums of all the choices made. In making these relevant choices and choosing alternation, it is important to go through the decision-making steps.

Decision Making Steps

Figure 2 explains steps to be followed in making adequate decisions.

Bagshaw [4] , states that the decision-making steps can be explained further:

- Monitor the Decision Environment: As a manager, it is important to observe and monitor the environment of decision making in order to plan with the information available both internally and externally.
- Explain the decision problem: based on the observation, the manager would have been able to get explanations for certain occurrences and should be able to attribute deviations where necessary and then take action as the case implies.
- Identify the decision aim: the expected performance outcome is identified and direction clear.

- Determine the problem: This is a total view of the problem to know the cause and possible solution, it involves analysis of the situation, identification of the deviations to set out objectives.
- Develop alternative solution: This is achieved though brainstorming or via personal observation and experience in development of alternative solutions.
- Evaluate alternative solution: The alternative solutions which are courses of actions or strategies need to be evaluated as to identify the optimal solution. The choice among alternatives is the essence of decision making.

In addition to the steps, Bagshaw [4] added that the Decision-making steps involve three approaches, the rational approach, the bounded rationality approach and the intuitive approach.

1) The Rational Decision Making Approach

The steps in the rational approach in making a good decision are basically the same no matter the type of decision needed in solving an identified problem. It has important equips the decision maker to establish decision criteria before you searching for alternatives so as to set criteria before picking an option.

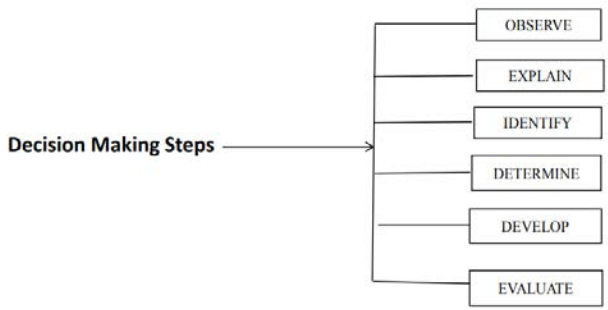


Figure 2: Decision making steps. Source: Researchers desk (2019).

It is also important to set criteria before the search for alternatives this is to prevent making mistakes with choices. The rational model urges the decision maker to generate all alternatives instead of a selected few:

when there is a pool of generated alternatives, positive decision making is possible from a wide range of choices. Decision-making model also involves a number of unrealistic assumptions. According to Bagshaw [4] observed that while the rational decision-making model may be a helpful tool for working through problems, it does not depict the frequency of decision making within the organisation.

2) The Bounded Rationality Approach of Decision Making

In today's competitive environment, with a high degree of a state of flux, it is almost impossible for managers to follow the systematic procedure outline in the rational approach. The attempt to be rational is bounded (limited) by the prevailing complexity of many problems [15] . It recognizes the limitations of our decision-making processes. According to this model, individuals knowingly limit their options to a manageable set and choose the best alternative without conducting an exhaustive search for alternatives. An important part of the bounded rationality approach is the tendency to satisfice, which refers to accepting the first alternative that meets your minimum criteria.

3) The Intuitive Decision Making Approach

The bounded rationality approach is followed by intuitive decision processes. Intuition is mostly appreciated where the manager had developed subconscious elements in solving problems based on long experience on work performance. It has emerged as an important decision-making model. It refers to arriving at decisions without conscious reasoning [17] . When we recognize that managers often need to make decisions under challenging circumstances with time pressures, constraints, a great deal of uncertainty, highly visible and high-stakes outcomes, and within changing conditions, it makes sense that they would not have the time to formally work through all the steps of the rational decision-making model. The intuitive decision-making model argues that, in a given situation, experts making decisions scan the environment for cues to recognize patterns [18] [19] [20] [21] .

TRENDS IN QUANTITATIVE ANALYSIS

Quantitative analysis has evolved over time with highly sophisticated machine, Programmes, functions and tools that aid managerial decision making. Quantitative analysis is considered to have emerged during World War II with team of operation researchers seeking to find solution to strategic and tactical challenges the military faces [22] [23] . According to Anderson [24] , challenge/problem was tackled via scientific methods in diverse fields such as the engineers, mathematicians, behavioural scientist. The trend today is a technology-powered quantitative analysis with a focus on machine learning, big data analytics, statistical package for social sciences (SPSS), spartial analysis, geocomputation, etc. Quantitative analysis trend is appreciated in research; methods of research and report following these trends. In addition to other quantitative function, globalisation, technological advancement and new drive for educational frontiers has given rise to recent patterns for which quantitative trends have become needful.

Recent Trends in Quantitative Analysis

1) Machine Learning: This is a subset of artificial intelligence (Industry 4.0) in the spheres of computer science. Machine learning is also statistically inclined using quantitative techniques to aid the computers with the ability to learn by progressively improve performance on a specific task and help to make end decisions. The name machine learning was first mentioned in 1959 by Arthur Samuel [25] . It evolves around patterns and computational learning theory in artificial intelligence, machine learning exploring the study and construct of algorithms that can learn from and make predictions on data such as algorithms to overcome the following static program instructions by making data-driven predictions or decisions, through building a model from sample inputs. Machine learning is employed in a range of computing tasks where designing and programming explicit algorithms with good performance is difficult or infeasible; example applications include email filtering, detection of network intruders or malicious insiders working towards a data breach, optical character recognition, learning to rank, and computer vision. Machine learning is closely related to (and often

overlaps with) computational statistics, which also focuses on prediction-making through the use of computers. It has strong ties to mathematical optimization, which delivers methods, theory and application domains to the field Jordan [25] . Machine learning is sometimes conflated with data mining, where the latter subfield focuses more on exploratory data analysis and is known as unsupervised learning. Machine learning can also be unsupervised and be used to learn and establish baseline behavioural profiles for various entities and then used to find meaningful anomalies. Within the field of data analytics, machine learning is a method used to devise complex models and algorithms that lend themselves to prediction; in commercial use, this is known as predictive analytics. These analytical models allow researchers, data scientists, engineers, and analysts to produce reliable, repeatable decisions and results and uncover hidden insights through learning from historical relationships and trends in the data. Machine learning also has intimate ties to optimization, formulated problems are learned as minimization of loss function or maximisation of positive choice function.

2) Big Data Analytics: Statistically what is being analysed is a data. Today's IT world is focused on the big data with the rapid rise in the internet and coupled with the category of breed of employees in this 21st century. The digitised economy is geared towards growth exponentially in proportion with the demand for data storage and analytics. It has also become a challenge to protect and analyse the volume of information generated and organisation depend on information gathering and storing [26] . Big data can be used to predict future volumes, gain insights and have provided precautionary measures of action for better decision making. Big data analytics is a way of extracting value from a pool of information to help the business world with respect to decision making. Big data analytics improve competitive advantage using a set of data algorithms especially for large data.

3) Statistical Package for Social Sciences (SPSS): is a powerful, user-friendly software package for the manipulation and statistical analysis of data. The package is useful for decision making by researchers, containing an extensive range of both univariate and multivariate procedures which is used for conclusion on decision to be carried out with respect to findings. Statistical analyses computed using the various versions of SPSS [27] .

The Statistical Package for the Social Sciences (SPSS) is a package of programs for manipulating, analysing, and presenting data; the package is widely used in the social and behavioural sciences. According to Tarone [28] , the core program of SPSS is based on a number of add-on modules that extend the range of data entry, statistical, or reporting capabilities. The most important of these analyses are the advanced models and regression models with add-on modules.

4) Spatial Analysis: Spatial analysis has several definitions to it, it has diverse and comprehensive capability covering simple visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimum routes, site selection, and advanced predictive modeling. In spatial, attention is concentrated on understanding and establishing variety across space. This inclination in this particular direction comes with the concerns of Space Analytical methods and it repudiates the rather inexperienced criticism that quantitative geography is undeservedly associated with search for global generalities and laws.

- Issues here are associated with the development of statistical techniques purposed at local rather than the global.
- There is slight movement in prominence considering the increasingly ready large and complex spatial set of data.

Spatial analysis unfolds the overwhelming rise in the computational power and readily obtainable spatial data of a period. [29]

5) Geocomputation Analysis: Geocomputation is a technique that elaborates primary quantitative within geography to take advantage of increase in computer power and data [29] [30] . Geocomputation is computer aided quantitative analysis. The computer performs a crucial part in this technique. It is an emerging and fast-growing field of research that recommends the use of computational and intensive techniques such as neural networks, heuristic search, and cellular automata for spatial data analysis. Data is gathered from within a geographical region of reference, showing a potential increase of data for analysis. Geocomputation computerises data rich environments with an affordable computational power in spatial data analysis and mining techniques. The computerised database is with geographical referencing for census tract or postal code. It is also a set of algorithm-driven technique covering neurocomputation, fuzzy logic, and cellular automata. Geocomputation technique or analysis

is explained in four different approaches e.g. computer intensive pattern search, exploratory spatial data analysis, artificial intelligence techniques, and dynamic modelling.

QUANTITATIVE ANALYSIS AND DECISION MAKING

An essential managerial skill is the allocation and utilization of resources in an effort to effectively and efficiently achieve the optimal performance especially in cases of complexity and dynamism, decision is based on intuition with a quantitative base that is reasonably accepted and practiced in the achievement of organisational goal. It is pertinent for managers to enhance their decision-making competence through experiential and scientific knowledge acquisition [24] . This will ensure a seamless decision-making process, an effective communication mechanism and efficient use of resources by the organisation. Quantitative as a decision-making mechanism aids manager with viable and adequate tools in effectively and efficiently carrying out managerial functions. Quantitative techniques or analysis in the organisation identifies and records decision type that will influence the goals of the organisation. Managers may enhance decision making capabilities by learning more about quantitative methodologies and by better understanding their contributions to the decision-making process. A manager who is knowledgeable in quantitative decision making procedures is in a much better position to compare and evaluate the quantitative sources of information and, ultimately, to combine alternatives in making the best possible decisions. Decision making as a behavioural method is closely tied to quantitative techniques in solving organisational problems to yield optimum result [31] . Quantitative factors in decision making cover investment appraisal, break even analysis, market research, sales forecasting, critical path analysis, decision trees, chi square, correlation analysis, Regression analysis, Simulation, transportation analysis, network analysis, t-test, etc. Giving numerical base for decision making and by way of reducing decision regarding monetary value placed on different choices in forecasting sales figures for a period, impact of redundancies over time and these data affords only a fragment of the concept [4] .

APPLICATION OF TRENDS IN QUANTITATIVE ANALYSIS ON DECISION MAKING

The future of the organisation lies in the decision-making ability of the manager and beyond that the techniques involved in making a hitch free decision is also key. To this end, the application of trends in quantitative analysis on decision making is explained below:

Machine Learning and Decision Making

Machine Learning is a powerful tool that aids the adaptation and accelerates the decisions that are made in today's organisation. Decision-making systems can be built to walk without human interference but that will be effective with inventions of machine learning that are able to make decisions on its own as part of its design. It is imperative for organisations today to leverage on machine learning for predicting and determining causality [32] .

Big Data Analytics and Decision Making

Information is a key factor in successfully influencing the decision making ability of any manager in making quality, accurate and bias decisions. Today's decision making amounts to the availability of data analysis for a smooth operation of the organisations; Decision is deduced from the analysed data. Data is appreciatively the latest input resource or material in this present time and age. Decision makers need to be able to gain valuable insights from such rapidly changing data of high volume, velocity, variety, veracity, and value by using big data analytics [33] .

Statistics Package for Social Sciences (SPSS) and Decision Making

The world is changing rapidly: the environment of business causing a change in the organisation as well. This change carries opportunities and difficulties too. In such an environment or society, decision making becomes difficult and complicated. The decision maker is meant to

look beyond and apply exact quantitative methods for decision support e.g. marketing research, analysing and using the data from marketing research, costs, revenues, profits, input, output modelling, simulation, quality control, etc. This variety of methods and techniques is usually supported by software usage, with user-friendly graphical design. One of the appropriate software for decision making support is SPSS. It is a useful tool for sustaining competitive advantage [34] .

Spatial Analysis and Decision Making

Decision making is either rationally or irrationally and spatial analysis as a quantitative tool can be employed by the decision maker in making thorough decision by visualising the problem, defining relationships between factors, predicting outcomes through modelling, evaluating how sensitive decisions are to changes in individual factors and finally visualising the spatial relationships between potential factors [35]

Geocomputation and Decision Making

Geocomputation can be linked with spatial analysis to an extent. geographical data that is generated via the geographical information system is useful in carrying spatial analysis. These data are needful in making decisions. Geocomputation is part of the information system field and it is a computer program application that analyses business data, present such data for decision making in an organisation. It is designed to assist the planner with a guide in making decision especially on land use e.g. organisation sites, airport, etc. and this is made possible with the creation of model to help identify the most effective decision path [36] .

CONCLUSION

Decision making involves solving a problem known as decision problem for which decision has to be taken resulting in a set of alternative actions and quantitative analysis is a tool that aids corporate decision making and also in individual decision making as well [37] . The decisions made from the alternative are implemented and monitored as to have a

feedback mechanism in control of the system and at every point in the system, information is needful to be fully loaded with the knowledge required to make a decision, the conditions and then the environment for such decision.

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CHAPTER 4

DAIRYMGT: A SUITE OF DECISION SUPPORT SYSTEMS IN DAIRY FARM MANAGEMENT

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INTRODUCTION

Dairy farming is a highly dynamic and integrated production system that requires continuous and intense decision-making. Several dairy farm components that include 1) cattle, 2) crops, 3) soils, 4) weather, 5) management, 6) economics, and 7) environment are extremely interrelated [1]. These components and their sub-components dynamically affect and are affected among them. Therefore, an efficient decision support system (DSS) framework within an integrated systems approach is critical for successful dairy farming management and decision-making [2-5].

This chapter describes the development, application, and adoption of a suite of more than 30 computerized DSS or decision support tools aimed to assist dairy farm managers and dairy farm advisors to improve their continuous decision-making and problem solving abilities. These DSS

emerged in response of dairy farm managers' needs and were shaped with their input and feedback [6-7]. No single or special methodology was used to develop each or all of these DSS, but instead a combination and adaptation of methods and empirical techniques with the overarching goal that these DSS were: 1) highly user-friendly, 2) farm and user specific, 3) grounded on the best scientific information available, 4) remaining relevant throughout time, and 5) providing fast, concrete, and simple answer to complex farmers' questions [2, 8-11]. After all, these DSS became innovative tools converting expert information into useful and farm-specific management decisions taking advantage of latest software and computer technologies.

All the DSS object of this chapter are hosted at http://DairyMGT.info, *Tools* section and are categorized within dairy farming management and decision making such as: 1) nutrition and feeding, 2) reproductive efficiency, 3) heifer management and cow replacement, 4) production and productivity, 5) price risk management and financial analysis, and 6) environmental stewardship. Depending on the complexity, the specific purpose, and the requirements of dairy farm decision makers, some DSS are completely online applications, others are Macromedia Flash tools, others are Spreadsheets, and others are self-extractable and installable programs.

This chapter discusses the challenges on the development of these DSS with respect to the trade-offs among user-friendly design, computational detail, accuracy of calculations, and bottom line efficiency performance and effective decision-making. It portrays DSS development strategies, within the computational resources available, that succeeded in their primary objective of providing dairy farm mangers fast and reliable responses to perform efficient and effective decision-making.

The chapter reveals practical and real-life applications of a number of these DSS to demonstrate satisfactory system assessment, acceptable future predictability, adequate scenario evaluation, and, consequently, satisfactory decision-making.

The chapter also covers aspects of DSS dissemination and adoption evaluation, including the inception and development of a dedicated webpage; local, national and international usage, requested presentations,

and academic publications.

The chapter also infers the possible role of emerging and evolving new technologies such as smart phones and tablets in the intersection of DSS, real-time applications, and mobile devices, which is a fast growing area of development within the dairy farming industry.

DESCRIPTION OF DAIRYMGT.INFO DECISION SUPPORT TOOLS

This section lists and describes the DSS object of this chapter. These DSS are categorized in main areas of dairy farm management, as they appear in the DairyMGT.info: *Tools* webpage.

Nutrition and Feeding (DairyMGT.info → Tools→ Feeding)

Dairy farmers recognize that the largest item cost in a dairy farm system is feed, whether purchased or farm-grown. Obviously the major source of income in a dairy farm operation is the milk sale. Consequently, managing and optimizing the milk income over feed cost is a critical decision that affects not only economic sustainability, but also has large impacts regarding environmental stewardship[12]. Farmers also recognize that every farm is completely different and that market conditions are constantly changing. Therefore, beyond established farm feeding rations, there is a need for tools to permanently adjust strategic feeding decisions. Take as an example corn grain and its highly volatile price. Corn is a staple feed commodity for dairy farm feeding and consequently its price influences largely diet costs. With sudden corn price swings farmers confront permanently the question of re-considering the amount of corn in the diet. This question can be responded by estimating the marginal value of milk (also depending on highly volatile prices) to corn according to lactation stage and current amount of corn in the diet. The optimal use of corn would occur when the marginal value of milk equals the marginal value of corn, which at research-based feed efficiency levels [13], would solely depend on the ever-changing price relationship of milk and corn. The tool "*Corn Feeding Strategies*" shows these relationships in a graphical, dynamic, and interactive way so dairy farmers can optimize

the amount of corn grain in each farm feeding group according to ever-changing market price conditions.

Take as another example the price of the main dairy cattle feed commodities and their relationship with milk price according to feed efficiency changes throughout lactation states. Research data indicate that the use of concentrates (i.e., corn, soybean meal) have a substantially higher impact on milk production during early or mid-lactation than in late lactation [14]. Under this premise, increased use of forages is justified in late lactation to maximize the overall milk income over feed cost, which however depends on ever-changing feed commodity prices. The tool "*Income Over Feed Cost*" graphs interactively the milk income over feed cost weekly for entire lactations and shows the impact of feed commodity prices on the dynamic milk income over feed cost value. Therefore, dairy farmers can fine-tune their feeding strategies to maximize their milk income over feed cost according to lactation states and feed prices swings.

Sometimes dairy farmers need additional help on formulating their diets to optimize feed concentrate supplementation. Research trails indicate that the optimal level of concentrate supplements in a diet could be achieved by using milk production response to crude protein (CP) and its components of rumen un-degradable protein (RUP), and rumen degradable protein (RDP), according to particular cow-group rations [15]. The tool "*Income over Feed Supplement Cost*" performs an optimization according to defined feed ingredients, prices, and CP (RUP, RDP) restrictions to maximize the net return. The tool helps dairy farm decision makers to select the most cost effective concentrate supplements in the diet, especially from the point of view of providing adequate amounts of RUP and RDP, which not only optimizes the net return, but also reduces the amount of nitrogen excretion and hence environmental impacts.

Dairy farmers also want to know what are the best-priced feed ingredient choices in the market. This information would drive farmer feed purchase decisions. The tool called "*FeedVal 2012*" is a dynamic and interactive matrix that finds the estimated price of a feed as an aggregated sum of its individual nutrients values according to the nutrient content and prices of a set of defined feed ingredients available in the market. The tool then compares the actual price of a feed ingredient with its calculated price.

The result is a list of ingredients with their relative prices, indicating if an ingredient is a bargain or an expensive proposition.

Another critical factor in the quest for feed efficiency and maximum milk income over feed cost is the analysis of "benchmarking" with respect to feed efficiency, milk income, and feed costs [16]. Results from surveying dairy farm rations and farm prices reveals an impressive difference regarding to feed costs, feed consumption, and overall milk income over feed cost among otherwise similar dairy farms. A large and important opportunity exists then to improve the milk value net of the feed costs by comparing performance among farms. Therefore an online database structure and DSS was developed: "*Dairy Extension Feed Cost Evaluator*," Figure 1. This tool performs advanced benchmarking analyses for a group of users within a region, state, or country throughout a defined timeline by querying an online database, which is permanently being updated by the users. The tool allows users to "drill-down" the analysis and find out the driving factors for differences, an important step toward improving dairy farm feed efficiency and income over feed cost.

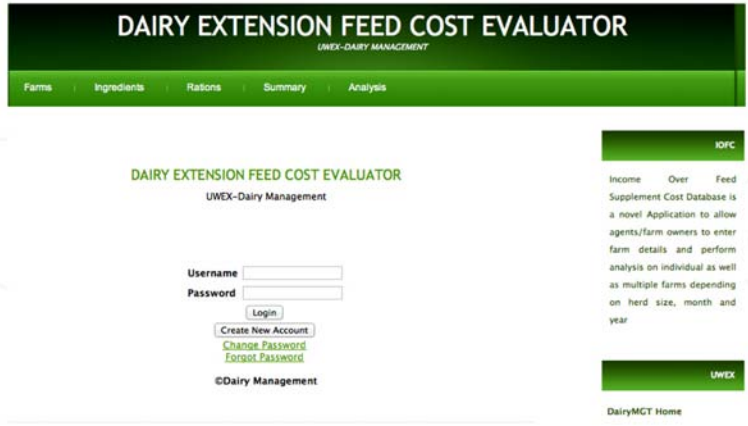


Figure 1: Screen snapshot of DSS Dairy Extension Feed Cost Evaluator.

Dairy farmers also require some simpler evaluation tools for feed additives. The tool "*Optigen® Evaluator*" analyzes the economic value of including this slow release urea additive while maintaining diets at the same level of protein and dry matter intake. The tool "*Dairy Ration Feed Additive Break-Even Analysis*" determines any additive's additional milk production needed to justify its economic inclusion in the diet.

Finally, regarding nutrition and diets, there is some evidence that dairy farmers might be over-feeding a large proportion of lactating cows when they feed the same diet ration to a large group of animals. Diets are normally formulated to provide enough nutrients to the most productive animals, which in turn gives extra nutrients to the less productive animals within the same group. Therefore, splitting lactating cows in smaller groups and offering group-specific feeding rations provide more precise nutrient requirements, increase herd's income over feed cost, and decrease nutrient excretion [17]. The tool "*Grouping Strategies for Feeding Lactating Dairy Cattle*" calculates dynamically individual cow nutrient requirements and optimizes cow grouping feeding strategies within particular farm constraints.

Reproductive Efficiency (DairyMGT.info → Tools→ Reproduction)

Reproductive efficiency plays a critical role in the economics of dairy farming. However, assess the economic value of it is extremely difficult and complex [5]. A first step on understanding the economic impact of reproductive programs is to demonstrate the milk value net of feed cost dependent on the pregnancy time. The tool "*Exploring Pregnancy Timing Impact on Income over Feed Cost*" shows interactively and dynamically a cow's total milk income net of feed costs to a fixed lactation's pregnancy time and defined lactation curves. The tool illustratesand quantifies the economic value of having cows pregnant at the right time.

Dairy farmers are also required to do complex decisions regarding the best reproductive programs for the lactating herd population. New reproductive management strategies, whether they use hormonal synchronization technologies, heat detection methods, or a combination of both, are continuously and permanently evolving. Dairy farmers need not only to keep up-to-date with all these technologies, but also make the best decisions according to their own conditions [5]. Dairy farmers usually know which reproductive programs are more efficient from the reproductive point of view of getting more cows pregnant. Farmers also have a good handle on costs incurred according to reproductive programs. Nonetheless, dairy farmers have difficulty assessing the overall

profitability of reproductive programs. Not surprisingly, they have long demanded for a systematic economic analysis to analyze reproductive programs. The tool "*UW-DairyRepro$Plus*" is a complex, still user-friendly, decision support systems that assess the economic value of farm-defined alternative reproductive programs for a particular farm according to prevalent market conditions. These tools allow farmers to be highly specific regarding their current or alternative reproductive programs. Besides reporting the most important reproductive parameters for each alternative program, the tools find the reproductive program with the best economic outcome and calculates the difference in net returns a farm would have when using alternative reproductive programs.

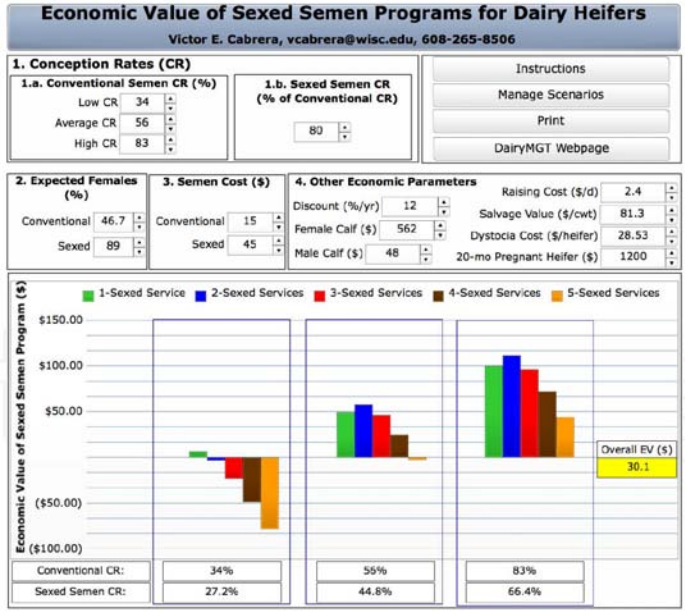


Figure 2: Screen snapshot of DSS Economic Value of Sexed Semen for Dairy Heifers.

Sex-sorted semen that increases the chance of female offspring is a relatively new technology being widely adopted in the dairy industry. Farm-specific sexed semen's economic value and, moreover, when and how to use it, are critical. The tool "*Economic Value of Sexed Semen for Dairy Heifers*" (Figure 2) finds interactively the gain (or loss) of different reproductive program management strategies that include sexed semen compared with solely using conventional semen [18].

As important as to find out the value of specific-defined reproductive programs is to explore the value of improving the overall reproductive efficiency. The tool "*Dairy Reproductive Economic Analysis*" is a Markov-chain stochastic dynamic model packed in a simple to use online application. This tool integrates detailed parameters of pregnancy, abortion, and culling risks to perform iterations during 9 lactations until a herd reaches a steady state [19]. Then, the economic value of a reproductive program is determined by using predicted milk production curves, calve value, replacement costs, and other economic figures. The end result is a net return tied to a reproductive performance.

Heifer Management and Cow Replacement (DairyMGT.info → Tools→ Heifers / Replacement)

Whether farmers raise replacement heifers or not, they benefit from decisions related to this dairy farming enterprise. One first step on the economic decision about heifers is to determine the overall cost associated with rearing heifers according to estimated time to first calving. The tool "*Heifer Break-Even*" calculate the daily and accumulated cost for rearing heifers up to 12 months, 24 months, and beyond 24 months according to farm-defined prices for forages, corn, and soybean meal. Farmers use this tool to decide if to raise their own heifers, use custom-raising heifer services, or simply buy heifer replacements, according to market prices.

When farmers raise heifers on-farm, another decision comes along: to use or not to use accelerated feeding programs for boosting the early development of calves. The tool "*Cost-Benefit of Accelerated Feeding Programs*" gives dairy farmers the opportunity to compare hand-by-hand their current heifers' feeding program with an alternative accelerated feeding program within farm defined conditions. This tool shows economic differences at weaning and calving and calculates the amount of milk amount that would be needed to pay for heifer rearing costs.

In addition to the decisions of raising heifers and if to use accelerated feeding programs, dairy farmers want to know the number of heifers needed to maintain (or increase) the herd size according to farm long-term goals, reproductive efficiency, and heifers' culling rates. The tool "*Heifer Replacement*" calculates the number of replacement animals

needed (springer heifers) responding to farm specific data inputs. Dairy farmers would need to buy (or sell) springing heifers if the number of he replacements is fewer (or greater) than the required number to achieve the goal of maintaining or expand the herd size. Consequently, they need support on estimating the right price to pay (or to sell) springing heifers. The tool "*Value of a Springer*" performs a projection of the net return an animal would have under farm specific conditions. This value indicates the value of a replacement to break-even its costs. Because of the uncertainty in the milk price, milk production, and the productive lifetime, the model presents outcomes under different price and lifetime scenarios, so farmers can make decisions based on their assertion of the future prices and their risk preferences.

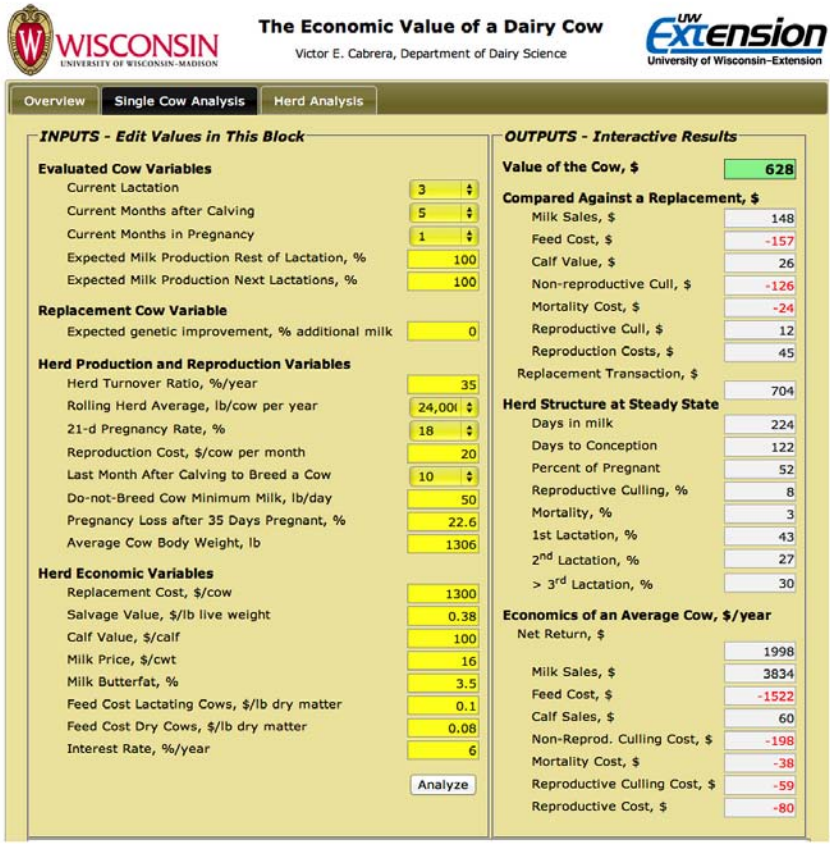


Figure 3: Screen snapshot of DSS The Economic Value of a Dairy Cow.

Furthermore, dairy farmers need to make critical decisions if to keep or replace a cow from the herd. The optimal decision will depend on which alternative would bring a greater net return in the future. The tool "*The Economic Value of a Dairy Cow*" (Figure 3) is a complex Markov-chain simulation model, still a user-friendly application that calculates interactively the economic value of a cow (or the value of each single cow in a herd) compared with its replacement [20]. Farmers use this value to make more informed decisions if to keep or replace cows. This tool, in addition, calculates the expected herd demographics and the average herd net return for better and additional dairy farm management and decision-making.

Production and Productivity (DairyMGT.info → Tools→ Production)

Dairy farmers face several decisions regarding production-related issues. In order to make best decisions, they would like to know how their farm milk production profile compares to other similar farms. Besides milk amount produced per animal, the shape of the herd's lactation curves is critical to pinpoint management weaknesses and strengths of a particular farm. The tool "*Lactation Benchmark Curves for Wisconsin*" displays different parity lactation curves for different production levels herds obtained by processing 3.6 million lactation records. Dairy farmers can define their own lactation curves to assess their production performance compared with the benchmarked records. Similarly, farmers find great benefit of projecting their own lactation curves and compare specific dairy herd cows to the standards of the whole herd, which can be accomplished by using the tool "*Milk Curve Fitter,"* Figure 4.

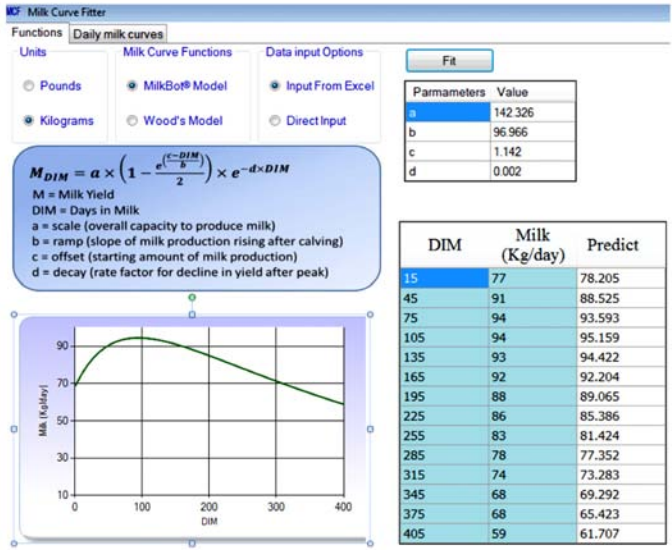


Figure 4: Screen snapshot of DSS Milk Curve Fitter.

As a result of benchmarking their herd's lactation curves, dairy farmers may contemplate a new set of decisions to improve productive performance such as switching the number of milking times per day [21] or re-consider the use of recombinant bovine somatotropin (rbST), a synthetic metabolic hormone that improves milk productivity. The tool "*Economic Analysis of Switching from 2X to 3X Milking*" performs a farm-specific partial budgeting analysis of the projected gain (or loss) when a farmer decides to milk 3 times a day instead of 2 times. The tool "*Economic Analysis of using rbST*" displays the economic gain (or loss) of using rbST as an interactive sensitivity analysis according to ever-changing milk price and estimated milk increase because of rbST under specific farm conditions.

Some dairy farmers are also interested in the possibility of either expand or modernize their farm facilities or increase their herd size. Therefore, they require support on important decisions that will drive the future of the dairy farm operation. The tool "*Decision Support System Program for Dairy Production and Expansion*" is a Spreadsheet application that allows dairy farmers to outline their current farm conditions regarding herd structure and market conditions, define a possible plan of expansion

or modernization including required loans (for facilities and animals), and project the cash flow of the entire farm up to a period of 54 months in the future.

Price Risk Management and Financial Assessment (DairyMGT.info → Tools→ Financial)

Unfavorable prices of milk and feed commodities together with increased price volatility create large uncertainty in the dairy farm business. Recent unprecedented uncertain times have prompted to re-visit farm's financial status and look for alternatives to stabilize net returns. It is critical to explore price risk management alternatives such as the relatively new revenue insurance program called Livestock Gross Margin for Dairy (LGM-Dairy) and to assess farm financial performance compared with peers [22].

In brief, the LGM-Dairy can protect the net margin (milk value less feed cost or milk income over feed cost) at a much lower cost than using comparable options in the future markets. The tool "*LGM-Analyzer*" (Figure 5) is an online, easy-to-use, suite of real-time, data intense, simulation, and optimization integrated modules to help on the decision of using LGM-Dairy. The *LGM-Analyzer* not only replicates the official premium calculation from the U.S. Department of Agriculture Risk Management Agency, but also is capable of perform historical sensitivity analysis as well as complex optimizations to minimize the premium cost at a level of target guaranteed income over feed cost. This suite of tools is also capable of comparing the LGM-Dairy with more traditional price risk management tools such as puts (Class III milk) and calls (corn and soybean meal) for feeds as bundled price options. The *LGM-Analyzer* connects live with the dairy and grain-based futures and market (through a structured query language) to determine the premium cost a particular farmer could expect according to a guarantee income over feed cost ("*Premium Estimator*"). Furthermore, a unique module ("*Least Cost Optimizer*") lets the user to minimize the LGM-Dairy premium cost at a defined level of income over feed cost insured. Other tools in the area of analysis of the LGM-Dairy include the "*LGM-Dairy Feed Equivalent*," a tool to covert feed diet ingredients to corn and soybean meal equivalents

needed for a LGM-Dairy contract and the "*Net Guarantee Income over Feed Cost*," a tool to help dairy farmers determine the income over feed cost to break-even all other costs of production, which should be covered by using LGM-Dairy.

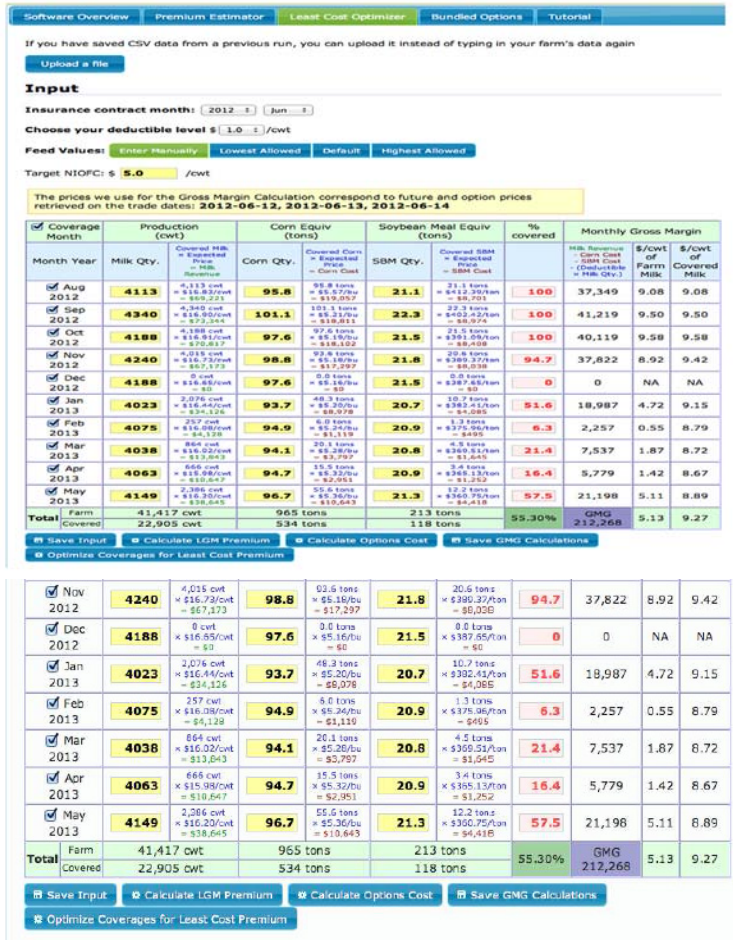


Figure 5: Screen snapshot of DSS LGM-Analyzer.

Also, performing a farm's financial benchmark assessment is critical in the process of measuring the financial health of a dairy farm. Moreover, this is usually required by lenders in order to consider loan applications. The "*Wisconsin Dairy Farm Benchmarking Tool*" is a database application that calculates 15 financial ratios including variables of liquidity, solvency, profitability, repayment capacity, and financial efficiency for a group of

more than 500 Wisconsin dairy farms during a period of 10 years. The tool then compares each one of these ratios with those of a particular farm. Therefore, farmers can assess their financial health compared with their peers. Furthermore, the tool provides a *DuPont* analysis, in which a farm is compared against the population with respect to revenue and profit generated for every dollar invested. Another related tool, "*Working Capital Decision Support System*" assists dairy farmers in identifying cash flows, project expected incomes and expenses, and identifies cash excesses and shortfalls well in advance of their occurrence.

Environmental Stewardship (DairyMGT.info → Tools→Environment)

The dairy farm business faces important challenges regarding increased environmental scrutiny. An increasingly important dairy farm management task is to maintain a farm nutrient balance and therefore avoid over-concentration of nutrients in or around the farm. Opportunities exist to better utilize nutrients in dairy farming and not only improve the balance of nutrients coming in and going out of the farm, but also decrease fertilizer expenses and therefore environmental concerns. Depending on the farm herd and crop characteristics, additional expenses might be required to comply with environmental regulations. In any case, an economic assessment along with the environmental requirements promotes better decision-making. A series of decision support tools deal with these sensitive aspects of dairy farming. The tool "*Dynamic Dairy Farm Model*" (Figure 6) is an integrated, whole-farm, simulation and optimization model that maximizes the net economic return while minimizing nitrogen leaching to surface and ground water sources. A simplified version of nutrient balance between nitrogen and phosphorus manure excretion for a fast assessment is the tool with name *"Dairy Nutrient Manager."* Also related, the "*Grazing-N*" is an application that balances nitrogen for dairy farms with grazing activities and the "*Seasonal Prediction of Manure Excretion,*" as its name says, helps dairy farmers project seasonally the amount of cow manure (and consequently nutrients in the manure) will be produced and will be needed to be recycled.

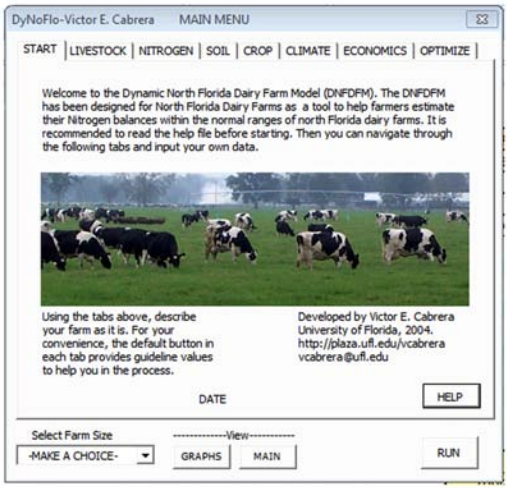


Figure 6: Screen snapshot of DSS Dynamic Dairy Farm Model.

DECISION SUPPORT SYSTEMS DEVELOPMENT: CHALLENGES AND TRADE-OFFS

A number of methodologies and software applications were used to develop the decision support tools above described (Table 1). The goal always remained to provide solid, but user-friendly DSS tools. The methodology as well as the software application approach followed the tool development and the ultimate goal pursued and not vice versa. It was usual to combine and adapt methodologies within a particular tool development. Following is a succinct description of the most important methodologies used for the DairyMGT.info DSS tools and a discussion of the approaches used for the software applications.

Methodologies used for the Decision Support System Tools

Partial Budgeting

Partial budgeting compares a current with an alternative technology by

balancing the economics of 4 elements that are assessed before and after the adoption of the alternative technology: 1) additional returns (adds), 2) reduced costs (adds), 3) returns foregone (subtracts), and 4) additional costs (subtracts) [23]. Partial budgeting could be a robust methodology when a direct change is expected from the new technology without major interaction with other system components beyond the analyzed variables. Partial budgeting is the underline methodology to assess the break-even level of using feed additives, the economic benefit of milking 3 times a day, the economic evaluation of using rbST, the assessment of corn feeding strategies, and the assessment of income over feed cost by different diets under commodity price changes.

Cost Benefit

The cost benefit methodology is similar to partial budgeting but determines profitability of a new technology over longer periods of time and therefore requires the specification of a discount rate that is used to calculate a net present value [23]. The cost benefit is the underline methodology for calculating the value of adopting accelerated heifer liquid feeding programs and is as a supporting methodology to find out the economic value of sexed semen for dairy heifers, the value of reproductive programs in adult cows, and to assess the net present value of alternative scenarios of possible dairy farm expansion or modernization.

Decision Analysis

The decision analysis is appropriate when probabilistic distributions are important factors in determining the final outcomes [24] as it occurs when analyzing the value of using sexed semen on heifers, comparing the value of reproductive programs in adult cows, or projecting the replacement flow needed to maintain the herd size. In the first two cases, conditional probabilities were used to successively determine populations of pregnant, non-pregnant, and eligible to breed animals along with their respective expected monetary contributions. In the case of the replacement flow tool, transition probabilities are used to dynamically project the herd dynamics across time.

Table 1: Principal methodology and software application of DairyMGT.info decision support system tools.[1]Flash: Macromedia Flash. [2]Online tools use a combination of software including HTML, PHP, JavaScript, C, CSS, and MySQL. [3]Requires software installation in local machine

Decision Support System Tool	**Underline Methodology**	**Software Application**
Feeding and Nutrition		
Corn Feeding Strategies	Partial Budgeting	Flash[1]
Income Over Feed Cost	Partial Budgeting	Flash
Income over Feed Supplement Cost	Linear Programming	Spreadsheet/Online[2]
FeedVal 2012	Matrix Solution	Online
Dairy Extension Feed Cost Evaluator	Database Management	Online
Optigen® Evaluator	Matrix Solution	Online
Dairy Ration Feed Additive Break-Even Analysis	Partial Budgeting	Flash
Grouping Strategies for Feeding Lactating Dairy Cattle	Mathematical Simulation	Online
Reproductive Efficiency		
Exploring Pregnancy Timing Impact on Income over Feed Cost	Mathematical Simulation	Online
Economic Value of Sexed Semen for Dairy Heifers	Decision Analysis	Flash/Online
UW-DairyRepro$	Decision Analysis	Spreadsheet
Dairy Reproductive Economic Analysis	Markov Chains	Online
Heifer Management and Cow Replacement		
Heifer Break-Even	Enterprise Budgets	Online/Spreadsheet
Cost-Benefit of Accelerated Feeding Programs	Cost Benefit	Flash/Online
Heifer Replacement	Decision Analysis	Spreadsheet/Online
The Economic Value of a Dairy Cow	Markov Chains	Online/Spreadsheet

Production and Productivity		
Milk Curve Fitter	Nonlinear Optimization	Installation[3]
Lactation Benchmark Curves for Wisconsin	Database Management	Flash/Spreadsheet
Economic Analysis of Switching from 2X to 3X Milking	Partial Budgeting	Flash
Economic Analysis of using rbST	Partial Budgeting	Flash
DSS Program for Dairy Production and Expansion	Markov Chains	Spreadsheet
Price Risk Management and Financial Assessment		
LGM-Analyzer	Mathematical Simulation	Online
LGM-Premium Estimator	Mathematical Simulation	Online
LGM-Least Cost Optimizer	Nonlinear Optimization	Online
LGM-Dairy Feed Equivalent	Matrix Solution	Online
LGM-Net Guarantee Income Over Feed Cost	Mathematical Simulation	Spreadsheet
Wisconsin Dairy Farm Benchmarking Tool	Database Management	Online/Spreadsheet
Working Capital Decision Support System	Enterprise Budgets	Spreadsheet
Environmental Stewardship		
Dynamic Dairy Farm Model	Markov Chains	Spreadsheet
Dairy Nutrient Manager	Mathematical Simulation	Spreadsheet
Grazing-N	Mathematical Simulation	Spreadsheet
Seasonal Prediction of Manure Excretion	Markov Chains	Spreadsheet

Enterprise Budgets

Enterprise budgets are a systematic way to list returns and costs and evaluate profits from inside a specific business enterprise [25] within

the dairy farm. This methodology is used to calculatethe heifer break-even by contrasting heifers' rearing costs with potential benefits. This methodology is also used, in more detail, in the tool working capital to project the cash flow of a dairy farm enterprise.

Linear Programming

Linear programming is a mathematical optimization algorithm to maximize or minimize a goal (e.g., maximum profit or minimum costs) within a set of constraints represented as linear relationships [26]. Linear programming is at the core of the tool income over feed supplementation cost in determining the diet composition that results in the maximum net return within a set of constraints of available feed ingredients. Linear programming is also used recursively in the dynamic dairy farm model to maximize the farm net return while minimizing nitrogen leaching.

Markov Chains

Markov chains are a mathematical system that undergoes transitions from one state to the next within a finite space of states as random processes. In dairy farming, Markov chains are widely used for decision-making to predict herd demographics or to project cows' probabilistic life [2, 10, 12, 19-20]. Markov chains are also very useful to implement decision support tools, as these are less computationally demanding than alternative methods. Markov chains are therefore important part of the DairyMGT.info DSS tools and are the backbone structure of the tools: seasonal manure prediction, dynamic dairy farm model, reproductive economic analysis, and the economic value of a dairy cow. Markov chains are also important part of the tools dealing with expansion and modernization and the one comparing the value of different reproductive programs for adult cows.

Mathematical Simulation and Projection

Mathematical simulation and projection is a general description that encompass a group of diverse and integrated empirical techniques and algorithms that have as main goal to represent observed data

as it happens in real-life situations when not a single method fits this condition to satisfaction. Mathematical simulation and projection is used in most of the DairyMGT tools. However, it is a core methodology in a group of them. For example, mathematical simulation is used in the grouping tool to calculate feed nutrient requirements for every single cow in a herd; in the timing of pregnancy tool to aggregate the overall milk production and feed consumption a cow will have depending on the time of pregnancy; and in all LGM related tools to generate thousands of replicates and calculate the statistics of net margins that will determine insurance premiums [27]. Also mathematical simulation and projection is important to predict cash flows within the expansion tool and to perform nutrient balances in tools such as dairy dynamic model, dairy nutrient manager, and grazing-N.

Nonlinear Optimization

Nonlinear optimization deals with finding an objective function of maximizing or minimizing a variable within a set of simultaneous constraints, where the objective function or some of the constraints have nonlinear relationships. Nonlinear optimization adds a set of complexity to the implementation of decision support tools because it is computational demanding. However, for some applications it is required. Since finding the global maxima for nonlinear problems it is not always possible, a compromise between finding a satisfactory answer and maintain the applications as user-friendly as possible is needed. Nonlinear optimization is used in the grouping, milk curve fitter, and LGM least cost optimizer tools. For the grouping tool, a nonlinear optimization algorithm groups lactating cows according to nutritional requirements with the objective function of finding the aggregated maximum income over feed cost through recursive iterations by allocating cows to size-defined groups. In the milk curve fitter tool, the user enters farm herd milk production and a nonlinear algorithm minimizes the residual difference between the farm observed data and the predicted data adjusted to a pre-defined milk lactation function such as Wood [28] or MilkBot [29]. The results are coefficients of the defined function that best represent farm-specific lactation curves. The LGM-least cost uses a nonlinear optimization to find out the minimum premium price to a defined target guarantee net

income over feed cost according to future projected commodity prices and farm specific conditions, replicating the rules governing the insurance product. The result is the least cost premium for a determined level of coverage within the LGM-Dairy insurance structure [30-31].

Matrix Solution to Multiple Equations

Matrix or algebra simultaneous equation solution is helpful in the area of nutrition and feeding to replace feed ingredients and maintain same level nutritional of the diet and same level of feed intake. It is also useful to value feeds depending on their nutrients content. Each feed ingredient is defined in function of its nutrient contents and its market price. When the number of nutrients equals to the number of feed ingredients (same number of equations as unknowns) the result is an exact value for each nutrient and therefore the predicted value of a feed ingredient is equal to the input value as it is the case in the Optigen Evaluator tool [32]. Similar approach is used for the LGM-feed equivalent, which converts any feed ingredient into equivalents of corn and soybean meal, as it is required for LGM-Dairy insurance contracts. The tool FeedVal 2012 goes beyond and analyzes a set of user-defined matrix between 2 and 50 ingredients and between 2 and 13 nutrients to find out the difference between the feed ingredient market price and the estimated price based on the nutrient composition value of the ingredient.

Database Management and Analysis

Some tools require a database interface and some mechanism of querying the database to retrieve information and to perform analysis dynamically and efficiently. Databases are permanently being updated. Database tools are the lactation benchmark curves and the dairy farm ratio benchmarking. The user does not update these database applications directly, but a server manager. The user queries the database and is able to compare specific farm data with a set of filtered information within the databases. Other type of database application is the feed evaluator tool that registers users in the system and allows them to enter and save their data. The users update the database and the queries retrieve real-time information anytime. Users can then compare their own data against to

a filtered group of other farms. A different concept is portrayed in all LGM related tools for which all the data (commodity prices of milk, corn, and soybean meal from the future markets) is retrieved real-time from the official sources anytime the user performs an analysis [29]. The calculation of either LGM premiums or least cost premiums changes depending not only on the user inputs, but also based upon the time of the query. The system saves historical information, so users can also do retrospective analyses.

External Simulation Models

Some tools require to be integrated with more complex, fully developed and established models. That is for example the case of the Dynamic Dairy Farm Model and the Grazing-N tools. In the first case, model requires assessments of crop production (corn, soybean, pastures, etc.), which are performed by using external crop simulation models from the family of Decision Support System for Agrotechnology Transfer [33]. The dynamic dairy farm model feeds the crop simulation model with data of soils, weather, and crop management schemes and the crop simulation models return predicted biomass produced, nutrient utilization, and nitrogen leaching from the soil. The Grazing-N application is integrated with the National Research Council model of nutrient requirement for dairy animals [34] according to a set of characteristics that include age, production, and live weight.

Software Applications

According to the type of application, the methodologies used in the tool, and, most importantly, the goal of the tool as a DSS, different software application approaches were used (Table 1). Most of the tools have been developed in different software applications with the objective of better meeting user styles and therefore capture larger audiences of users.

Spreadsheet applications are a very popular format among dairy farmers and consultants because of their familiarity with them, the possibility of using the same spreadsheet for further analyses, and the capacity of save and maintain a copy of it in a personal computer. Spreadsheet application

was the elected method for a number of DairyMGT.info tools (Table 1). Most of the spreadsheet applications, however,required some type of Visual Basic code embedded into the application (macros).

Other group of tools uses Macromedia Flash as the software application. Macromedia Flash has the advantage of having a nice interactive visual interface connected with a calculator. From the point of view of the user, Flash tools are probably the easiest to use. They havethe additional advantage of becoming stand-alone applications and therefore of being used offline or embedded in Power Point presentations or Portable Document Format (PDF) files. One problem with Flash applications is, however, its limited computational functionality. Flash applications have only a set of limited mathematical functions without the possibility of using macros or combinethemwith code programming. Also Flash applications are not compatible with Apple smart phones and tablets. Current tools that are only Flash applications within the DairyMGT.info DSS tools will eventually be converted also to be online applications.

Other group of tools can be classified in the general category of online tools. These use an array of different software applications. What they all have in common is that these work in any web browser and eventually in any device and in any platform including smart phones, tablets, Apple, Linux, PC, etc. Calculations and analyses are normally performed in the DairyMGT.info web server, so the online tool is only an interface between the device of the user and the server. In general, online tools are very efficient and reliable tools that have the advantage to be always up-to-date: users always experience the latest version of the tool. Other important advantage is that complex processes and mathematical calculations can be managed using a combination of web code such as HTML (hyper text markup language), PHP (hypertext preprocessor), JavaScript (prototype-based scripting language), C (general-purpose language), CSS (style sheet language), MySQL (relational database management system), or others. Another advantage of online tools is that their design layout can be very efficient and solid once the tool is deployed. A drawback for developing online tools, however, is the need of expertise in web-based code writing. Nonetheless, online tools are very efficient and probably a trend to which many of the tools of DairyMGT.info will continue to gravitate.

ILLUSTRATION AND PRACTICAL DECISION-MAKING

Group Feeding

The value grouping feeding strategies was analyzed by applying the grouping tool to 30 dairy farms in Wisconsin. Test records were collected and adjusted to datasets consisting of cow identification, lactation, days after calving, milk production, and milk butterfat for each cow in each farm. The aim of this exercise was to demonstrate the value of grouping compared to no grouping without knowing studied farms' actual feeding strategies. Therefore, same procedure and assumptions were followed on each analyzed farm: 1) comparison of no grouping versus 3 same-size groups, 2) prices at $15.89/45.4 kg milk, $0.14337/0.454 kg CP, and $0.1174/4.19 mega joules (MJ) net energy, 3) average body weight of 500 kg for first lactation cows and 590 kg for cows in second and later lactations, 4) requirements of CP and net energy at the 83rd percentile level of the group (mean + 1 standard deviation), and 5) a cluster grouping criterion (grouping cows depending on their CP and net energy requirements for maintenance and milk production).

Evaluations clearly and consistently demonstrated that the income over feed cost (IOFC) in all analyzed farms was greater for the 3 feeding groups strategy than the no groping strategy (Table 2).

Table 2: Comparison of income over feed cost (IOFC) of no grouping versus 3 same-size feeding groups for Wisconsin dairy farms assessed by the tool: *Grouping Strategies for Feeding Lactating Dairy Cattle*

	Number of lactating cows on analyzed farms (n = 30)	**No grouping IOFC**	**3 same-size feeding groups IOFC**	**Additional IOFC of doing 3 same-size feeding groups**
		----------$/cow per year----------		
Mean	788	2,311	2,707	396
Minimum	<200	697	1,059	161

Maximum	>1,000	2,967	3,285	580

The analysis indicated that farms could realize between $161 and $580/cow per year (mean = $396) of additional IOFC by switching from no grouping to 3 same-size feeding groups using the cluster criterion for grouping. These values represented an increase of between 7 and 52% of farm calculated IOFC. It was concluded then that grouping would have important economic implications in farm profitability and that further analysis should be done at farm-specific level and in a permanent basis by using the *Grouping Strategies for Feeding Lactating Dairy Cattle* DSS tool.

Sexed Semen

The *Economic Value of Sexed Semen for Dairy Heifers* tool was used for general conditions of Wisconsin dairy farms based on data of a sample of 309 dairy farms and 38 custom heifer growers, a survey performed by county extension agents [35]. At the time of the analysis, using the aggregated data of the 347 operations, the average economic benefit of using sexed semen, as calculated by the tool, was $30 per heifer. Results confirmed that most of these farmers were using optimally this new technology. They were using it for first and second service only, which was the same optimal strategy found by the tool [35]. A main conclusion of this analysis was that the sexed semen technology has an economic benefit, but it would be mostly recommended when the conception rate of the sexed semen is at least 80% of the conventional semen, the value of the heifer calf is high, and when the price of the sexed semen is twice or less than that of the conventional semen. Due that the conception rate of both the conventional and sexed semen and the market prices are important determinant parameters, a main recommendation was that the analysis should be performed on a farm-specific basis and on a permanent basis, for which the decision support tool plays an important role.

Dairy Reproductive Economic Analysis

Published data along with dairy farm records were collected and summarized to create a representative farm to assess the value of

improving reproductive efficiency measured as improving the 21-day pregnancy rate using the tool *Dairy Reproductive Economic Analysis*. Data consisted of detailed information on transition probabilities arrays of replacement and abortion risks; definition of lactation curves, and several economic parameters. Then, the DSS was used multiple times to represent incremental gains in reproductive efficiency.

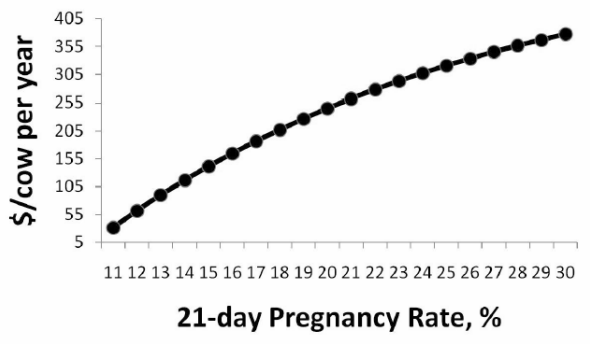


Figure 7: Projected net economic gain of improving 21-day pregnancy rate from a baseline of 10% assessed by the tool: Dairy Reproductive Economic Analysis.

Figure 7 portrays a marginally decreasing trend of economic gain with respect to 21-day pregnancy rate: the higher the original 21-d pregnancy rate, the lower the gain. Nonetheless the tool shows clearly that even at 30% 21-day pregnancy rate, an extremely (and unusual) good pregnancy rate, there is still an opportunity of additional gains because of improved reproductive efficiency. The tool, furthermore presents the main factors from which the additional value comes (in order): higher milk income over feed cost, lower culling costs, higher calf revenues, and lower reproductive costs. These results are being used in a large extension undertaking to promote improved reproductive efficiency in hundreds of dairy farms, but always with the final recommendation that specific farm data and information from current market conditions should be used with the DSS tool to have a more precise assessment.

Decision Support System for Expansion

Three hundred dairy farms completed a mailed questionnaire regarding

their desires and needs of expansion or modernization [36]. Seventy eight percent of farms (26% of respondents) indicated that were planning to expand or modernize their installations and listed as the most important reason of doing that the expected increase on farm net return. Importantly, they acknowledge largely the uncertainty of the process of expansion as a large hindrance and therefore they asked for decision support tools that would allow them project systematically their options and analyze scenarios. More than 20 of these farmers were then contacted and offered to perform those projections by using the tool *Decision Support System Program for Dairy Production and Expansion*. The overall outcome was that all farmers visited agreed that the tool represented reasonably well their farm sand therefore they would trust its future projections. Further analyses were used to confirm or reject their pre-conceived evaluations and to assist farmers to make more informed decisions throughout the process of expansion or modernization. More than 10 farmers did some adjustments in their expansion or modernization process because of the tool and all of them indicated will continue using the DSS tool throughout their expansion or modernization operation.

The Economic Value of a Dairy Cow

Representative data from Wisconsin farms were collected from official sources, farm records, and market reports to become a baseline scenario [20] from which users could select modifications according to their own conditions. Results of these data contained in the tool *Economic Value of a Dairy Cow* indicated that the expected milk production of the cow was the single most important factor for replacement decisions. The impacts of increasing or decreasing up to 20% (120 to 80 in Table 3) the average milk production of a cow, a reasonable assumption, are portrayed in Table 3. It is evident that the milk production expectancy of following lactations is a much more important factor for pregnant cows whereas the impact of milk production expectancy of this lactation and future lactations are similarly important factors for non-pregnant cows.

Although these numbers are good indicators for farm decision-making, the need of using the tool with specific farm conditions and under current market condition could not be over emphasized.

Table 3: Impact of expected milk production on the cow value of a 2-month pregnant, 8-month after calving cow and a non-pregnant, 7-month after calving cow assessed by the tool *Economic Value of a Dairy Cow*. Bolded values represent the cow with average production in the herd (100%). [1]Cow's expected milk production (% of the average cow) from the current state to the end of the present lactation. [2]Cow's expected milk production (% of the average cow) in all successive lactations

Expected Milk Production (% of the average cow)		**Cow Value of a 2-month pregnant, 8-month after calving cow, $**			**Cow Value of a non-pregnant, 7-month after calving cow, $**		
Rest of Lactation1	**Successive Lactations2**	**1st Lactation**	**2nd Lactation**	**3rd Lactation**	**1st Lactation**	**2nd Lactation**	**3rd Lactation**
120	120	2,458	2,038	2,002	1,973	1,485	1,462
120	100	1,045	877	829	1,109	857	814
120	80	-380	-284	-345	244	230	165
100	120	1,891	1,499	1,477	1,184	796	809
100	**100**	**479**	**338**	**304**	**320**	**168**	**161**
100	80	-934	-823	-870	-545	-460	-487
80	120	1,325	961	952	395	106	157
80	100	-88	-200	-221	-469	-521	-491
80	80	-1,501	-1,361	-1,395	1,344	1,149	-1,139

This tool *Economic Value of a Dairy Cow* was also used to value the animal farm assets in a farm. The tool was first set with all parameters concerning to the specific farm and with economic variables representing the market conditions. Followed, the farmer created a list of all cows in the farm including their current state (lactation, month after calving, and pregnancy status) and, importantly, their projected milk production. Then, a cow value was calculated for every single animal in the herd. Finally, the calculated salvage value was added to the cow value. The farmer was then able to use these data for continued monetary support from a financial institution.

The LGM-Dairy Least Cost

During the months LGM-Dairy revenue insurance program was offered in year 2011, the average savings when using the LGM-Dairy Least Cost tool was 27.8% (Table 4). The tool was used during those months to assess the premium cost for a 200-cow farm producing 31 kg milk/cow per day. Based on experience and expertise with a number of dairy farmers and consultants in Wisconsin, the strategy was to insure a minimum income over feed cost of $5/46.4 kg milk during the effective insurance period that is 10 month s per contract (starting 2 months after the contract month).

Considering that the level of insurance protection is exactly the same whether to paying the regular premium or a least cost premium in Table 3, the savings are substantial. The main difference between regular and least cost premiums is the allocation of milk and feed being insured according to the covered months in the future. In the regular premium, the default situation is to assign the same level of milk quantity for protection every month. The least cost optimization, however, finds a better allocation that based on the underline simulated data determines a better plan that results in a much lower premium, but the same level of protection.

Table 4: Savings on premiums when insuring net margins using the LGM-Dairy insurance program during the year 2011 assessed by the tool *LGM-Dairy Least Cost* using default amounts of corn and soybean meal as feed insured and assuming a reasonable insurance deductible of $1/46.4 kg milk for a 200-cow dairy farm producing 31 kg milk/cow per day

Month	Regular Premium, $	Least Cost Premium, $	Savings on Premium, %
January	4,384	3,389	22.7
February	4,904	3,429	30.1
March	5,209	3,863	25.8
October	4,019	2,685	33.2
November	4,216	3,064	27.3

Dynamic Dairy Farm Model

The *Dynamic Dairy Farm Model* was applied on a typical North Florida dairy farm of 400 cows with a production of 7,711 kg/cow per year having 62 ha of crop fields and pastures. A dual optimization including maximization of profit while relaxing N leaching indicated that the nitrogen leaching ranged between 4,800 to 5,000 kg/year whereas the profit would change between $70,000 and $70,600 (Figure 8) [2].

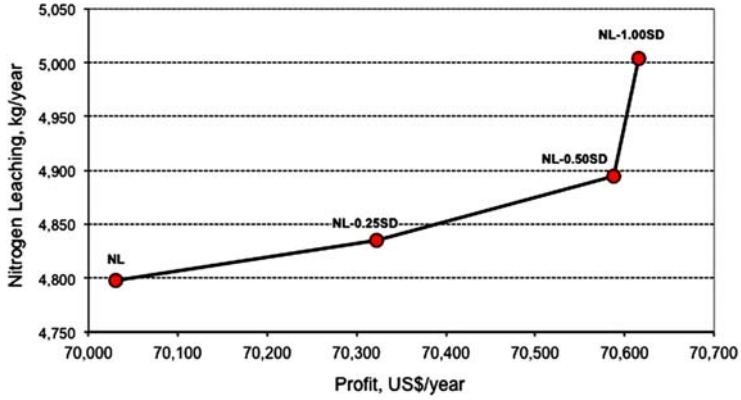


Figure 8: Dual optimization of profit maximization by relaxing nitrogen leaching assessed by using the tool Dynamic Dairy Farm Model. NL is average nitrogen leaching and SD is standard deviation.

Furthermore, strategies to reduce nitrogen leaching would compromise profit. Depending on the farm goals and environmental regulations, the *Dynamic Dairy Farm Model* proved to be an effective tool to screen options and study whole farm management strategies. As in previous cases, farm specific conditions along with current market conditions need to carefully be defined before doing those assessments.

EVALUATION OF DISSEMINATION AND ADOPTION: POTENTIAL IMPACT

Following is some evidence that indicates the DairyMGT.info Website has become the place-to-go for decision-making tools related to dairy farm management in Wisconsin and a trusted reference with increased visibility in other states and internationally. The DairyMGT website was officially launched at the end of 2009. A predecesor webpage existed since June 2008. between April 2012, and a rate of when email registration was required. According to *Google Analytics (http://www.google.com/analytics/)* the Wisconsin Dairy Management domain (DairyMGT.info or DairyMGT.uwex.edu) received 45,307 page views during the year period ending on April 30, 2012. Fifty nine percent were visitors from the U.S.A. and the rest from other 135 countries. From these, the most important countries were: India (5.5%), Australia (3.3%), Argentina (2.6%), Canada (1.9%), Mexico (1.8%), Kenya (1.6%), United Kingdom (1.5%), Italy (1.5%), Turkey (1.3%), Brazil (1.2%), Peru (1.2%), South Africa (1.0%), Pakistan (1.0%), and Spain (1.0%). Inside the U.S.A., visitors came from all states, but 63% of them were from Wisconsin. Other important states were: California (7.4%), Minnesota (3.1%), Illinois (2.8%), New York (2.6%), Iowa (1.6%), Texas (1.5%), Florida (1.3%), Pennsylvania (1.3%), Michigan (1.3%), and Washington (1.0%).

During the same period of time, May 2011 to April 2012, 1,635 users of decision support tools elected to register their emails on the DairyMGT.info system. A thousand and fifty five did it during the months of 2011, a period in which email registration was optional. During Januaryto April 2012 a rate of 5 emails registrations a day was recorded. During the one year period May 2011 to April 2012 there were 9,336 downloads of the top 25 DSS tools as shown in Table 5.

Table 5: Ranking of the most downloaded tools of DairyMGT.info Decision Support System tools during the period May 2011-April 2012

Rank	Decision Support Tool	Downloads
1	The Wisconsin Dairy Farm Ratio Benchmarking Tool	1,280
2	LGM-Dairy Insurance Related Tools	1,279
3	Dairy Reproductive Economic Analysis	1,030
4	Corn Feeding Strategies	655
5	UW-DairyRepro$: A Reproductive Economic Analysis Tool	592
6	Optigen® Evaluator	482
7	Economic Analysis of Switching from 2X to 3X Milking	479
8	Lactation Benchmark Curves for Wisconsin	454
9	Grouping Strategies for Feeding Lactating Dairy Cattle	432
10	Heifer Break-Even	346
11	Milk Curve Fitter	313
12	The Economic Value of a Dairy Cow	312
13	Decision Support System Program for Dairy Production and Expansion	252
14	Economic Value of Sexed Semen Programs for Dairy Heifers	245
15	Dairy Ration Feed Additive Break-Even Analysis	240
16	Herd Structure Simulation	228
17	Milk Component Price Analysis	218
18	Heifer Replacement	215
19	Exploring Timing of Pregnancy Impact on Income Over Feed Cost	196
20	Dynamic Dairy Farm Model	156
21	Cost-Benefit of Accelerated Liquid Feeding Program for Dairy Calves	113
22	Dairy Nutrient Manager	98
23	Grazing-N: Application that Balances Nitrogen in Grazing Systems	97
24	Economic Evaluation of using rbST	90
25	Seasonal Prediction of Manure Excretion	48

A number of tools have been adjusted and translated to other languages to better represent conditions in other regions or in other countries following user inquiries and requests. This was the case for the tools: *Economic Value of Sexed Semen for Dairy Heifers*, *UW-DairyRepro$: A Reproductive Economic Analysis Tool*, *Value of a Springer*, and *Income Over Feed Supplement Cost* translated to Spanish and adjusted to Argentinian conditions. The *Economic Value of Sexed Semen for Dairy Heifers* tool was in addition translated to Chinese.

Another evidence of DairyMGT.info DSS demand is the world wide requests for talks regarding these tools. During the past 4 years (May 2008 to April 2012) 168 talks have been given regarding DairyMGT.info tools, a rate of 3.33 talks per month. These talks had a total attendance of about 6,500 people. One hundred and twelve of these talks were in Wisconsin (3,200 people); 25 in other states (1,700 people), and the rest, 31, in other countries such as Mexico, Chile, Peru, Argentina, Honduras, and Nicaragua (1,600 people).

Evidence of adoption together with functionality and benefits of the DSS tools can also be measured by comments and feedback reported by users and other stakeholders. Some anonymous test imonials about DairyMGT. info DSS Tools are listed below.

- "The Income over Feed Supplement Cost is a very useful tool that allows me to find out the best ingredients to buy and provide clear and practical advise in a number of clients I work with" – A dairy farm nutritionist.
- "I have used the tool 2X to 3X milking with a number of farms and consultants and it has always been well received. It does an excellent job of determining the economic impact of switching milking frequencies." – A county Extension agent.
- "The Optigen tool is a very simple application, yet it makes a quite powerful impact because it opens a realm of opportunities in the field." – A dairy industry service provider.
- "…the Sexed Semen evaluator brings very useful information and it is a tool that people can really use and apply within field situations. This is a very useful tool" – A veterinarian attending dairy farms.

- "I think that the information and spins of using the Income over Feed Cost database tool are great and powerful" – A dairy farm consultant.
- "The tools related to economic evaluations of reproductive programs in dairy cattle are going to be incredibly useful." – A dairy Extension specialist.
- "The State of Wisconsin has led the nation in number of contracts and milk insured under the LGM-Dairy program, which reflects, at least in part, the usage and practical application of the LGM-Dairy Analyzer tool of the UW-Madison" – An Extension specialist. "[The LGM-Dairy Analyzer] …is having a direct and measurable impact [in our dairy industry]" – A University administrator.
- "We are defining reproductive strategies for our herd and we found invaluable the use of the [DairyMGT.info] management tools in our planning design. We specially appreciate the clarity of the applications and the simplicity of concepts that make these tools very practical and applicable." – A dairy farm manager of several dairy farms.
- "The [DairyMGT.info] decision support tools have really helped out our dairy farm in may aspects including financials, replacements, reproduction, and even nutrition." – A senior dairy science student and dairy farmer.
- "These [DairyMGT.info tools] are a collection of the most practical tools I have ever seen." – A well-established county Extension agent.

FUTURE DEVELOPMENTS: KEEP UP WITH TECHNOLOGY AND NEEDS

A number of emerging and evolving technologies are today available to dairy farmers more than ever. These include the use of smart phones, tablets and similar hardware devices; more efficient software resources; and improved data networks. There is no doubt the trend of fast technological improvement in the area of computer, software, and gadget development will continue even at a faster pace. Progressive farmers and

an increasing proportion of Extension agents and dairy farm consultants are already using these technologies. New technologies bring challenges to keep information systems up-to-date, but at the same time bring great opportunities for improved DSS development.

One important advantage of smart phones and tablets is their portability along with connectivity. Nowadays farmers enjoy voice and, importantly, data network and therefore the capability to save and retrieve data eventually from anywhere at anytime. For example, a farmer can have complete information of a cow (e.g., age, lactation, pregnancy status, production history, today's production, genetic background, health incidence, etc.) at the time the cow is being registered through a smart phone system whether the cow is in a corral, in the milking parlor, or out in the field grazing. This gives the farmer the opportunity to make critic a land time-sensitive decisions right away. This could be one of the major benefits of smart phones and tablets applications. Decision support systems have to be integrated with these new technologies and need to take advantage of these important advantages.

One drawback, however, of smart phones and tablet applications is their restricted screen size and some hardware and software limitations. Applications need to be especially designed for smart phones and tablets. Normally, the information entered and retrieved would need to be summarized or would require additional layers of navigation. Extra design details could, though, lead to more compact, more intuitive, and overall more efficient DSS.

There is a trade-off of functionality and payback. The industry seems to favor both types: application for conventional computers and laptops in addition to those applications for smart phones and tablets. The decision-maker selects what type of tool to use for a particular situation. From the developmental standpoint, this is an additional challenge that requires additional work and expertise.

Important considerations regarding upcoming and developmental technologies are the increasing need for integration of DSS with information systems currently used in a farm. Most of the farmers are already using some type of software or information systems for operational management such as feeding, general record keeping,

reproductive synchronization programs, identification, heat devices, or others. The DSS portrayed in this chapter and similar have the opportunity of becoming a bridge among these information systems. Decision support systems can use live information from farm records and provide predictions that go beyond the simple record keeping summaries. Farmer expertise combined with real-time DSS projections using farm record keeping systems is a powerful combination for efficient and effective decision-making in dairy farm management.

CONCLUSION

More than 30 computerized decision support system tools have been developed to assist dairy farmers in their continuous decision-making needs. All these tools are openly available at http://DairyMGT.info under the *Tools* section. Tools are grouped in major management areas of dairy farming such as feeding and nutrition, reproductive efficiency, heifer management and replacement, production and productivity, price risk management and financial assessment, and environmental stewardship. A number of methodologies and combinations of methodologies as well as different software applications were used to develop these decision support systems with the ultimate goal to always provide solid, but still user-friendly management tools for dairy practical farm decision-making. Methodologies included partial budgeting, cost benefit, decision analysis, enterprise budgets, linear programming, Markov chains, mathematical simulation and projection, nonlinear optimization, matrix solution, database management, and use of external simulation models. Software used to develop the tools included Macromedia Flash, HTML, PHP, JavaScript, C, CSS, MySQL, Spreadsheet applications, and executable programs. The DSS have proven to be effective decision-making tools for improved dairy farming operation. Large dissemination and impact of these DSS tools can be verified by having 9,336 downloads of these DSS tools during the one-year period between May 2011 and April 2012 and the request of 168 talks with 6,500 people in attendance across the world during the 4-year period between May 2008 and April 2012.

ACKNOWLEDGMENTS

The development and maintenance of the DairyMGT.info tools has been possible by the partial support of several extra-mural grants: Agriculture and Food Research Initiative from the USDA National Institute of Food and Agriculture Competitive Grants No.: 2010-51300-20534, 2010-85122-20612, 2011-68004-30340 and several Hatch grants to V.E.C from the College of Agriculture and Life Sciences at the University of Wisconsin-Madison. Acknowledgement is extended to a number of people involved at different levels in the development of these tools; Collaborators: B.W. Gould, R.D. Shaver, M.A. Wattiaux, L. Armentano, J. Vanderlin, K. Bolton; Students: J.O. Giordano, J. Janowski, M. Valvekar, E. Demarchi, A. Kalantari; Programmers: A. Kalantari, N. Suryanarayana, K. Nathella, V. Vats, A. Gola.

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CHAPTER 5

HOW FRAMING EFFECT IMPACT ON DECISION MAKING ON INTERNET SHOPPING

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ABSTRACT

Framing effect is an understanding and assessment that individual implements different behaviors when facing to the multiple choice that expressing the same meaning. Previously, scholars went through numerous empirical studies regarding impact of the method as well as environment in making decision of online purchasing [1] - [4] . Also, scholars have proved that there are complex influences of psychological factors when consumers make decisions of shopping. Therefore, the article aims to analyze the impact of faming effect in e-commerce when consumers make decisions so as to summarize the shortage in academic and practical aspects.

Keywords: Framing Effect, Online Shopping, Making Decision, E-Commerce

INTRODUCTION

Nowadays, online shopping has become the trend of consuming model. According to the report announced by Chinese Online Shopping Marketing Analysis in 2012, the number of transaction in online consuming market reached approximately one thousand two hundred billion yuan (RMB) in 2012, increasing by 66.5 percent than in 2011. In 2012, the rate of transaction in online retail took up 6.1 percent among social retails. In this case, the data from online shopping in China is drawn attention to scholar for research about consumer behavior in making decision, which drives the development of E-commerce.

Consumers constantly confront the situation that when you intend to buy a shampoo in one online store where provides the free-delivering service if paying 45 yuan RMB, another store, on the contrary, charges 55 yuan RMB for the same product including price of product (45 yuan RMB) and cost of delivering (10 yuan RMB). In this case, which store will you choose? What's more, when we see the slogan on the website from an online store where signs that those who find out the fake product could get the compensation with ten times of the retail price; similarly, another store insists that no fake for sale because the store is qualified by the brand, how do we make a decision?

The situations we described above are belonging to the different recognition, value perception and decision- making under the same information with the different expression. The significant difference between online consuming and physical consuming is that most of consumers purchase products on the internet before searching information of products that provided by the website in the uncertain or potentially risky environment, while shopping in the physical store runs the opposite. Hence, how we can make decisions rationally is a hotspot in academic of framing effect.

As for the novelty of the study is on one thing that we suppose there is a relationship between online shopping and diversity of framing effect because most of the previous researches have proved that in different occasion traditional consuming decision will be influenced by the framing effect. However, the research did not involve more detail in whether there are different impacts on shopping behavior on the internet

or decision-making in e- commercial environment as a result of different conditions and decisional environment in online shopping, which doesn't have the same factors as traditional consumption. Similarly, the previous researches have proved experimentally that different environments and conditions would have different impacts on purchase decisions so that it forces us to believe that framing effect integrated by e-commercial situation would bring the another effect on decisions of consumption and behaviors. On the other things, in terms of the category of precise consuming behavior and decision behavior, there is no relevant research made on these before. As for the consequence of purchase, it is related to various aspects (i.e., whether to purchase, the quantity of product, the types of product).

DEFINITION, ORIGIN AND CATEGORY OF FRAMING EFFECT

Definition and Origin of Framing Effect

Before the theory of framing effect, scholars presented the Expected Utility theory demonstrating that in uncertain and potentially risky situation, individuals estimate the potential consequence before making decisions. The theory dominated the crucial place in risky decision until 1944; Von Neumann and Morgenstern [5] carried out a new utility model according to this theory and supposed that human preferred to make decisions to match the highest expectation.

However, not all the people could exhibit rational behavior in our daily life because of the limited knowledge. Individuals are not competent to make perfect in decision with rational principle during the period that people lack of knowledge and unforeseen risks. That is the reason why decision-making could not stand in line with Expected Utility Theory, which stimulates psychologists and economists to research the related theory about decision-making.

Framing effect is origin from the problem of Asian disease that Kahneman and Tversky studied [6] . They got ready for preventing from extremely

terrible disease which was coming and anticipated 600 people would lose lives in this disaster. Therefore, they showed us two expressions of plans about the solution.

A classic example of framing effect is Tversky and Kahneman's [6] Asian disease problem. In their study, the projects were required to select between a confirmed consequence that led to a certain survival of one third of 600 hypothetical patients (200 people) and a risky probabilistic consequence, a one-third probability that all 600 people would survive and a two-thirds probability that no one would survive.

In contrast, the projects described as loss were required to select between a certain consequence that led to a certain death of two thirds of 600 hypothetical patients (400 people) and risky probabilistic result, a one-third possibility that no one would die and a two-thirds possibility that 600 people would lose their lives.

As a result, most of their subjects (72%) favored the certain thing when the choice results were framed in terms of lives saved whereas most of the subjects (78%)in another group favored the gamble (the possibility) when the same choice outcomes were framed in terms of lives lost. We could find out that these problems expressed the same meaning. The unique distinctness was the key word in beneficial environment was described a survival, another group was the death.

Accordingly, people code the possible choice outcomes as gains and losses, and tend to be risk averse when choosing among prospects seen as gains but risk seeking when choice selections were framed positively, people are fancy to recognize them as gain and become more risk averse. On the contrary, when the same selections are framed negatively, people are more likely to foresee them as lost and become more risk finding. There is no doubt that Tversky's theory makes a contribution to framing effect analysis and our essay.

Category of Framing Effect

With development of theory of framing effect, scholars expand the research of various phenomena, and the tech- nological innovation develops numerous new situations, which arouse awareness of

psychologists and economists. For these reasons, framing effect should have a clear category.

Bidirectional and Unidirectional Framing Effects

X.T. Wang [7] found out dynamic and mechanism of framing effect in terms of risky choice of death, public property and individual benefit. As a result, there are two types framing effects defined with theory and empirical recognition, namely bidirectional framing effect and unidirectional framing effect.

Bidirectional framing effect, a traditional framing effect, drives to change risk preference when positive framing choices are transferred to negative framing choices. Faming Hou designed the experiment to demonstrate that in terms of personal property, individual tended to risk averse while the one who stayed in the negative framing effect focus on risk seeking.

However, there is no preference change under unidirectional framing effect. In fact, when the hypothetical patients were described as subjects' own family members, the subjects, although clearly being risk seeking, become extremely more risk seeking if the choice consequence was framed negatively.

Risky Framing Effect, Attribute Framing Effect & Action Framing Effect

Risky framing effect, the most typical explanation, is used for highest times in framing research. F.M. Hou [8] preceded the experiment that how post-graduate students and employed people made risky decision in terms of life, money and personal things. At last, he found out that there were extremely different preferences of making decision under the framing effect.

Attribute framing effect will infulence individuals encoding and assessment of the object or characteristics. F.M. Xu [9] summarized the traits of attribute framing effect including: 1) no risk; 2) distinctive; 3) no preference change by comparing with other types of framing effects. As a common phenomenon in economics, Xu concluded the previous

explanation of attribute framing effect from other researchers, addressed the perspective and explored widely regarding the origin, factors of impact, application, the relationship with other decisions. In addition, this framing effect is applied in consuming domain constantly so that the contribution of research could bring huge impact on consuming decision.

C.J. Liang and X.R. Li [10] deemed that action framing effect was a behavioral purpose that individuals wanted to achieve one certain goal and a behavioral consequence related to one certain goal. The positive and negative action framing effect is the relationship between the individual and goal achievement. An experiment, designed by C.J. Liang and X.R. Li, illustrated that positive action framing effect intensified the impulsive behavior of consumer who is directional. Since the appearance of action framing effect, researchers struggled to study mechanism and factor of that to understand the origin and performance so that company could set up an effective strategy to persuade consumer to take action and prevent negative effect.

Theoretical Interpretation of Framing Effect

Prospect Theory

Prospect theory, was put forward by Kahneman and Tversky in 1979, is the first theoretical explanation of framing effect, which reveals the people who would not complement completely rational action always prefer to deviate rationality. The theory of the individuals in decision-making can be divided into two stages, editing and evaluation. Kahneman and Tversky argued that, in the editing stage, individual decision makers mainly through coding, combination, decomposition, reducing or other related processes methods, integrated information; mean- while, in the evaluation stage, according to the value function and weight function the individual decision makers selected different options of utility value [6] .

In prospect theory, the reference point is an important criterion of evaluation when making decision [6] . Choosing what kind of reference point is the vital role in changing and manipulating people's decisions.

What's more, the value function is to coordinate the reference point as the center, presenting an s-shaped curve. Loss area presents the convex curve and decreases rapidly resulting in that people are more sensitive, while yield area appears concave curve. That explains the reason why under framing effect, when making decision, individuals facing with a positive, active benefit, tend to avoid risk as opposite as the negative, more people tend to seek risk. Comparing to the pain from lost, the joy of the equivalent gain is more strong, namely loss aversion [11] .

With the development of research, scholars have found that there are drawbacks in prospect theory that cannot fully explain the framing effect. First, the reference point and the value function is difficult to measured and estimated; second, the differences of the individual decision-making cannot be reflected in the prospect theory. In order to solve these problems, scholars turned to consider cognitive theory where the fuzzy-trace theory hit the world.

Fuzzy Theory

Fuzzy theory was created by Reyna (1991), used to interpret the traditional framing effect [12] . The principle of theory is to prefer to operate to reason informational instinctive gist rather than a logical way. Also, theory proved that the advanced judgment and decision-making was based on a simple, selective gist of mental representation (fuzzy memory trace) rather than a more specific, quantitative digital representation (literal memory trace). Trace, a single meaning extracted from the information (semantic representation), is related to the personal knowledge, understanding, culture and development level [13] - [16] . Because in the field of personal development and the need for more professional knowledge, their decisions would tend to be based on the meaning of information, rather than the details of verbatim [17] .

Nowadays, scholars attempt to apply actually to practice with the theory. They deem that people are parallel and independent to extract essence trace and literal trace information, prefer to trace information and make judgments based on the information [18] . The expression of fuzzy effect of tax revenue can promote the development of the market. Individual preferences exist fuzzy processing but there is no linear relationship between the objective digital results and individual subjective perception

of its. In that case, bonus will become the extra income for individual in our mind; in addition, the overall wealth will be rising as a cognitive. On the contrary, no one focus on the digital information which impacts our preference in decision-making by the description of the fuzzy model [19] . J.W. Duan [20] , by means of empirical experiment in terms of market competition and starting business defined as two risky choices, proved that the influence by fuzzy theory in market competition situation outweighed the counterpart of entrepreneurship, and the former has a significant level, the latter run the opposite which to verify that under circumstance of the entrepreneurial risk, most people in the judgment of characterization of digital information roughly estimate fuzzy information, and the fuzzy representation has significant impact on the final choice.

Indeed, the fuzzy theory in terms of memory, reasoning, intuition and other related cognitive factors interpreted the decision-making behavior, but because gist of trace is complicated to be measured and a strong fuzzy cognitive causes different interference, therefore scholars put forward another theory called "equate-to-differentiate theory".

Equate-to-Differentiate Theory

The theory, presented by Chinese scholars [21] - [24] was based upon limited rational point of view [25] . As the content of the theory, living in risky and uncertain circumstances, human being does not tend to match the maximum expectation in decision-making, but choose upon identifying one form whether there are advantages and disadvantages. The significantly difference compared with Expected Utility theory is equate-to-differen- tiate theory denies decision preference that is to achieve maximum expectation. The specific process is divided into two parts, equate and differentiate. Decision maker will equate the less different result on one dimension and define the extremely different dimensions as top priority of options. This is the perfect example that making decisions by means of the principle of "weaken advantage".

Equate-to-differentiate model illustrated and explained the classic framing effect, since the framework of the subjective option can be described in two dimensions containing best possible outcome and worst possible outcome. Human beings with lower cognitive ability consider

that the results are subjective or equal, leaving an- other single dimension be regarded the difference of options. The process of "equate" can let decision makers have lower cognitive ability. In the "differentiate" stage, if the decisive dimension is one of the best possible results, individuals tend to pursue the best goal during this period, or if the definitive dimension is the worst possible result, then the decision make us avoid the worst possible target.

DECISION OF CONSUMER ON ONLINE SHOPPING

The Concept

Every day each person has to make numerous decisions with all aspects of daily life. Broadly speaking, decision-making is to select the best one from two or more choices and the choice must be feasible as well. Actually, buying decision is a part of the consumer behavior [26] . Some scholars believe that decision-making of consumer is the purchasing intention, reflecting the psychological mechanism of consumption decisions. Therefore, this article upon the background of network consumption decisions, compared the traditional consumption mode, researches new consumption patterns of consumer's decision-making behavior on internet environment.

Some researches focused on consumer's decision-making process on network. Simon thought that the process of shopping decision-making was divided into the following steps: cognition, design and choice [25] . Additionally, buying decision, defined by AMA (the association of American market) and based on switching, contains perception, emotion, cognition, behavior and the interaction between environmental factors. Haubl and Trifts believe that potential consumers seem to utilize two steps to reach the decision [27] . The first is to identify the possibility of choice to obtain the demand by means of scanning a large number of products. The second is to precede evaluation of the choice above in deep way and compare according to specific reason and consumer decision-making. S. Chen supposes that consumers purchasing decision refers to the process of purchase [28] . In other words, the consumer achieves

the certain requirements with information searching, seeking solutions, choosing and determining the optimal process, post-purchase evaluation and a series of activities. C.S. Wu and F.F. Cheng believed that consumers purchase decision is mainly made up of three parts, including purchase intentions, purchase attitude and willingness to pay [29] .

To sum up, the emphasis of the different scholars of understanding consumers' network decision-making is multifarious, but the essence of decision-making described by scholars has a consistency, namely meeting the needs of consumers. Hence, in this paper, the concept of a purchase decision is defined that consumers meet their own needs somehow, through the network media to make decisions mainly including the purchase intentions, purchase attitude and willingness to pay.

Purchasing Decision Model

Nicosia Model

Nicosia Model was put forward in 1966, as the core content of the book called Process of Consumers' purchase. There are four areas simulated by Nicosia. Phase 1 is a procedure from information releasing to consumer attitudes. In that procedure, the enterprise through the dissemination channels pass relevant brand's contents to consumers, this information will be treated with consumers to form a specific attitude towards a product. Phase 2 is called evaluation. After the consumers receive information from dissemination, they will form a certain attitude of brand in their mind. After that, consumers search the relevant information of the product with this certain attitude and estimate the content of the information for its corporate communications and product to trigger purchase motivation. Phase 3 is called purchasing behavior that the driving of the consumers' motivation in consumer decision and the specific purchase behavior. Phase 4 is called feedback that shape the experience as the memory in the brain, which guide future consumption, after consumption of experience or product and that feedback to enterprise from the consumption experience of consumers. As shown in Figure 1.

Nicosia Model concisely induces the consumer decision-making process,

but the process does not illustrate the impact on external factors and ignores the situation that the interaction and communication between consumers and enterprises are multitudinous.

Howard-Sheth Model

This model was put forward by Howard and Sheth together in 1977, enriched the consumer decision-making process and classified into four categories: input variety, cognitive structure, the structure of the study, output results. The input variety is stimulus or input including three factors: product essential factor (i.e., quality, price, features, service, and utility); the symbolic factor (i.e., medium as the transmission of information constitute); social environmental factor which is the external environment for product information transferring stimuli (i.e., family, related groups and the social hierarchy). Cognitive and learning structures describe that after stimulated by external factors, consumer trigger a series of changes in psychological activity and the psychological process of the purchase decision.

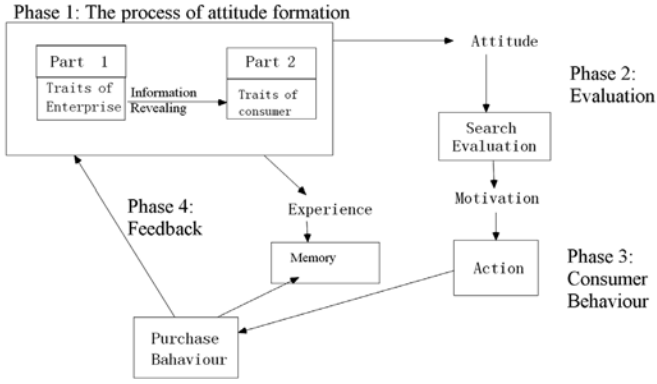


Figure 1: Nicosia model.

Cognitive structure includes the public search, fuzzy knowledge and attitude of stimuli and preferences of perception, While learning structure between consumer decision-making and external stimuli contains the criteria of selection, the brand understanding, attitude, trust, motivation, satisfaction, intention, reflecting the process of processing and forming a attitude toward products in our brain as a vital procedure of making purchasing decision after accepting external stimuli. Finally, the output

results, reflecting that the consumer finally trigger a product purchasing behavior, contains three meanings. First, the attention of consumers about a product and the understanding of the brand; second, emotional response related to the learning structure; third, interacting behavioral responses whether decided to implement a specific behavior. Exactly as shown in Figure 2.

The description of Howard and Sheth model are logical and practical, especially suitable for consumers of various products brand choice and purchase [30] . But the consumer decision-making process is embedded in a particular social system or deciding correlative system, therefore, the study overlooked the consumer decision- making in the correlative system between each other [31] .

EBM Model

EKB model is put forward by Engel, Blackwell and Kollat as a systematic and comprehensive model of decision-making in 1968 [32] . The core content of model is to distill systematically each variety and the relationship among them from the consumer decision-making process. In order to make the EKB model more effective description of consumer behavior, so Englel, Blackwell and Miniard revised the content of EKB model and turned out a new model that was called EBM model, which became a kind of explanatory model and was divided into four parts: 1) the central control system, namely process of the consumer psychological activity; 2) part of informational process; 3) the decision-making process; 4) environment. They believed that external stimulating factor would stimulate the brain cortex to filter pro- cessing information. Stimulating factors mainly include commodities, the mass media and enterprises promotion, etc., through the central control system—visual, hearing, feeling and memory, and standard of consumption would be integrated, so as to know the goods and make a comprehensive assessment and selection, eventually become the decision result. At the same time, environmental factors which are also defined as economic, political, cultural and social factors can affect the decision-making process as well. Consumers after decision-making began to implement specific and concrete consumption behavior and evaluate the product after purchase use and consumption

experience to feedback to the central control system, which became the influence factors of consumer spending decisions in the future. As shown in Figure 3.

Kotler Stimulus-Response Model (Kotler Model)

Kotler stimulus-response model was presented by Kotler (1995) with the perspective of psychology and systematic analysis on the consumer's decision-making behavior as well as combining the general pattern of human behavior, also called "S-O-R" model [33] . S for stimulate, O for organisms and R for response. Part S is a stimulus that arouse the attention of consumers, including external stimulus (i.e., product, price, channel and promotion) and environmental stimuli (i.e., economy, politics, culture, science).

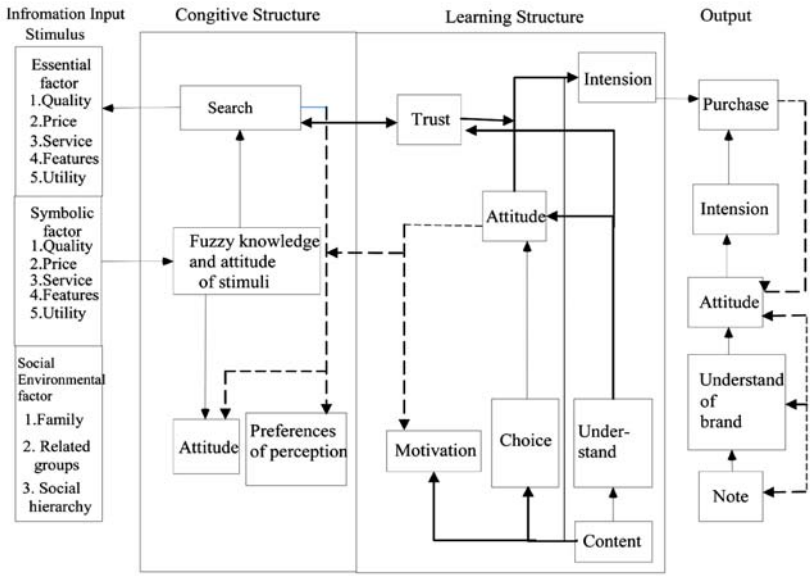


Figure 2: Howard-Sheth model.

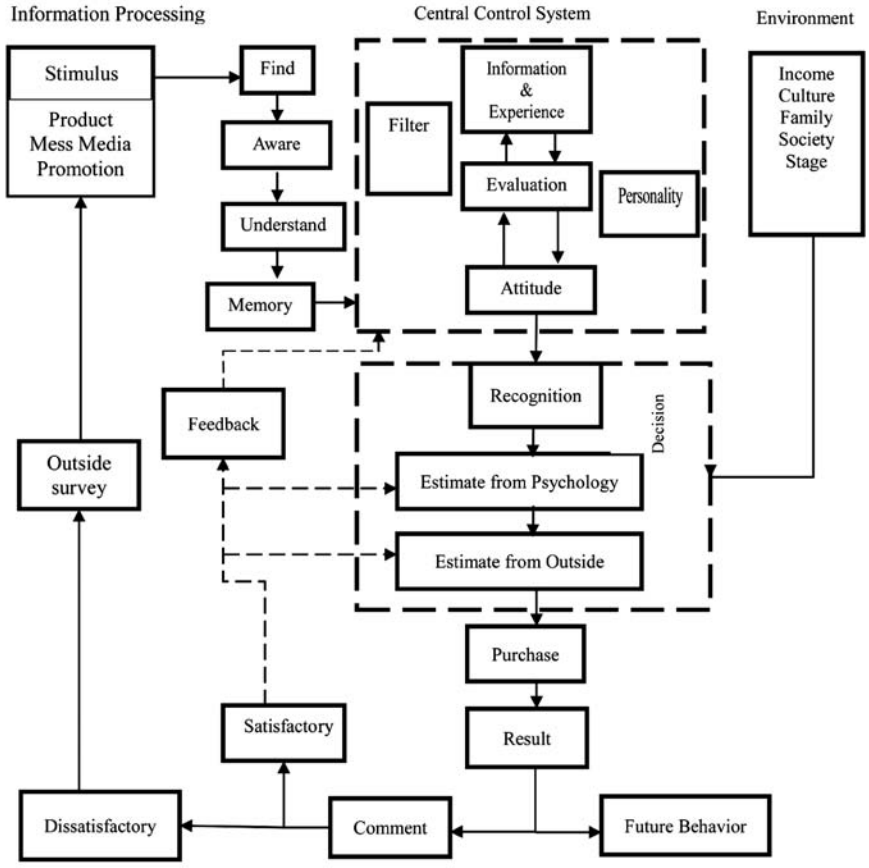


Figure 3: EKB mode.

Part O is called "Black Box", representing the consumer's psychology, mainly including the characteristics of consumers (i.e., social, individual, psychological and cultural) and the consumer decision-making process (i.e., problem recognition, information searching, standards, assessment and purchase behavior). Meanwhile this part, which plays an essential role in the consumer behavior, brings an important impact on consumer behavior. Whereas Part R is the concrete consumer's decision-making behavior (i.e., commodity choice, the choice of suppliers, brand choice and purchase quantity). As shown in Figure 4.

The shortcoming of the model is that it neglects brain processes after accepting information and over emphasizes on "black box", namely the

characteristics of consumers and the consumer psychological activity influence on consumer decision-making.

Model of Consumer Decision-Making on Network

Decisions between consumption on network and consumption in traditional way have many similarities. Different scholars analyzed network consumption and generalized the corresponding model according to the traditional consuming decisions. Q. Ke [34] , who searched from Kotler model and combined the feature of network consumer behavior (individuation, rationalization, initiative), built up pattern of the network consumers' purchasing behavior. As shown in Figure 5.

S.S. Li [35] combined Nicosia and Howard-Sheth model with the characteristics of online consumer to put forward the integration of the traditional shopping model, online information searching and offline consumption and online consumption of the comprehensive model. The model is added the way of purchasing into the scope of the consumer decision-making to which is needed to consider and makes up the shortage of traditional and online shopping decision model when considering decisions. What's more, the model is based on limited type of consumers and dilated consumers. Limited type of consumers are characterized by medium intervention, limited information searching, simple rules, limited backup solution, while dilated consumer runs opposite side [36] . As shown in Figure 6.

With the development of e-commerce and information technology, consumer spending patterns will become diverse, and factors which influence behaviors of shopping will also increase, because the consumer decision- making model also needs to be integrated into numerous comprehensive factors, but the main process is inseparable from the general decision model. To be honest, the environment of e-commerce is complex, consumer demand and behavior must be analyzed constantly so that we can fully understand the consumer's decision- making behavior.

RELATED RESEARCH ABOUT RELATIONSHIP BETWEEN FRAMING EFFECT AND CONSUMER DECISION-MAKING

Currently, application of framing effect obtained certain achievements in terms of investment, management, pro- fessional, tourism, insurance, etc. All of them have the empirical research. In recent years, the studies of the framing effect that was applied in consumer decision-making behaviors are also gradually got attention [37] [38] . But the framing effect in the field of consumption decisions did less, especially in the network of consumer decision-making.

Levin [39] , C.L. Liang [10] and others combined with the framing effect and utilized beef products and digital camera as two subjects to research empirically intension and impulse buying decisions of college students. The results showed that under the risky framing effect, subjects tended to select the products with the description of the loss. On the other hand, under attributed framing effect, most of subjects favor the positive description. In the action framing effect, Levin and others showed that the framework didn't impact on the decision and there was no action framing effect. However, the result gone through by the experiment of C.L. Liang was just opposite.

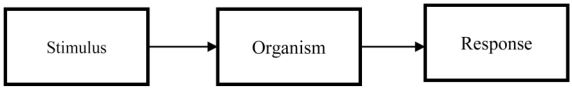


Figure 4: Kotler model.

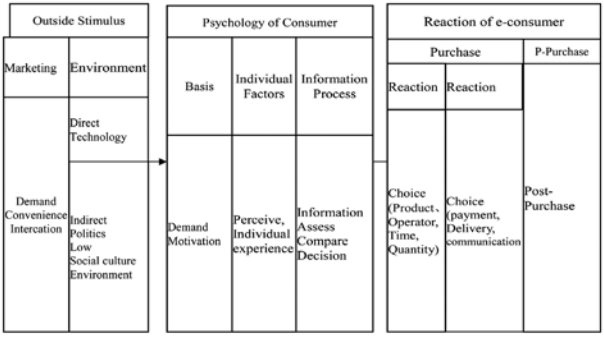


Figure 5: Network shopping decision model.

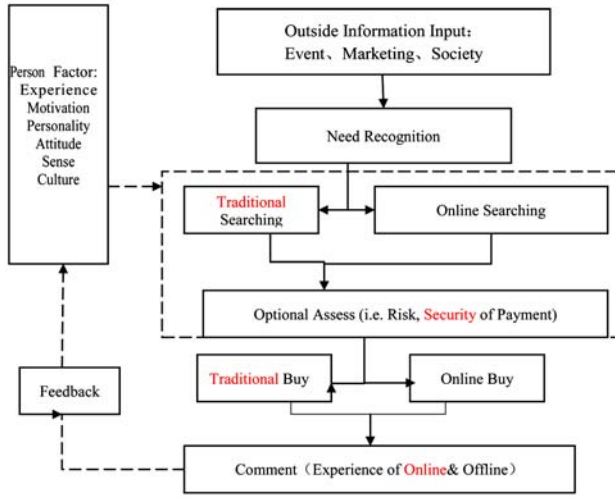


Figure 6: Integrated network shopping decision model.

In addition, the frame will affect consumer perception of price. Bingbing Mou and their partners designed the questionnaire and experiment to prove how the cognitive closure need and promotion strategies presented versus discount impact 240 college students in fuzzy consuming decision [40] . On one hand, the author thinks that with the high cognitive closure in circumstances of fuzzy purchasing, consumer decide what they want to bur without too much hesitation but being more vulnerable to "promotional informational framework". On the other hand, the influence of low cognitive closure runs an opposite trend. There is nothing different reaction between discounts and gifts.

S.L. Li and her partners [41] made an empirical analysis of the relationship between price framework in the bundling and consumer preferences from the perspective of product attributes. They found that when a pleasure and a firm supplies were bundled, price discount embodied in hedonic products had less expected guilt and high purchase intention than those of the real products which save money. Hence, expected guilty is the intermediary role between price framing effect and consumers' purchase intentions.

Schindler and his teammates [42] focused on how the process of sales promotion information effect influences customers when buying a car.

The results revealed that consumers were not willing to remove the stuff from car that did not operate as a function, comparing to add functionality. The reason was that the function removed from the car was regarded as a lost, while adding a new function was viewed as a benefit.

The scene experimental method of Y.R. Cheng [43] was adopted. Under conjunction with the framing theory and cognitive theory, Cheng introduced how attribute framing effect, action framing effect, cognitive needs and the integration among three factors influence on college students' consumption decisions. The results illustrated that attribute framing effect and cognitive needs had a significant influence on college students purchase intentions, attitude and the way of payment. Initially, intention, attitude of target products and payment of college students who are low cognitive need are significantly higher than counterpart of university students with high cognitive need. In addition, when students, with the low level of cognitive needs and who was influenced by the framework of positive characteristics, have the higher level of purchase intention than university students that impacted by the negative description for target product. On the contrary, there is no obvious effect on purchasing intentions, attitudes and way of payment under both description of framing effect. Finally, the action framework would bring no impact on college students' consumption intention, attitude and payment.

SHORTAGES AND PROSPECTS

The Shortage of Current Research

On one hand, compared with characteristic of traditional consumption, the network consumer behavior has new trait, namely the consumers cannot let consumer directly contact with the goods what they want, which is regarded as a highly complex shopping environment. On the other hand, the platform of internet offers a high information exchange environment. In other words, consumers who shop online interact with machines constantly where the web pages are exhibited by the complicated content. Not only do they have to make a based decision of

online shopping, but also make a decision of the purpose, brand, channel, payment, time and quantity.

The development of the Internet, reaching the peak of information transfer, provides people with a bigger platform to communicate with each other, interact with each other, but no matter how enormous the consumption environment change, study in traditional purchase or online purchase is related to the characteristics of today's consumers. To be honest, most of consumers are more personalized; initiative, considerate and psychological mature in terms of cutting off the cost and time than any time before. In that case, the process of network consumption contains a lot of text information as the major stimulation factors; however the influences of graphic form of information description on diversity of consumer decisions are the same. What's more, a few previous researches are related to the influence of framing effect in the field of consumption. At the same time, scholars just focused on college students' group or a particular category as subjects rather than a wide range. Hence, this kind of research could not represent the general consumers, broader target product or more comprehensive consumption environment. We need more empirical study to adapt to the development of Internet and e- commerce and emerging products in the e-commerce platform.

The Future Research Prospects

In the classification of the framing effect, risky framework, attributed framing v and action framing effect in the field of consumption lead to the different results. Risk framework can influence consumer about the related risky decision (e.g., the channels of consuming, way of payment). And in attributed framing effect, positive characteristics framework is the key attributes of goal and the event which symbolize the information that make decision makers are comfortable and satisfactory as opposed to negative framework. This frame is a kind of manifestation in terms of psychology of consumer, which affect the consumer's intention, purchase attitude, willingness to pay and other psychological mood; But in action framing effect, positive action framework is that if consumers who choose this option will have a particular interest or benefit, otherwise, they will suffer from economic, healthy, experiential or others loss, which is defined as negative action framework.Above all, the authors have

several important key points for the future research. First, in e-commerce scenario, is there an effect of framing effect on intangible product consumption decisions? As we know, most of intangible products are the kinds of consumption experience, such as travel services, the process of information gathering and processing is the most important part of tourist destination products and services, and now increasing number of consumers choose online consumption on tourism products and offline experiences, which forms a new consumption environment. Thus, the study of the effect of framework in the field can offer a good scientific basis to tour operators, managers who are competent to come up with product information effectively and contribute to the development of tourism.

Second, under e-commerce business environment, how new promotions in terms of price framework influence brand preferences. In current period, many e-commerce platforms (e.g., Taobao, Jingdong, Suning) deliver a new form of information of promotion that captures attention of consumers, for example, some electronic suppliers offer "0 yuan" product (RMB), or free cost for products in a limited time. This kind of strong and positive action framework attract consumers to lock certain products with the obvious advantages compared with other brand promotion. Will the consumers put their whole mind into plundering this brand with attractive discount?

Third, living in the e-business environment, what is the effect of framework on quantity of consumption? With the convenience of logistics system, online shopping impels consumers to buy the same brand with multiple units. However, for whether there is influence on quantity of consumption, we need more empirical researches in the future, because there are different ways of promotions reveal that buy more get more benefit and they do not need to consider how heavy the product. This topic has strategic significance for the retailers and suppliers who could come up with the attractive expression of promotion to capture the market share.

Fourth, how do the combination of cognitive need and framing effect impact consumption on the internet? H.H. Liang's [44] experiment revealed that cognitive need has a significant impact on individual decisions. Additionally, results of individuals' investing decisions are

influenced by decision goal and different individual factors. But the relationship between cognitive needs and framing effect and whether the combination of them will impact consumption on the internet are questioned by some scholars. We need more cases and scenes to testify.

Xiaoying Li, Wenquan Ling Fifth, research has focused on decisions about the framing effect of risk framework, but little study regarding attribute framing effect and the action framing effect, especially whether there is a relationship between attribute framework and action framework, so more researches are needed.

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CHAPTER 6

DEVELOPMENT OF INTELLIGENT DECISION SUPPORT SYSTEM FOR SELECTION OF QUALITY TOOLS AND TECHNIQUES

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ABSTRACT

This research derives systematic analysis and synthesize previous research published with aim to highlight and develop a decision aid for Quality Tools and Techniques (QTT) selection which enable practitioner make a rational and structured decision though development of Intelligent Decision Support System (IDSS). Vast numbers of QTT for problemsolving and improvement activities give a significant challenge to determine the suitable QTT. The chosen QTT affect the effectiveness of improvement activity and misused of QTT can slow down the improvement process and flawed the conclusion. The IDSS namely eCIFOD was produced by translating the QTT mapping into the SQL

Union and SQL Inner Join. PHP scripts were developed to run the system and uploaded to online after the Black Box Testing show good result. A single case with a single unit of the case study research strategy was used to conduct the user acceptance testing unveil the positive feedback from the user in term of feasibility, usability, and utility. Development of empirical IDSS for selection of QTT through providing structured and intelligent decision making provides holistic decision support for practitioner to select most optimize QTT to be used for improvement purpose.

Index Terms: Intelligent Decision Support System (IDSS), Quality Tool and Technique (QTT), selection method.

INTRODUCTION

Over the last 30 years, many new management methodologies aimed at the improvement of quality have been developed [1]. According to the situation in the manufacturing sector, the issues of quality play an important role [2] in order to achieve higher profits, but at the same time the product or service meet the customer satisfaction [3]. Quality movement and its practices are an interesting topic and it also a huge topic of discussion since last few decades with various issues in past, current and as well as future issues. The quality practices apparently evolved together with the topic of discussion, but the intentions remain unchanged to ensure quality cannot be taken for granted because of the consequence of ignoring the quality can affect the reputation of the organization. The quality movement under the subject Total Quality Management and Business Excellence, found the increasing trend of the article's publication related to management techniques and tools from 1987 to 2011 [4]. They also found that the amount of research in 2002–2011 is significantly higher than that in the first decade 1987–1996. The findings somehow tally with the result from the Scopus search engine as per Fig. 1. By using few keyword downloaded, there is a huge number of documents found in the Scopus search engine. When arranging the number of documents based on a yearly basis, there is increasing trend from 1971 until 2017 which indicate the important and significant to the industries especially organization which eager to adopt improvement.

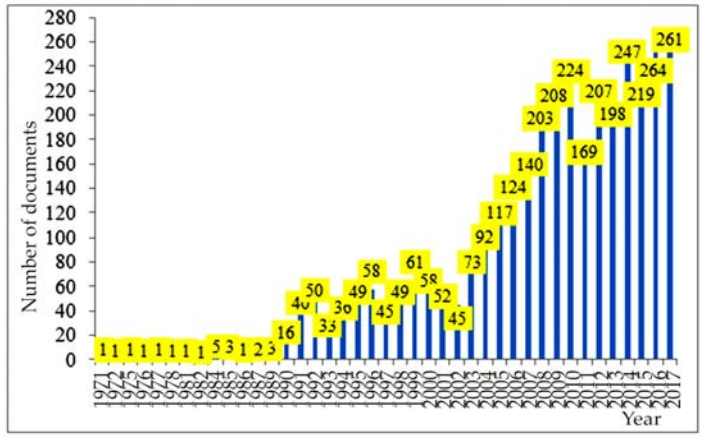


Figure 1: Studies related to Quality Tools and Techniques (QTT).

SELECTION OF QTT

Quality cannot be obtained consistently by coincidence, but through designated improvement. The quality improvement methodology is based on the improvement of systems and processes through a variety of tools and techniques [5], [6]. Publications in general management and strategic decision-making have urged managers to employ a rational decision-making process, when considering the adoption of new improvement.

Selection Dilemma

In order to support, develop and advance a process of continuous improvement, it is necessary for an organization to select appropriate tools and techniques [7]. This is important because the chosen QTT can affect the effectiveness of improvement activity. The QTT can be very effective and also can be very ineffective and affect the improvement process. Misused of QTT can slow down the process and flawed the conclusion [8]. It is very important to know which QTT to be used in improvement activities [9]. However, selection of the most appropriate tools has been always not easy due to a huge number of QTTs available [9], [10].

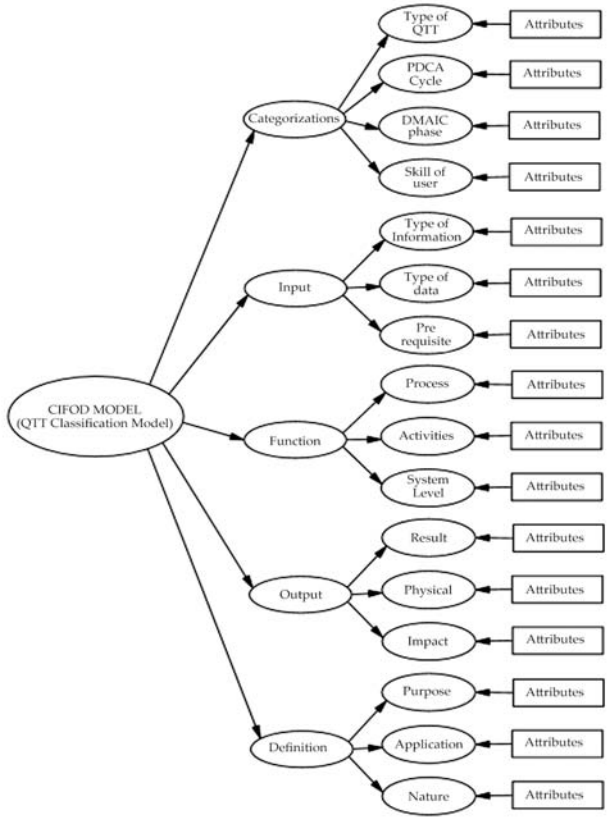


Figure 2: CIFOD model.

Vast amount of QTTs will create difficulty for the user to choose the most appropriate QTT during problem-solving and improvement activity. Therefore, there is a need to find a proper solution to help the user to ease the selection of QTTs. There are many materials such as books and articles to describe the QTTs. However, to understand each QTT by looking to each material will require a lot of time to finish. Typical instrument to help the user to select proper tools is using a matrix diagram. Usually, the selection of QTTs was influenced by the knowledge of the user. The knowledge gain by them typically obtains through experience and training. The content of the training usually will explain the how and when to use QTTs. However, to attend the training some investment is required and the more training, the more investment needed [11], [12]. The investment cost is a factor to choose the QTT and the cost

included training the people to use the tool, cost to employ consultants to implement the QTT successfully and sometimes require the cost to buy supporting software to use the QTTs [13]. On the other hand, the experiences of user help them to choose the right purpose of QTT in order to ensure the effectiveness of QTTs. [14] have identified that the results from the application of a particular QTTs are relying heavily on the skill and experience of those implementing it.

Selection of Attribute for QTT

Apparently, the selection of QTTs is depending on the user's knowledge and this knowledge is considered as the information that able to define the QTTs to help the user choose the QTTs. Exploring the body of knowledge of QTTs is able to classify them into specific attributes that help the user to understand QTT in a wider perspective. In this study, the information was obtained via comprehensive literature and input from quality practitioners that involved in Team Excellence (TE) Convention organized by Malaysia Productivity Corporation (MPC). From comprehensive data analysis through the Confirmatory Factor Analysis and Expert Opinion, the concluded attributes of QTT were established and can be used to well define the QTTs.

Table I: Example Of Qtt Mapping

Attributes \ QTT	Ishikawa Diagram
Categorization	
Type of QTT	Basic QTT, Analytical QTT
Place of QTT in PDCA cycle	Plan
Place of QTT in DMAIC phase	Define (D), Measure (M), Analyse (A), Improve (I)
Skill or experience of user	Novice
Input	
Type of information needed	Process knowledge
Type of input data	Non-numerical

Prerequisite QTT require before using the QTT	No
Output	
Result produced	Classifies, organises, prioritizes
Physical result generated	Diagram
Impact on quality	Long term
Definition	
Purpose of QTT	Grouping, visualizing, generates, analysing, showing, and identifying
Application of QTT	Showing relations, structuring ideas, understanding and analyzing the problems and process, problem solving, and identifies waste
Nature of QTT	Tool
Function	
Process to implement QTT	Market research, control and measure, storage, engineering services, manufacturing process, product designing, sales, technical preparation of production, product utilization, purchasing, customer services, company-wide, and healthcare
Activity requires QTT	Supplier improvement activities, process control activities, process improvement activities, internal customer focus activities, external customer focus activities, reporting activities, measurement activities, inspection activities, leadership activities, quality system activities, participation activities, recognition activities, education activities, training activities, consultation activities, management of processing activities, and performance of processing activities
System level	Company, outbound supply chain, inbound supply chain, plant, hospital, department, line, cell, and job

The classification of QTT's attributes will help to sort the attributes in a more organized arrangement and easy to understand. In this study, the classification is referred as the outcome of grouping the QTT's attributes into logical categories. The classification of these attributes is illustrated in Fig. 2 that also known as CIFOD Model. CIFOD is the acronym of those 5 main groups namely Categorization, Input, Function, Output and Definition that consist of 16 subcategories and 140 attributes.

CIFOD model represents the collective classification of QTT's characteristic with various attributes that will be used for the QTT selection. The wide-range of QTT's background of this model give an

opportunity to practitioner to select the QTT within their knowledge and need. Thus, this model apparently can help the practitioner that has limited experience and knowledge on the QTT. Subsequenly, the attributes in CIFOD model were used as an input in the web-based intelligent decision support system for QTT selection that will help the user to choose the most appropriate QTTs even in the large amount of QTTs.

QTT Mapping

QTT mapping is the action of identifying and matching the characteristic of QTT with the attributes in the CIFOD model. The QTT mapping is conducted by using Consensus Group Techniques [15] that consist of 13 experts from academics and industrial practitioners. From this method, this study found that 140 attributes were able to map with 45 QTTs and the consensus able to reach above 75% for each QTT mapping although the experts are from different fields such a manufacturing industries, service sector and government agencies.

Hence, the attributes found in this study were proven as the identity or characteristic of the QTT. Table I show the characteristics of Ishikawa diagram based on the QTT's attributes that was found during the QTT mapping.

The findings from QTT mapping is translated into a table form. The attributes that belong to the QTT was marked as 1 and if not was marked as 0. The QTT mapping table was used for set up the SQL database.

Selection Method for QTT

Generally, if the decision is made using a typical method such as through a discussion (collection of opinion and experience) or using the reading materials (e.g. books and journals) can be called as a manual decision. The CIFOD model with the QTT mapping in the matrix or table format, if used as a decision-making tool, is also identified as a manual decision method. Therefore, the manual method basically refers to either to refer a specific diagram or use a matrix to choose the QTT and computerized method can be reffered as system selection method with support from any computer technology such an IDSS.

There are 4 references found that discussed on the method of QTT selection exclusive the typical selection method through DMAIC phases or PDCA cycle. From these references, there are two types of selection, either manually selects the QTT or by using the system to select the QTT. The content of theses QTT selection methods mainly uses the attributes of QTT as selection criteria. Table II shows the type of selection found in each reference. The selection method using DSS is apparently much better to compare to manual searching as this system is able to reduce the selection time and able to compile the result in an informative way such as using graphic and percentage. However, both references that use DSS as a selection method did not provide any empirical evidence on the effectiveness of the system in selecting the correct QTT during improvement and problem-solving activities.

Table Ii: The Selection Method From Previous References

No	Authors	Type Of Selection
1	Pavnaskar, Gershenson and Jambekar (2003)	Manual (Using Diagram)
2	Hagemeyer, Gershenson and Johnson (200)	Manual (Using Matrix)
3	Chen (2009)	Computerized (DSS)
4	Starzyńska and Hamrol (2013)	Computerized (DSS)

DEVELOPMENT OF ECIFOD

This research focused on the development of Intelligent Decision Support System (DSS) that physically translated the CIFOD model with the QTT mapping to a computerbased system with a web-based format. The physical output of this phase is a new product so-called eCIFOD

A system that integrates the knowledge from experts is known as Knowledge-Based Decision Support System (KBDSS) or Intelligent Decision Support System (IDSS) [16]. Thus, the word intelligent basically refers to the knowledge-based that fundamentally reflects the content of QTT mapping that was developed in the previous phase. From this highlight, this study adapted similar terminology which is Intelligent

Decision Support System (IDSS) as a computer-based information system to support decision making in selecting the appropriate QTT for improvement and problem-solving activities.

Several processes of software development were conducted in this phase such as designing the algorithm and setting up the SQL database. The prefix e- is used as an indication of web-based IDSS. The web-based IDSS refers to a computerized system that delivers decision support information or tools to a decision maker or analyst using a web browser such as Internet Explorer or Mozilla Firefox [17]. There are five types of IDSS namely data-driven, model-driven, knowledge-driven, document-driven, and communications driven and all of these types of IDSS can be implemented using web-based technologies [17].

PHP Script

Since this study used web-based IDSS, the PHP scripting language is used to transform the CIFOD to eCIFOD. PHP was designed for web page creation and primarily coded in C as a scripting language. The scripting language is designed to communicate instructions to a computer and the server. It is a set of instructions that used to produce the desired output. The PHP script language was created to develop the instruction to the server and to develop the interface for clients.

Since the database involved, the Structured Query Language (SQL) is used as the primary standard for database languages. The most well-suited Database Management System (DBMS) to working with PHP is MySQL. MySQL is an open source DBMS that mainly used on the web and the systems that run on the server. To administrate the MySQL, this study used phpMyAdmin software as an administration tool for MySQL. Finally, there were 22 main PHP files created to develop the eCIFOD. 11 files created as input to the system that used to select the attribute of QTT and 11 files created as an output from the system to list out the QTT based on the selected attributes.

Table Iii: Php File Created To Develop Ecifod

Classification of QTT	Union		Inner join	
	Input	Output	Input	Output
Categorization	search3.php	search4.php	search-innerjoin.php	search-innerjoinresult.php
Input	inputsearch.php	inputresult.php	inputsearchinnerjoin.php	inputresultinnerjoin.php
Function	functionsearch.php	functionresult.php	functionsearchinnerjoin.php	functionresultinnerjoin.php
Output	output3.php	output4.php	outputsearchinnerjoin.php	outputresultinnerjoin.php
Definition	Definitionsearch.php	Definition.php	Definitionsearch-innerjoin.php	Definition-result-innerjoin.php
Overall (Expert)	N/A	N/A	qttfullinnerjoin.php	qttfullinnerjoinresult.php

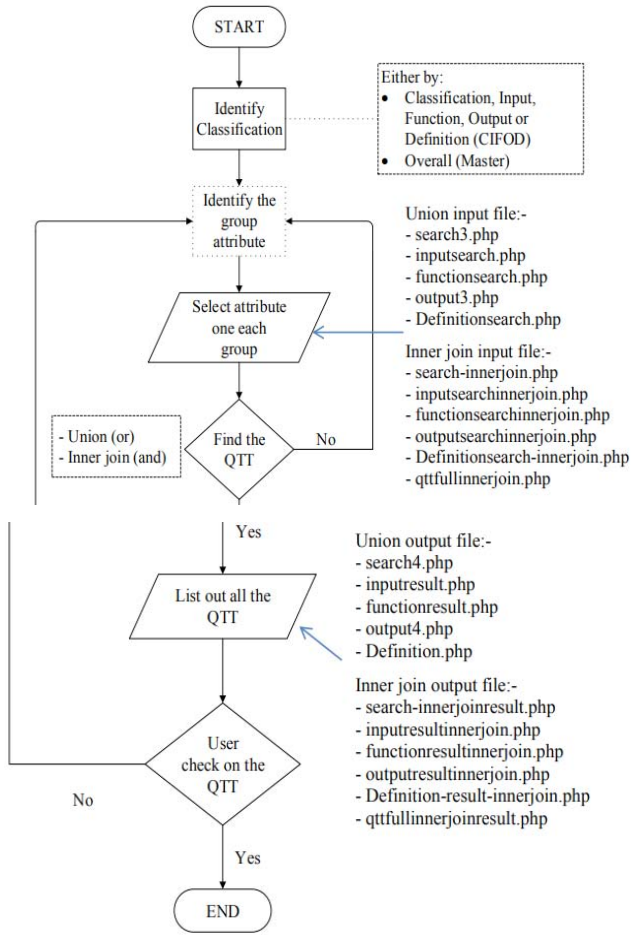


Figure 3: The logical flowchart and the files created in eCIFOD.

The eCIFOD was designed to find the QTT in a single classification or combined all classification in one group namely 'expert'. However, the combined classification to find the QTT was designed only in the inner join command as this command is a specific search to the specific identity

of QTT based on the attributed selected. Table III tabulated the PHP files created based on the CIFOD classification and the SQL searching method namely union and inner join. Fig. 3 mapped the files created with the logical flowchart of eCIFOD.

SQL Database

The database was first set up prior to creating the input and output PHP program files. Fig. 4 shows the view of the general setup of the database based on each construct and overall attributes, namely qttfull, as well as the view of QTT mapping in the database.

This research created 12 PHP files for this preference as shown in Table IV, either based on the attributes in each classification or based on the full list of attributes. There were 6 files to get the overall table of QTT mapping and 6 files to visualize single QTT with its attributes.

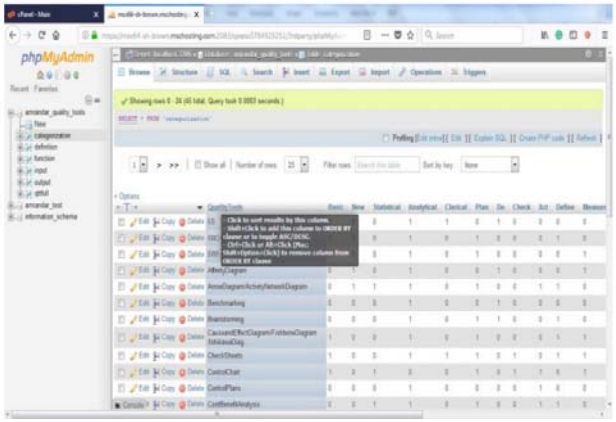


Table V shows the important source code for union structure and Table VI for inner join structure, that are taken from one of the construct (i.e. Categorization) that used in the PHP script to make the program (i.e. eCIFOD) able to produce the lists of QTT based on selected attributes.

Figure 4: General setup of the database.

Table Iv: Attributes In Each Construct

Classification of QTT	Master Select	
	Overall QTT	Single QTT
Categorization	categorization1.php	categorization2.php
Input	Input2.php	Input3.php
Function	function1.php	function2.php
Output	output1.php	output2.php
Definition	Definition1.php	Definition2.php
Overall (Expert)	Viewfullmaster.php	Viewfullresult.php

The input files in the union and inner join mainly use the multiples checked checkboxes operation to find the QTTs based on the user selections. Meanwhile, the output files for both union and inner join were mainly used SQL query operation to match the selection with the data in the SQL database.

The difference between union and inner join for eCIFOD is the union will list out all the QTT that related to the selected attributes, meanwhile, the inner join will consider the selected attributes as the specific identity of the QTT and list out the QTT that match with the identity.

Table V: Example Of Sql Source Code Union

Name Page:	Search4.php
Query:	$query_RecordsetQTT
Database Name:	qualitytools
Classification Name:	Categorization
Echo/Sample Column:	$QTT1, $QTT2, $QTT3, $QTT4, $QTT5

HEADER/END;
<?php do { ?> <td><?php echo $row_RecordsetQTT['qualitytools']; ?> </td> <?php } while ($row_RecordsetQTT = mysql_fetch_assoc($RecordsetQTT)); ?>
UNION CODE: ***Function explanation;***

//SELECT `***Database Name***` FROM `***Classification Name***` A WHERE A.`***Column Name*** ` = 'Y' UNION SELECT `***Database Name***` FROM `***Classification Name***` B WHERE B.`***Column Name*** ` = 'Y'
Echo CODE; ***Function explanation;***
//echo $***Column Name1***. "==" . $***Column Name2***. "==" . $***Column Name3***. "==" . $***Column Name4***. "==" . $***Column Name5***. "==";
ACTUAL from PAGE;
NO 1; //SELECT `**qualitytools**` FROM `**categorization**` A WHERE A.`**type1.basic**` = 'Y' UNION SELECT `**qualitytools**` FROM `**categorization**` B WHERE B.`**type2.new**` = 'Y'

Echo Function;
NO 2; //echo $**QTT1**. "==" . $**QTT2**. "==" . $**QTT3**. "==" . $**QTT4**. "==" . $**QTT5**. "==";
UNION CODE STRUCTURE ***Start Union Code for Column No 1.*** ***Name of Column No 1 = basic***
if ($QTT1 <> NULL){ $query_RecordsetQTT = "SELECT qualitytools FROM categorization WHERE `basic` = ". $QTT1; }
Function explanation;
if ($***Column Name1*** <> NULL){ $query_RecordsetQTT = "SELECT ***Database Name*** FROM ***Classification Name*** WHERE `basic` = ". $***Column Name1***; }

For example, if the user selects 'Basic' and 'New' in the Categorization checkboxes, the output of union will list out 14 QTTs that refer to 7 basic quality tools and 7 new quality tools. In the inner join, if the user selects 'Basic' and 'New', the output will be nothing because there is no QTT that is considered as basic and new quality tools at the same time.

BLACK BOX TESTING RESULT

In order to validate the functionality of the decision support system, the Black Box Testing was used in this research. Functional requirements define what the system must do where the system will apply logic to an input and produce the required output. Thus, the test was conducted to ensure the PHP script produces the correct output and to eliminate any bugs. The test was conducted to the final version of eCIFOD and total 34 tested were conducted in Black Box Testing. Table VII shows the main result of Black Box Testing of eCIFOD. The result of Black Box Testing shows that all tested were passed, thus the scripts were able to produce the desired output as instructed in the PHP script. The holistic case study design was used to test the application of eCIFOD in the actual phenomenon. The eCIFOD was used to support the improvement

team to select the QTT in order to reduce the defective percentage from 7% to 3. 9 QTTs were adopted from eCIFOD, namely Gantt Chart, Affinity Diagram, Prioritization Matrix, Check Sheet, Ishikawa Diagram, Brainstorming, Pareto Chart, Graph and Matrix Diagram. The improvement was successfully conducted within 3 months.

USER ACCEPTANCE TESTING

The User Acceptance Testing (UAT) was conducted to measure the applicability of eCIFOD. 3 types of quality attributes or criteria adopted from Microsoft Application Architecture Guide with total 10 measurements were used to measure the user acceptance level. The result shows the user acceptance level is 3 and above, indicate that the eCIFOD meet the user requirement and able to support the improvement team to select suitable QTTs during the improvement activities.

Case study research strategy was adopted to test the eCIFOD in actual application. A single case study that refers to Company X with a single unit of analysis that refers to the improvement team was chosen to test the eCIFOD. The improvement project was successfully implemented by the improvement team with the support of eCIFOD. 11 QTTs were adopted in the improvement projects that selected by using the eCIFOD.

Table Vi: Example Of Sql Source Code Inner Join.

Name Page:	Search-innerjoinresult.php
Query:	$query_RecordsetQTT $query_RecordsetQTTb
Database Name:	qualitytools Z.QualityTools
Classification Name:	Categorization
Echo/Sample Column:	$QTT1, $QTT2, $QTT3, $QTT4, $QTT5

HEADER/END;
<?php do { ?> <td><?php echo $row_RecordsetQTT['qualitytools']; ?> </td> <?php } while ($row_RecordsetQTT = mysql_fetch_assoc($RecordsetQTT)); ?>
QUERY CODE BUILD;

$query_RecordsetQTT = "SELECT Z.QualityTools FROM categorization Z";
INNER JOIN CODE: ***Function explanation;***
if ($QTT1 <> NULL){ ***$query_RecordsetQTT***.= ", ***Classification Name*** A"; ***$query_RecordsetQTTb***.= " AND A.`Basic` = ". ***$Column Name1***. " AND A.***Database Name*** = Z.***Database Name***"; }
Echo CODE; ***Function explanation;***
//echo ***$Column Name1***. "==" . ***$Column Name2***. "==" . ***$Column Name3***. "==" . ***$Column Name4***. "==" . ***$Column Name5***. "==";
ACTUAL from PAGE;
NO 1; if (**$QTT1** <> NULL){ **$query_RecordsetQTT**.= ", **categorization** A"; **$query_RecordsetQTTb**.= " AND A.`Basic` = ". **$QTT1** . " AND A.**QualityTools** = Z.**QualityTools**"; }

Echo Function;
NO 2; //echo **$QTT1**. "==" . **$QTT2**. "==" . **$QTT3**. "==" . **$QTT4**. "==" . **$QTT5**. "==";
INNER JOIN CODE STRUCTURE ***Start Union Code for Column No 1.*** ***Name of Column No 1 = basic***
if ($QTT1 <> NULL){ $query_RecordsetQTT.= ", categorization A"; $query_RecordsetQTTb.= " AND A.`Basic` = ". $QTT1 . " AND A.QualityTools = Z.QualityTools"; }
Function explanation;
if (***$Column Name1*** <> NULL){ $query_RecordsetQTT.= ", ***Classification Name*** A"; $query_RecordsetQTTb.= " AND A.`Basic` = ". ***$Column Name1*** . " AND A.***Database Name*** = Z.***Database Name***";}

This result shows that the attributes of QTT's characteristic through eCIFOD was able to support the user to choose the right QTT for improvement activities. In the selection of QTT through eCIFOD, from 11 QTT, 10 QTTs were selected by using full search Inner Join function. It shows that the user needs to find the QTT based on specific attributes that come from a combination of several attributes from various classifications.

Table Vii: Summary Result Of Black Box Testing

Test No.	Test name	Function Being Tested	Expected Result	Status (Pass/ Fail)	Description
1.	QTT mapping under Categorization	QTT mapping table	Table of QTT mapping as in a database	Pass	List of QTT with the mark as '1' and '0' that similar in the database
2.	Single QTT under Categorization	List of attributes for each QTT	Table of attributes for each QTT as in a database	Pass	The attributes of each QTT with the mark as '1' and '0' that similar in the database
3.	Union function under Categorization	Checked checkboxes	All 17 checked checkboxes can be ticked.	Pass	The '✓' appeared
4.	Union function under Categorization	'Find' button hover	Once clicked, it links to the result page	Pass	Result page show list of QTTs in a table form and show number of QTTs (records) found.

CONCLUSION

This study produced an independent process of QTT selection by using IDSS namely e-CIFOD, that was developed through comprehensive CIFOD Model and was tested in actual improvement practice. The e-CIFOD is foreseen can avoid bias because it can be used without heavily rely on the experience worker or influence by the popularity of certain QTT.

In addition, this study able to provides comprehensive guidelines for practitioner and researcher in term of selecting the most appropriate QTT to be used for problem solving and improvement activities. Improving the quality of processes and maintaining acceptable levels of performance quality are critical factors in the success of any organization and remain competitive [13].

Future research can explore the application of Artificial Intelligence (AI) such as an Artificial Neural Network and Fuzzy Logic, in the developing the QTT selection and use the attributes of QTT as the variable of measurement. The new equation may arise from this approach to find the QTT from the variables.

ACKNOWLEDGMENT

Special thanks to supervisor Prof Dato Dr Khairanum Binti Subari for valuable idea and contribution to this research. Also to corresponding author, Mr Ikbar, Dr Fairul Anwar and Mr Rahmat for review and provide assistance while completing this research.

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CHAPTER 7

DESIGNING EFFECTIVE FORECASTING DECISION SUPPORT SYSTEMS: ALIGNING TASK COMPLEXITY AND TECHNOLOGY SUPPORT

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INTRODUCTION AND MOTIVATION

Forecasting is critical to successful execution of an organization's operational and strategic functions such as for delivery of a cost effective and efficient supply chain [1]. The complex and dynamic organizational environment that defines much of today's forecasting function is often supported by a range of technology solutions, or forecasting decision support systems (FDSS). Typically, FDSS integrate managerial judgment, quantitative methods, and databases to aid the forecaster in accessing, organizing, and analyzing forecasting related data and judgments [1-2]. Forecasting task complexity can negatively impact forecast reliability, accuracy, and performance [3-4]. Specifically, it can influence two elements of forecaster behavior – deriving forecasts and judgmental adjustment of these forecasts [5]. In executing these functions, forecasters

may utilize different heuristics for complex series as opposed to simple ones in order to mitigate cognitive demands [6-7]. Because selection and execution of these heuristics can be influenced by forecaster experience and knowledge-base, integrating time series complexity into Forecasting Support Systems (FSS) design can bring greater objectivity to forecast generation, while simultaneously providing meaningful guidance to forecasters [1].

Advances in design and use of FDSS, however, have been slow to come because of the following range of problems that limit their usefulness in the forecasting domain. Firstly, FDSS are expensive to create, operationalize, and calibrate and therefore, require significant organizational investment. Second, and most significantly, forecasts generated by such expensive FSS are often subjected to judgmental adjustments. Such adjustments may be driven by forecaster confidence, or lack thereof, in FDSS capabilities as well as forecaster's sense of ownership once they make judgmental adjustments as opposed to just accepting outputs of a forecasting model. Third, forecaster confidence in FDSS and its outcomes is influenced by numerous system abilities such as strength of and confidence in explanations provided about forecast creation [8], information presentation [9], data about the systems past success rate [10], support from analogical forecasting tasks [11], and ability to decompose the forecasting problem [12] to mention a few. Lastly, the functionality and processes underlying FDSS are sometimes difficult to align with the experiential thinking of forecasters [11], i.e. If such support systems adaptively support complex and simple tasks according to task demands, forecasters may be less tempted to make judgmental adjustments [11, 13-14].

The above discussions and supporting literature reaffirm that the level of agreement between a task and the functionalities of the supporting technologies, i.e. the task-technology fit (TTF), can determine individual performance on tasks [15-19]. TTF studies suggest that the extent to which a technology supports individuals in performance of their portfolio of tasks can determine the degree of success in the execution of their tasks through both improved performance and better system utilization [15, 20]. In a sense then, TTF provides important justifications for discretionary use of FDSS for simple and complex tasks. Under conditions where FDSS perform well empirically, it would likely be worth committing the

time and resources to utilizing the FDSS. In contrast, where FDSS do not perform effectively or performs as effectively as human judgment, such commitment of time and resources to parameterize the FDSS may not be warranted. It has been asserted that certain functionalities of a technology are better suited for specific types of processes or tasks [17]. To this end, improved alignment between FDSS and FDSS-supported tasks, essentially better Forecasting Task-Technology Fit (FTTF), can mitigate the factors driving forecasters to make *ad hoc* adjustments of questionable validity done for rationalizing their worth [19].

In this study, we specifically examine the issue of forecasting task complexity and commensurate FDSS support to provide a framework for FSS design and implementation using the TTF as an underlying motivator. In doing so, we achieve the following:

- Develop a characterization of complex and simple time series forecasting tasks. Herein, we rely on historical patterns and domain-based features of time series to develop discrete task profiles along a simple to complex continuum.
- Review evidence from the empirical literature regarding forecasting task complexity and its implications for FDSS design and suggest designs that would benefit the forecasting process.
- Develop an agenda for research and discuss practice-related issues with regard to balancing forecasting utility with efficiency given the costs of FDSS.

LITERATURE REVIEW

Task-Technology Fit

TTF theory defines tasks as actions carried out by individuals to process inputs into outputs [20] and task profile as aspects of these tasks that might require users to rely on information technology. Technologies are defined as any set of tools, such as FDSS, required for executing these tasks. The fit between tasks and technologies, then, refers to the "degree to which a technology assists an individual in performing his or

her portfolio of tasks" [20]. In the usual case, TTF theory is implemented at two levels: (a) an organizational level that examines the presence of data, processes, and high-level system features (e.g. system reliability) to fulfill the broad needs of a decision domain, and (b) a context level that examines the presence of system features specific to a decision context e.g. system capabilities for time series forecasting or group decision making. Studies in both contexts develop TTF concepts from three perspectives: identification of (a) a task profile [15] i.e. tasks specific to the domain of study; (b) technology features or needs specific to a task profile; and (c) impact of TTF on individual performance. We discuss these findings in the next sections.

Most TTF studies characterize tasks based on organizational level decision support needs such as information and data quality, access, procedures surrounding data access, and system reliability [19-21] characterized tasks in terms of non-routineness, defined as lack of analyzable search behavior, and interdependence with other organizational units. Later a dummy variable was added to capture managerial factors as a determinant of user evaluation of information system use [20]. Recently, an increasing number of studies have examined tasks more contextually i.e. specific to the domain of study. Most commonly, these studies classified tasks according to their complexity [22-23]. Also characterized tasks were characterized on the basis of complexity and proposed a task classification that ranged from simple to fuzzy tasks [23]. In group decision making, [15] extended this classification to further define task complexity in group decision making. These studies define task complexity as having four dimensions: *outcome multiplicity* suggesting more than one desired outcome, *solution scheme multiplicity* suggesting more than one possible approach to achieving task goal, *conflicting interdependence* which can occur when adopting one solution scheme conflicts with another, and *outcome uncertainty* defined as the extent of uncertainty regarding a desired outcome from a solution scheme. Others found that task support for virtually-linked teams often translated into those related to conflict management, motivation/confidence building, and affect management [17]. Other applications of TTF theory appear in mobile-commerce for the insurance industry [24], consumer participation in e-commerce [25]), and software maintenance and support [16]) among others. In the forecasting domain, surprisingly we found only one TTF study [19],

that adapted organizational level factors to the forecasting domain by examining needs related to forecasting procedures.

In the TTF framework, technological support has been characterized most often in terms of hardware, software, network capabilities, and features of the support system. Others, for instance, developed technology characteristics based upon input from an independent panel of IS experts [20-21]. These technology capabilities included relationships between DSS and its user, quality of support, timeliness of support, and reliability of system among others. Further, some relied on the same technology characteristics for considering adoption of Personal Digital Assistants (PDAs) in the insurance industry [24]. In keeping with the underlying emphasis of TTF, i.e. fit between tasks and technologies, context-dependent studies have focused on specific capabilities for the domain of interest. For instance, others examined richness of communication media for resolving conflict between virtual teams and motivating positive team work [17]. And some proposed that technologies supporting group decision making must be capable of providing communications support and structuring group interaction processes along with supporting information processing needs of the group [15]. Finally, [19] leveraged the framework of [20] to the forecasting domain by focusing more significantly on system functionality and capabilities—specifically focusing on data, methods, and forecasting effectiveness.

TTF studies have most commonly examined two outcomes of alignment between task and technology – system utilization and task performance. It was found that there was a suggestive relationship between TTF and system utilization and a strong positive connection with performance but mediated by utilization [20]. In contrast, it was suggested that TTF strongly predicted customer intention to purchase from an e-commerce site [25]. Also it was confirmed that a strong relationship between performance on certain insurance tasks and use of mobile devices exists [24]. Finally others found that FSS characteristics, specifically forecasting procedures included in the FSS, to be positively related to perceptions of TTF which, in turn, positively related to forecasting performance. In general, these results confirm a strong association between performance and alignment between task needs and supporting technologies [19]. This is a critical linkage for our study.

Adapting TTF to the Forecasting Domain

Time series extrapolation calls for quantitative methods to forecast the variable of interest with the assumption that behaviors from the past will continue in the future [2]. Time series forecasting is also found to improve with use of domain knowledge such as for series decomposition [26]. In essence, successful time series extrapolation relies upon recognizing idiosyncratic aspects of the series as defined by patterns in the historical data as well as domain knowledge likely to emerge through unknown future generating processes. Considering this, the implementation of time series task classifications using TTF theory is best achieved by following the context-specific approach discussed earlier as this perspective emphasizes conditions that impact the contextual usefulness of FSS. In other words, if for the task that a forecaster must execute, the time series, serves as input into the FDSS, task characterizations may best emerge from the features of the series being processed. For purposes of this paper, we follow recommendations by [15, 23] to classify decision tasks, specifically time series, along a simple to complex continuum.

Complexity in Time Series Forecasting

Complexity is inherent in the forecasting process [12]. While it can be argued that all one needs is a forecasting method and adequate data, a non-trivial view of the forecasting process suggested by [2] provides a more realistic perspective—that of decomposition. Each stage of the forecasting process entails coordinated action that requires use of judgment and analytical skills, inputs from multiple organizational units, as well as validation and integrity checks. When decomposed into its components, the forecasting process integrates domain knowledge, historical data, causal forces acting upon the domain, as well as physical characteristics of the process producing the measured realizations that are to be forecast [12].

Of interest in our study, however, is characterization of complexity in the context of the task i.e. the time series being forecast. Forecasting literature has provided some interpretations of complex time series. Most commonly, time series are defined as complex if the underlying process-

es that generate them are such [27]. Chaotic time series, as opposed to "noise driven series", wherein observations drawn at different points in time follow a non-linear relationship with past observations of variables [28] have also been referred to as complex series. More recently, studies have characterized complexity in terms of time series composition. For instance, [26] describe complex time series as those where forecasters expect conflicting underlying causal forces, i.e. underlying forces will push the series in different directions in the forecast period. In essence, such series can be represented as a composite of multiple series where the challenge is to determine the overall effect or momentum of these multi-directional forces whose net effect could be static i.e., no movement due to offsetting causal forces.

Most views presented above define complexity in terms of either specific patterns in historical data (e.g. variation or volatility) or underlying processes and influences (e.g. causal forces). This constrained view of time series complexity is surprising considering the taxonomy of time series features available in existing literature. Time series features often captured in empirical literature include stationarity or non-stationarity of series [29-31]. Stock market forecasting studies have often relied on capturing features like volatility persistence, leptokurtosis, and technical predictability of stock related series [32-33] classified time series in terms of three features – irrelevant early data (where the generating process has fundamentally and irrevocably changed such that it creates a misleading impression of the future), outliers, and functional form. Although focused on assessing judgmental confidence intervals, some have characterized time series in terms of trend, level, seasonality, and noise [34]. These features provided 57% of the explanation for confidence intervals chosen by forecasters, suggesting that possibly a finer breakdown of series characterizations may be worth consideration. For purposes of this paper, we rely on a more extensive taxonomy of time series characterizations suggested by [35-37] to classify time series along the continuum of simple to complex tasks. Their classification is particularly relevant because it captures not merely a range of patterns in historical data but also underlying generating processes and judgmental expectations about the future based on domain knowledge. Initially it was suggested that there were 18 such features [35] and these were later expanded to 28 by [36 - 37]. For purposes of this paper, we use a subset of these 28 features, particularly in the context of the four feature sets discussed earlier in this

paragraph. These time series features are described at length in Table A in the Appendix and in [35].

Time Series Task Characterizations

As mentioned previously, some have classified tasks along a simple to fuzzy (complex) continuum such that system features could be developed in alignment with the task [15, 23]– in essence, TTF. Table 1 defines the key tasks types and their characteristics proposed in [15].

Table 1: Overview of Suggested Task Characterizations [15]

Task Categorization	**Description**
Simple Tasks	Low uncertainty; low conflicting interdependence; clear solution
Problem Tasks	Multiple solution schemes to a well-specified outcome. Needs involve finding optimal way of achieving the outcome.
Decision Tasks	Finding solutions that meet needs of multiple conflicting outcomes. Selecting best option from several available.
Judgment Tasks	Conflicting and probabilistic nature of task related information. Need to integrate diverse sources of information, predict future states.
Fuzzy Tasks	Multiple desired states and multiple ways of getting to them. Unstructured problems that require effort to understand. High information load, uncertainty, and information diversity. Minimal focus for the task executor.

In Table 2, we offer a simplified adaptation of this taxonomy for the forecasting domain and classify series as simple, moderately complex, and complex. Time series features in [35], hereafter referred to as C&A, were used to develop the complexity taxonomy. The C&A's feature set is particularly relevant because it captures not merely a range of visible patterns in historical data that can influence judgmental forecasting processes (e.g. outliers, trends, and level discontinuities), but also recognizes underlying generating processes and domain-based expectations about the future. These features, described in Table A in the Appendix, could broadly be categorized into four clusters: (a) *uncertainty* defined by

variation around the trend and directional inconsistencies between long and recent trend, (b) *instability* characterized by unusual time series patterns such as irrelevant early data, level discontinuities, outliers, and unusual observations, (c) *domain knowledge* defined as availability (or lack thereof) of useful domain knowledge and underlying functional form of the series i.e. multiplicative or additive, and (d) *structure*, the presence or lack of a significant trend i.e., a perceptible signal. In forecasting literature, these features are the most comprehensive attempt to characterize series for use in an FSS, Rule-based Forecasting (RBF). RBF studies have extensively validated these features, first in C&A on 126 time series, then in [38] across 458 time series, and finally on 3003 M3 competition series [36]. Considering this, we relied on a subset of these 28 features (see Table A - Appendix and C&A) for development and validation of our taxonomy. The four feature clusters discussed above were used for classification as they have the potential of destabilizing a time series (C&A). Table 2 below provides a conceptual view of the details of this classification. Using features from C&A, time series tasks can be classified into four categories with simple and complex forecasting tasks being the two ends of this continuum. *Simple forecasting tasks* represent low instability and uncertainty, demonstrate relatively clear structure in their underlying trend patterns, and do not rely on significant domain knowledge to generate useful forecasts. In most instances, demographic series such as percentage of male births tend to regress towards a known mean [37], have slow but steady trends, and variations that are rare, unusual, and easily accounted for, thereby making them easier to forecast. Alternatively, domain knowledge is clear and non-conflicting. Such tasks are expected to pose low cognitive load on the forecaster because confounding features and underlying processes are few and, consequently evident.

Table 2: Time Series Task Classification Based on Series Features

Series Characteristics	Simple Time Series	Moderately Complex Time Series	Complex Time Series

Instability Recent run not long Near a previous extreme Irrelevant early data Changing basic trend Suspicious pattern Outliers present Level discontinuities Unusual last observation	Few or no instability features present	Some instability features present	Many instability features present
Uncertainty Coefficient of variation > 0.2 Difference between basic and recent trend	Low variation about the trend Recent and basic trends agree	Medium to high variation about the trend Recent and basic trends may disagree	High variation about the trend Recent and basic trends disagree
Structure Significant basic trend Clear direction of trend (up or down)	Insignificant trend No or low trend	Significant trend Clear direction	Significant trend Lack of clarity in direction due to confounding features
Presence of Domain Knowledge Causal forces Functional Form	Additive or multiplicative series Simple, consistent causal forces	Multiplicative series Multiple causal forces	Multiplicative series Unknown or inconsistent causal forces

At the other end of the continuum, by contrast, *complex forecasting tasks* are characterized by greater instability and uncertainty, do not demonstrate a clear generating structure, and may require "systematic" integration of a complex set of domain knowledge features that send

conflicting signals [26]. For instance, forecasting monetary exchange rates is made challenging by the low signal to noise ratio and the non-ergodic nature of the process caused by numerous undetermined underlying drivers [37]. Such series may pose greater cognitive demand on the forecasters who may find it difficult to isolate features such as trends and instabilities and recognize underlying processes.

Moderately complex time series will fall somewhere along the continuum (see Table 2). These tasks demonstrate some instability, variation about the trend may be higher than for simple series, and/or recent and basic trends may conflict. The structure of such series demonstrates a more complex interplay of domain knowledge than for simple series, thereby lending multiple possible solution schemes depending upon interpretation and application of domain knowledge. An example of decomposition of UK Highway deaths illustrated these conflicting scenario possibilities where the decomposition of the series yielded two conflicting elements of domain knowledge – growth in traffic volume and decay in decline in death rate [39]. Decomposing the time series into its components helped improve forecasts for the target series.

Judgmental Accuracy on Complex and Simple Forecasting Tasks

In earlier sections, we have mentioned the dearth of studies in forecasting on complexity and its implications on performance and outcomes. Consequently, we have relied on general studies in other domains to highlight implications of complexity in forecasting complex versus simple tasks. Most fundamentally, [23] defines simple tasks as those that are not complex. In general, more complex tasks require greater support [15] and richer information presentation [40-43]. Complex tasks increase cognitive overload and place greater information processing requirements on the user, thereby reducing performance [44-45]. Under such situations, decision makers choose "satisficing" but suboptimal alternatives [46] thereby lowering decision accuracy. When task complexity does not match abilities of the decision maker, motivation and consequently, performance may decline [47]. Using a Lens model approach, [48] attributed poor judgment in complex task settings to limitations in participants' ability to execute judgment strategies as

opposed to their knowledge about the task domain, essentially a lack of experiential acuity. This could be attributable to loss in perceived self-efficacy and efficiency in application of analytical strategies.

In the forecasting domain, studies have uncovered confounding effects in situations that manifest uncertainty and instability. For instance, [34] found that as the trend, seasonality, and noise increased in a time series, forecasters indicated wider confidence intervals, and hence uncertainty, in their forecasts. Further, [49] also found that while forecasters successfully identified instability in time series, their forecasts were less accurate than statistical forecasts when such instabilities were present. Considering this, even experienced forecasters may find lowered performance in complex settings. These multidisciplinary findings then suggest:

- *Practical Proposition 1:* Judgmental forecasts of complex time series will be less accurate than judgmental forecasts of simple time series.
- *Practical Proposition 2:* Judgmental forecasts of moderately complex time series will be less accurate than judgmental forecasts of simple time series but more accurate than those for complex time series.

FDSS, through effective design, can allay the cognitive and human information processing demands that task complexity can place on the decision maker, and thereby potentially increase system use and confidence. DSS range from simple decision aiding such as using visual, as opposed to text-based, presentations to complex intelligent systems that adaptively perceive and respond to the decision context. The alignment between task needs and technology support, however, needs reflection. If misaligned, decision maker performance can be compromised. For instance, [50] evaluated a DSS for treatment of severe head injury patients by comparing physician expert opinions with results generated by the DSS. The study concluded that the tool was not accurate enough to support complex decisions in high-stress environments. Similarly, [51] found that providing certain types of cognitive support for real-time dynamic decision making can degrade performance and designing systems for such tasks is challenging. Based on these studies, the following can be proposed:

- *Practical Proposition 3:* FDSS generated forecasts for complex time series will be more accurate than judgmental forecasts of complex time series.
- *Practical Proposition 4:* FDSS generated forecasts for complex time series will be more accurate than judgmental forecasts of moderately complex time series.
- *Practical Proposition 5:* FDSS generated forecasts for simple time series will be as accurate as judgmental forecasts of simple time series.

Judgmental Adjustment of FDSS Generated Forecasts

While existing forecasting literature has yielded several recommendations for forecast adjustment, once again, this area suffers from lack of sufficient empirical findings regarding adjustment of forecasts for complex and simple tasks. Here too, we rely on multidisciplinary studies and findings from our own studies [52] to support our propositions. Forecasting literature, for instance, has suggested that statistically generated forecasts should be adjusted based on relevant domain knowledge and contextual information that practitioners gain through their work environment. Others [53-54] demonstrated that familiarity with the specific factors being forecast was most significant in determining accuracy. Judgmental adjustments should also be applied to statistically generated forecasts under highly uncertain situations or when changes are expected in the forecasting environment, i.e. under conditions of instability. Both uncertainty and instability, according to our earlier framework in Table 2, lend complexity to the forecasting environment.

Managerial involvement in the forecasting process, primarily in the form of judgmental adjustments, has been questioned in terms of value added benefits. For instance, [55] suggest that benefits of managerial adjustment in stable series may not be justified as automatic statistical forecasts may be sufficiently accurate. In contrast, they recommend high levels of managerial involvement in data that has high uncertainty, in a sense, high complexity surrounding it. In our own empirical studies comparing FDSS and judgmental forecasting behaviors [52], we find that when given FDSS-generated forecasts, forecaster adjustments to simple series harm forecast accuracy but improve accuracy of complex series

when compared to unadjusted FDSS forecasts. Furthermore, when given simple series, forecasters react to complex series by assuming forecast values to be too low and, in response, adjust forecasts more optimistically than necessary. In contrast, they view the forecasts for simpler series to be aggressive and accordingly overcompensate by suppressing the forecasts. Accordingly, we propose:

Practical Proposition 6: Forecasters will adjust complex series more optimistically than simple series whose forecasts will be suppressed.

- *Practical Proposition 7:* Adjustments to FDSS-generated forecasts for simple series will harm forecast accuracy.
- *Practical Proposition 8:* Adjustments to FDSS-generated forecasts for complex series, if executed correctly, can improve forecast accuracy.

As a caveat to the last proposition above, judgmental adjustments to complex forecasts may be best supported by FDSS in a way that the adjustments are structured [53] and validated automatically through improvements in forecast accuracy [35, 39]. In the following sections, we rely on the TTF framework and other DSS studies to propose ways in which FDSS could be best designed to adaptively support simple to complex tasks.

IMPLICATIONS FOR FSS DESIGN AND RESEARCH: PUTTING THEORY INTO PRACTICE

In conjunction with the decision maker, DSS have been shown to generate better decisions than humans alone by supplementing the decision makers' abilities [56], aiding one or more of phases of intelligence, design, and choice in decision making [57], facilitating problem solving, assisting with unstructured or semi-structured problems [58-59], providing expert guidance [60], and managing knowledge. Our discussion above raises additional issues pertinent to FDSS design with emphasis on overcoming inefficiencies such as bias, irrationality, sub-optimization, and over-simplification that underlie judgmental adjustments. Since a growing body of research is focusing attention on specific DSS features such as information presentation, model building and generation, and integration of dynamic knowledge, in this section we view DSS design from the

perspective of making directive and non-directive changes in forecaster behavior regarding application of adjustments. Such behavioral changes can be brought about in two ways: (a) by guiding and correcting forecaster behavior during task structuring and execution and (b) by encouraging evaluative analysis of decision processes through structured learning [61].

Our empirical research has raised two key observations related to forecaster behavior and implications for FSS design:

1. Forecasters will make adjustments to forecasts even when provided highly accurate forecasts. However, the direction and magnitude of these adjustments may be defined by complexity of the forecasting tasks. Considering this, FSS should offer system features in congruence with adjustment behaviors.
2. Design of FSS must necessarily factor in, and adapt to, forecasting task complexity.

Elaborating on these findings, we make several propositions for FSS design in the next few sections.

Design FSS that Adapt to Task Complexity

For years, DSS designers have proposed designing systems that adapt to decision makers [62-63] and align with their natural thinking. Adaptive DSS support judgment by adjusting to high level cognitive needs of decision makers, context of decision making, and task characteristics [64]. The FTTF framework proposed in this paper provides a task-based approach to such adaptive systems. As a time series is initially input into the FSS, automated feature detection routines can categorize time series along the simple to complex continuum. Task profiles gathered in this way could be used to customize levels of *restrictiveness* and *decisional guidance* for simple versus complex tasks.

Restrictiveness is the "degree to which, and the manner in which, a DSS limits its users' decision making process to a subset of all possible processes" [65, p. 52]. For example, a DSS may restrict access to certain data sets or ability to make judgmental inputs and adjustments to the system. Restrictiveness can be desirable when the intention is to limit harmful decision choices and interventions. However, general IS literature has largely recommended limited use of restrictive features

in DSS [1, 61, 65-66]. Excessive restrictiveness can result in user frustration and system disuse [65, 67]. It can also be difficult for the designer to determine *a-priori* which decision processes will be useful for a particular situation [1]. However, when users are poorly trained [1], known to make bad decision choices, or when underlying conditions are stable, restrictive DSS features can be beneficial.

Decisional guidance is "the degree to which, and the manner in which, a DSS guides its users in constructing and executing the decision-making processes by assisting them in choosing and using its operators" [65, p. 57]), can be informative or suggestive. *Informative guidance* provides factual and unbiased information such as visual or text based display of data thereby empowering the user to choose the best course of action. *Suggestive guidance*, on the other hand, recommends an ideal course of action to the user such as by comparing available methods and recommending the one deemed to be most suited to the task at hand. Also [1] provide an excellent and extensive review of decisional guidance features for FSS that we recommend highly. To complement their recommendations, in the next few paragraphs, we provide additional design guidelines emergent from the theme of this study.

1. *A.1 Restrict Where Harmful Judgment can be Applied:* When unrestricted, forecasters are free to apply adjustments at many levels in the forecasting process such as toward data to be used or excluded, models to be applied and those to be ignored, and changes to decision outcomes. Similarly, as we demonstrated in our Study 2 [52], inexperienced forecasters may attempt to overcome their limited knowledge of underlying decision processes by making adjustments to the final outcomes [1]. FSS can restrict where such judgmental adjustments are permitted. Specifically, judgment is best utilized as input into the forecasting process or within the context of a validated knowledge base rather than as an adjustment to the final decision outcome [55].
2. *A.2 Restrict FSS Display Based on Task Complexity:* Since complex tasks pose significant demands on human cognitive and information processing capabilities, FSS displays for such tasks can be restricted as opposed to simple tasks that can benefit from decisional guidance. Since simple tasks create lower cognitive strain, performance on such tasks can potentially be improved

by increasing user awareness of the forecasting cues such as by displaying features underlying the time series, generating processes, forecasts from alternative methods, and forecasting knowledge underlying the final forecasts. For instance, [49] found that making available the long-term trend of a time series improved forecaster accuracy since it allowed them to overlook distracting patterns and apply knowledge more consistently.

As decision makers have a tendency to trade off accuracy in favor of cost efficiency, *informative* and *suggestive* guidance could be displayed prominently such that the forecaster does not have to drill down to make such trade-off decisions [68]. However, this same information presented to the forecaster for complex tasks can result in greater information overload, cognitive strain, and over-reaction. Indeed, [69] confirm that in complex task settings, decision makers tended to ignore suggestive advice and focused on informative guidance. To reduce this cognitive load, several of the above discussed features could be hidden and made available as layered drill-down options. Such adaptive support can reduce information overload and related information processing challenges in the context of complex tasks [66], and is replicable across different contexts and organizational settings.

3. *A.3 Provide and Adapt Task Decomposition According to Task Complexity*: Individual decision maker's working memory is limited and consequently, complex tasks broken into simple "chunks" can be more effectively executed when compared to tasks not so simplified [12]. Cognitive overload may be avoided through effective and efficient design materials [44] ranging from better information presentation to providing greater structure to the learning environment [70] such as through use of decomposition strategies to simplify the subject domain. Decomposition is found to improve performance over unaided and intuitive judgment [71-72] by breaking down a complex, holistic task into a set of easier tasks which are more accurately executed than the more holistic task [1]. Others [73] also found that DSS users were able to leverage more information when they used decomposition for forecasting tasks. While there are neurological explanations for why decomposition is effective [74-75], from a psychological perspective, decomposition allows the decision maker to op-

timize the problem solving domain into manageable chunks so that information processing for each chunk can be minimal and relevant while cognitive overload is minimized [70, 76-77].

Although it can be argued that decomposition can be a restrictive DSS feature when its use is forced upon the decision maker [1], most often, a user may not focus on the benefits of decomposing a task or may not recognize how to proceed with decomposition. To this end, we suggest that decomposition be implemented in both restrictive and decisional guidance mode. Specifically, we use the framework by [12] who suggests that decomposition can be applied at three levels: *decomposition via transformation*, i.e. identifying characteristics of the forecasting task and domain; *decomposition for simplification*, i.e. understanding components of the forecasting process from problem formulation to forecast use (Armstrong, 2001 [2]); and *decomposition for method selection* i.e. applying forecasting knowledge and rules to selecting fitting methods. Herein, we propose *transformational decomposition* should be a restrictive feature in FSS. This decomposition of time series into its features can enhance forecaster ability to recognize meaningful patterns as opposed to random ones.

In the same vein, *simplification* of the problem domain could follow restrictive design by using the forecasting process presented in Figure 1 to design FSS modules. In such a design, then, the flow of activities presented in Figure 1 could be used to restrict more rapid convergence on forecast methods and use. In contrast, the evaluative component of this given process can lend itself to decisional guidance in numerous ways discussed later in this section. Decomposition by simplification can also be implemented by narrowing task demand for complex decisions. For instance, [49] recommend that forecasts should not be required for multiple time periods because forecasters tend to anchor long-term forecasts to short-term forecasts. Our data indirectly suggests that complex series generate higher errors and such anchoring and adjustment can compound errors across the long-term.

Finally, *decomposition for method selection* could largely be implemented as decisional guidance. Users may be prompted with forecasts from multiple relevant methods (selected using rules applied to time series features) to consider use of alternative methods and processes. Suggestive

guidance on how to proceed with method selection and combination could be useful for simple tasks.

As decision situations become complex, guidance may need to be modified to minimal levels as such situations are already characterized by information overload. Adding suggestive guidance to this mix can lead to the FSS itself complicating the decision situation. Forecasters may become increasingly frustrated with interventions from such guidance and consequently engage in deleterious decision making behaviors. These suggestions are supported by [69] who found that for highly complex tasks, subjects who were provided with suggestive guidance performed poorly at the task when compared to those who were provided informational guidance or no decision support. Specifically, we suggest that for complex tasks, informational guidance be provided such that users can determine best strategy on their own or ignore the additional information as desired.

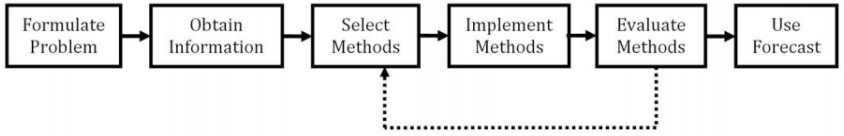


Figure 1: Components of the Forecasting Process as Presented in [2].

1. *A.4 Provide In-Task Feedback for Simple Tasks and Shift to Post-Task Feedback on Complex Tasks:* Feedback is intended to promote learning and behavior modification with the assumption that organizational practices encourage such review. Broadly speaking, evaluative feedback can be offered to forecasters at two stages – *during task execution* and *post task execution* – the former being critical to effective forecasting and the latter being beneficial for fostering reflection and learning [1]. Suggestive and informational feedback regarding impact of their current actions on other aspects of the forecasting environment may contain the extent to which a series of poor adjustments may be executed. However, feedback during execution of complex tasks can frustrate the user. Forecasters facing complex tasks may not have the time or cognitive resources to reflect adequately upon the impact of their adjustments on the environment [78] and consequently fail to consider control actions that can impact

the forecasting environment. Indeed, corrective process-based feedback has been found to be transient and shallow [79-80] and inadequately contributes to long term behavior modification [81].

To this end, FSS developers may primarily focus on post-execution feedback for complex tasks. Post-task feedback has been found to improve decision quality [82] and attainment of challenging goals [83], particularly when the feedback is informative [69]. Further, [1] suggest four forms of post-task feedback: *outcome feedback*, result of outcomes from the forecasting task; *performance feedback*, assessment of performance such as forecast accuracy; c*ognitive process feedback,* effectiveness of forecasting process deployed; *task properties feedback,* information about the task e.g. presence of conflicting underlying series. Considering that the intention of post-execution is to foster learning, holistic learning is possible for instance, by providing informative guidance on the above aspects complemented with the ability to drill down to the suggestive components, and may be most beneficial to forecasters.

Simple tasks, in contrast, do not require the same level of feedback and support as complex tasks. Moreover, these tasks are cognitively less demanding. Consequently, in-task feedback may not be detrimental and may be designed to provide the user with guidance such as by displaying features of the time series and discussing their impact on forecasts, providing original series contrasted with series that have been cleansed of distracting features such as outliers and irrelevant early data, and providing forecasting guidance in form of rules and relevant methods. As a case in point, RBF rules that pertain to a specific set of features present in the task being executed could be displayed such that the user can recognize the knowledge that has gone into generating the forecast.

2. *A.5 Restrict Data and Models According to Task Complexity:* Restrictiveness may be relaxed for simpler tasks by increasing the range of available data and models. FSS can shift to making some desirable processes easy to use while making other, less desirable alternatives, more difficult [1]. Automating and thereby simplifying the application of desirable strategies can serve to reduce the effort associated with executing the more desirable strategies [84] and thereby reduce the need for making damaging judgmental adjustments to the decision process [13].
3. *A.6 Restrict to Impose Standards and Best Practices:* Finally,

restrictions can be applied when certain organizational best practices and standards need to be applied in the forecasting process. For instance, a critical issue in supply chain forecasting is an escalation of forecasting adjustments as a forecast moves down the supply chain, thereby contributing to the bullwhip effect [85]. Embedding restraints in the forecasting system that contain the magnitude and directionality of adjustments may potentially reduce the risks associated with overcompensating for each element of the supply chain. This is particularly true for complex data where forecasters may overemphasize random patterns in the data or simple series where forecasters may want to overcompensate for seemingly aggressive forecasts. These restraints may be in the form of boundaries or confidence intervals which adapt to the nature of the complexity being presented to the forecaster.

Design FDSS to Increase Forecaster Confidence

Earlier, we discussed judgmental adjustments as a mechanism for forecasters to develop ownership of the forecasts. If FSS can be designed with features that enhance forecaster confidence in its abilities, possibly the compulsion to make judgmental adjustments may be mitigated. Most studies have focused on DSS use and satisfaction and suggested user attitudes towards DSS and their satisfaction with DSS as indicators of DSS use [86-87]. However, our concern in this paper extends beyond use since forecasters may use an FSS to generate forecasts and still make judgmental adjustments. Confidence in the system can be enhanced by making its abilities transparent to the forecaster by making the FDSS and its features fully disclosed [35]. Furthermore, a well validated FDSS that has demonstrated stability across time and multiple data sets can potentially improve confidence [88]. This validation is particularly simple to implement in FDSS due to the well-defined and universally accepted success measure, forecast accuracy. Confidence in an FDSS may also be enhanced by highlighting the credibility of knowledge underlying it. When transparent to forecasters, use of expert knowledge, empirically validated findings, and methodical calibrations can potentially enhance forecaster confidence in system abilities, and thereby mitigate the need for adjustments. Finally, user involvement in systems design and

development has been shown to increase user satisfaction with and commitment to the system and its outcomes [89-91]. For instance, [92] found that forecasters involved in defining features of the FSS such as display and models indicated greater satisfaction with FSS forecasts, even though their overall accuracy was lower than those who were constrained in their involvement.

Implications for Practical Design Research

In the sections above, we have offered numerous suggestions regarding FSS design. While some of these have been researched and validated, most require further research attention particularly in light of the simple-complex task classification that forms the foundation of our paper. To this end, we first suggest that our proposed task classification be tested on a broader time series base to (a) determine if the application of this framework is generalizable to a larger set of time series, and (b) whether the patterns of judgmental performance and adjustments we observed across the two studies [52] hold ground in a larger context. If our results are proven across a broader base, implications for FSS design are numerous in terms of recommendations addressed earlier.

Beyond confirmation of the FTTF framework, there are numerous opportunities for examining FSS design issues. Most importantly, our proposition has been that FSS should be designed to not only enhance forecaster support for task execution but also to promote effective behavior modification during and post execution. Such learning and modification will occur over long term system utilization, features supporting feedback and learning in FSS should occur early in the design process. This has implications for finding the ideal balance between restrictive and decisional guidance features and identifying the decision making stage to which these are best applied. As [69] suggest, increased decisional guidance during problem formulation can have an adverse effect on judgmental task performance but providing feedback at the right opportunity can improve performance. In response, much research is required to identify aspects of forecaster behavior that are amenable to behavior modification and those that are not, nature of desirable support, and stage of forecasting process where these support features are best applied.

SUMMARY AND CONCLUSIONS

The practical implications of our chapter are, indeed, numerous from the eight practical propositions to the six design FSS aspects regarding adaptations to Task Complexity and issues having to do with forecaster confidence. We summarize these here next. First, fitting technology support to task characteristics can provide a useful mechanism for identifying gaps between system functionality and user needs. Understanding task characteristics and corresponding support needs will enable FDSS designers to create systems that better suit and adapt to user needs. Second, a methodical integration of task and support technologies can lead to greater user commitment, thereby reducing forecaster's tendency to make deleterious *ad hoc* adjustments. Task-technology fit can enable identification of functions for which human intervention can be problematic and thereby restrict or guide selection towards improved choice [65, 93]. For instance, systems that complement limitations of human information processing (HIP) may improve decision maker performance [40] because they mitigate cognitive overload that constrains human performance on complex tasks [94]. Finally, a well-designed and optimally utilized FSS has a strong positive impact on individual performance and system adoption [20]. From an organizational perspective, this can have measurable positive implications for return on investments [95-96].

From a forecasting perspective, this study has yielded several insights to forecaster behavior and implications for FDSS design. We find that little has been done in the forecasting literature by way of developing a formal taxonomy for forecasting tasks. The principal reason for this is that a taxonomy for forecasting tasks essentially depends upon a codification of series complexity. We have endeavored to begin this classification work [52]. Our framework provides an initial attempt to do so in the domain of time series forecasting. Researchers in various other domains may find explorations of similar classifications to be beneficial in making recommendations for systems design in their own domains. Further, we find that forecasters' behaviors regarding direction and magnitude of these adjustments is impacted by complexity of the forecasting task, thereby underscoring the value of parsing out simple from complex tasks. Finally, considering the above contributions, we recommend the need for

congruence between system features and task features. Our research, in some aspects, is exploratory in nature and further work is required to solidify this research stream.

Table A.

Feature	**Description and Implementation as in C&A**	**Operationalization**
Coefficient of Variation (CV)	Standard deviation divided by the mean for the trend adjusted data.	Automatic identification - C&A
Regression T-Statistic (T-Stat)	The t-statistic for linear regression. If T-statistic is greater than abs(2), the series is classified as having a significant basic trend.	Automatic identification - C&A
Functional Form (FF)	Expected pattern of the trend of the series. Can be multiplicative or additive.	Judgmental identification - C&A*
Basic Trend (BT)	Direction of trend after fitting linear regression to past data.	Automatic identification - C&A
Recent Trend (RT)	The direction of trend that results from fitting Holt's to past data.	Automatic identification - C&A
Near a Previous Extreme (Ext.)	A last observation that is 90% more than the highest or 110% lower than lowest observation.	Automatic identification - C&A
Outliers (Out.)	Isolated observation near a 2 std. deviation band of linear regress.	Automatic identification - C&A
Recent Run Not Long (RR)	The last six period-to-period movements are not in same direction.	Judgmental identification - C&A
Changing Basic Trend (CB)	Underlying trend that is changing over the long run.	Judgmental identification - C&A*
Irrelevant Early Data (Irr.)	Early portion of the series results from a substantially different underlying process.	Judgmental identification - C&A
Unusual Last Observation (ULO)	Last observation deviates substantially from previous data.	Judgmental identification - C&A*
Suspicious Pattern (Sus.)	Series that show a substantial change in recent pattern.	Judgmental identification - C&A

Level Discontinuities (LD)	Changes in the level of the series (steps)	Judgmental identification - C&A*
Causal Forces (CF)	The net directional effect of the principal factors acting on the series. *Growth* exerts an upward force. *Decay* exerts a downward force. *Supporting* forces push in direction of historical trend. *Opposing* forces work against the trend. *Regressing* forces work towards a mean. When uncertain, forces should be *unknown*.	Judgmental identification - C&A
Trend Conflict (TC)	If recent trend conflicts with causal forces, e.g. recent trend is growing while causal forces are decay, then a trend conflict is flagged.	Judgmental assessment for this study
Trend Variation (TV)	Standard deviation divided by the mean for the trend adjusted data. If coefficient is >0.2, the series is flagged as being uncertain.	Automatic identification - C&A

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CHAPTER 8

ADVANTAGES OF FUZZY CONTROL WHILE DEALING WITH COMPLEX/UNKNOWN MODEL DYNAMICS: A QUADCOPTER EXAMPLE

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ABSTRACT

Commonly, complex and uncertain plants cannot be faced through well-known linear approaches. Most of the time, complex controllers are needed to attain expected stability and robustness; however, they usually lack a simple design methodology and their actual implementation is difficult (if not impossible). Fuzzy logic control is an intelligent technique which, on its basis, allows the translation from logic statements to a nonlinear mapping. Although it has been proven to effectively deal with complex plants, many recent studies have moved away from the basic premise of linguistic interpretability. In this work, a simple fuzzy controller is designed in a clear way, privileging design easiness and logical consistency of linguistic operators. It is simulated together to a

nonlinear model of a quadcopter with added actuators variability, so the robust operation of the controller is also proven. Uneven gain, bandwidth, and time-delay variations are applied among quadcopter's motors, so the simulations results enclose those characteristics which could be found in reality. As those variations can be related to actuators' performance, an analysis can be driven in terms of the features which are not commonly included in mathematical models like power electronics drives or electric machinery. These considerations may shorten the gap between simulation and actual implementation of the fuzzy controller. Briefly, this chapter presents a simple fuzzy controller which deals with a quadcopter plant as a first approach to intelligent control.

Keywords: Fuzzy control, intelligent control, quadcopter, robust control, simulated uncertainty, artificial intelligence, non-parametric variability

INTRODUCTION

Power electronics systems are commonly comprised of nonlinear time-varying components which impose an overall complex dynamic behavior. As these systems are commonly integrated together as actuators with electric machinery or other transducers, the resulting plants are hard to analyze, model, and control. As linear models and linear controllers have been thoroughly studied, linear approximations to such systems are desired. However, such simplifications omit some important features of the physical media and lead to higher controller burdens or impossible realization [1]. Consequently, power electronic systems in plants are dealt with using three main methods: (1) facing their complexity by using difficult approaches, (2) simplifying their features and constraining controller design, or (3) finding nonparametric models which approximately capture the system behavior.

As control specifications cannot be followed by traditional controllers, artificial intelligence (AI) can be incorporated to the control strategy to achieve higher goals [2]. AI is a set of computational techniques which try to imitate human brain processing or practices found in nature to solve a given problem. For control systems, these methodologies can provide acceptable, or even improved, performance based on any amount

of previous knowledge [3]. The increased usage of AI and its increased acceptance are mostly due to some important characteristics. Firstly, they can deal with uncertainty [4] as they can be adapted to a system's variations, sensor noise, or be defined in an uncertain manner [1]. Secondly, they are versatile, so mixed methods involving two or more AI techniques and traditional methods are readily found in literature as pointed in [2, 5, 6]. Finally, they are general, so their application to different case studies is possible and facilitates their continuous improvement. They have been proven to work properly as a direct substitution for linear controllers (as pointed in [7] on fuzzy systems) and as effective alternatives for controlling nonlinear, and uncertain plants [8].

Fuzzy systems (FS) compose one major part of the intelligent control spectrum. They are based on fuzzy logic first proposed by Zadeh [9], which expands set theory in such a way that an element can belong to a set with some membership value, instead of the traditional binary belongingness of "true" or "false". Although fuzzy control will be later discussed in detail, it is worth mentioning that it provides a way to deal with uncertainty through linguistic "elastic" categories and logic inferential rules. Narrowing the distance from human logic to numerical implementation has permitted control systems to be defined in terms of linguistic control rules from experts [6]. This is possible as fuzzy logic control (FLC) specifically converts linguistic rules into a nonlinear mapping [10], allowing dynamic modeling and controller description to be done as simple linguistic statements. The previously presented point of view related to designer experience represents only the most basic approach to FLC; however, it stands as an effective control technique which requires little knowledge about the plant [10, 11].

There are more specific reasons why FLC can be preferred over or together with traditional techniques. Linder and Shafai [12] specify that a quantitative controller's refinement tuning cannot be properly performed, as there is no guidance on the meaning of each parameter. They specify that the controller's refinement tuning can be properly executed when the controller is built over linguistic rules that preserve their actual meaning. They also say that achieving a quantitative control of nonlinear systems is difficult and not quite realizable. This last statement is confirmed by Precup and Preitl [7] who use a model-based FLC constrained by H-norms. FLC can be implemented despite the complexity as commented

by Khan et al. [13] who presented a fuzzy controller tuned through genetic algorithms: "*...the unnecessary mathematical rigorosity, preciseness and accuracy involved with the design of the controllers have been a major drawback*". They show that if FLC cannot cope with specific desired controller characteristics, there are intelligent ways in which the controller can be tuned, avoiding experts' possible limitations and preserving interpretability. There is no intention from the authors of this chapter to discredit advanced traditional control techniques; however, there are many works which point to real benefits of using intelligent control.

FLC has suffered of criticism for lacking a systematic design approach and a stability analysis method; in addition, the high cost of setting up a FLC as a replacement of an industrial standard PID has discouraged its usage [10]. The PID controller has been used not only as a standard controller but also as a reference for comparison when it comes to evaluating a controller's performance. Most control designers are familiar with PID, which is taken as an easy alternative and a starting point when facing a given plant. The familiarity to PID controller, its known performance, and its relative implementation feasibility have obscured some of the clear benefits of FLC. Nevertheless, Nithya et al. [14] shows that FLC exhibits an improved performance over PID controllers when dealing with first-order plus dead time systems; Gupta et al. [11] remark that nonlinear characteristics make PID unsuitable while intelligent control can cope with control specifications; and Linder and Shafai [12] and Kalavathi and Reddy [6] say that FLC greatly outperforms PI/PID controllers. In some cases, FLC is becoming an immediate choice when dealing with nonlinear, time-delayed, and high-order systems [15]; parameter variance has also been properly tackled by FLC [7]. Altogether, it is accepted as a better alternative than its PID counterpart [4]. As said by Precup and Preitl about fuzzy control: "*The use of linguistic rules and approximate reasoning is a simple and easy way to solve concrete control problems. Sophisticated models and control design tools are not necessary. It is sometimes the only way to begin to approach the control of a complex, uncertain, or ill-defined plant*" [7].

Some efforts have also been made to expand FLC application by finding similarities to traditional controllers, providing model-based approaches, integrating with other traditional/intelligent techniques, and incorporating

features like adaptability to FLCs. Some examples of the aforementioned directions can be found in works like [2] where the equivalence of a FLC with a PID controller together with a relay is explained. Self-regulated fuzzy controllers which incorporate adaptability are also found in the literature as in [4], and robustness enhancement has been achieved by merging fuzzy logic with sliding-mode control as presented in [16] and by Feng [10] who presents a survey on model-based FLC. However, FLC is known as a robust alternative on its own merits [5]. Measuring noise can be incorporated directly if FLC is designed based on type-2 fuzzy logic [1], and simple applications are possible in industrial standard controllers as reported in [4] where an OMRON PLC is used.

Fuzzy logic, as a fundamental part of intelligent control, can face complex systems with relative ease, still providing robustness and logical interpretability. Quadcopters are a great example of such systems which integrate uncertainty and parameter variability, electric machinery, and power electronics; due to their nature, they seem as a good test-bench to evaluate FLC performance. Quadcopters have gained some field in the research area as they are particularly well suited for unmanned tasks such as search and rescue, surveillance, remote inspection, and as military units [17]. These tasks involve parameters which are not easily obtained or estimated, and can result in uncertain modeling ([17, 18]) which must be alleviated by dependable controllers. Altogether, quadcopters represent a challenge for control designers nowadays [16].

Most of the time, mathematical models cannot fully represent the physical reality of a given plant, and in the case of quadcopters, the inner processing, power electronics, and electric machinery are often assumed not to impose restrictions to system performance. Actually, the quadcopter's motor information is normally unknown, so approximation techniques are needed as in [17]; their response to input desired values is normally assumed to be immediate, repeatable, and reliable even when complete studies about BLDC motors have shown the opposite as in [11]. All aforementioned subsystems are complex and would need a deep mathematical analysis to provide valid simulated results when integrated. Achtelik et al. [18] propose a non-intelligent controller and specifically say that quadcopter modeling must avoid simplifications like linearization and that algorithms must be exact as the update rates of processing units are low. Li and Song [5] also identify the overall quality

of the model as problematic for control design. Actual implementation also requires the measured data to be "clean," and sometimes redundancy is recommended as noise is unavoidable [19]. It is quite obvious that no control technique will tackle all of these problems at once due to increased complexity; however, model simplification together with uncertainty considerations could lead to a valid solution focusing on robustness against model uncertainties and sensors noise.

In this spirit, many works have simulated, tested, and compared traditional simple, complex, and intelligent techniques over quadcopter devices and models. A short survey about non-intelligent control techniques applied to quadcopters was presented by Li and Song [5] specifically covering the PID, LQR, H, sliding-mode, feedback linearization, adaptive control, and backstepping techniques, presenting their individual benefits and drawbacks. An adaptable controller based on a real-time quadcopter model was tested by Achtelik et al. [18] showing great performance even with complete parametric ignorance; Mirzaei et al. [16] present a fuzzy indirect adaptive sliding-mode controller which provide robust performance toward noise and plant uncertainties.

It is not the main aim of this chapter to present a novel control technique or to solve all aforementioned issues regarding quadcopter control, but to test the effectiveness of simple FLC to face this complex plant, focusing on the effects of assuming quadcopter's subsystems to be non-ideal. As most traditional simple controllers require assumptions about the specific quadcopter dynamics, or limitations on the controllers to provide a mostly hovering behavior, the approach of this work is to show how linguistic interpretability can cope with less conservative control specifications while ensuring a certain amount of inherent robustness. For this purpose, a fuzzy controller will be designed and simulated together with an ideal quadcopter model so that a robustness comparison can be made later, when the processing unit, power electronics, and electric machinery are assumed to incur a time delay and parametric variance. This analysis provides some insight to the "natural" benefits of intelligent control and its great potential to confront complex scenarios (besides its criticized heuristic approach), while presenting a simple and effective way to deal with quadcopter dynamics with some commentary facing actual implementation of the controller.

Nevertheless, fuzzy control has also been used from more formal points of view which consider model-dependency, self-tuning, stability analysis, hybrid methodologies, etc. Chen et al. [20] present some major ways to incorporate FLC on robust control study area; Li and Ruan [4] show a very simple way to provide adaptability to a FLC, while Li et al. [2] provide adaptability to a PID controller through fuzzy logic and Chen et al. [21] to a smith predictor. Complex systems can also be modeled through Takagi-Sugeno (TS) fuzzy models [10] and some plants have been controlled by TS controllers and TS observers as shown in [3]. TS fuzzy systems are also behind gain scheduling topologies like those presented in [7] and [22]. Other intelligent techniques can be incorporated to enhance the design process, as in [13] where genetic algorithms are used to tune the FLC to guarantee optimal performance. Gupta et al. [11] show how FLC has been merged with artificial neural networks and traditional PID controllers to control BLDC motors. Lastly, Nithya et al. [14] show tuning schemes, auto-tuning, and model-based tuning FLC for first-order plus dead time models (FOPDT) in their cited literature; they propose a simple Mamdani FLC to deal with these kinds of systems.

We will use a Mamdani FLC which is opportunely simplistic in nature. It shows how it is adequate to take one of the simplest fuzzy topologies to deal with a complex (and current) plant, and it shows how the control design methodologies can come from basic logic premises. The simple FLC has been improved in many ways, so the perspective shown in this work should be taken as a starting point and as a sufficient statement to favor the usage of intelligent controllers alone or together with other techniques.

FUZZY LOGIC CONTROL

Fuzzy logic first intent as expressed by Zadeh [9] was to solve a membership problem. Including elements into a labeled set can be easy and straightforward as long as those elements can be clearly identified as members of the set. However, there will be some elements whose membership is ambiguous or unclear. The real issue here is that a label assigned to a set includes a meaning, subjected to human interpretation. Height measurements will not be easily classified in labeled sets as “Tall”, “Medium”, and “Short” because there is not a clear boundary

between them, and their meaning is also subject to the experience and context of who interprets it. Consequently, crisp elements such as height measurements can belong to more than one set. Their membership should not be binary (true/false), but fuzzy [0, 1], representing how much an element belongs to each set attached to a particular linguistic meaning. The membership value of an element can be assigned depending on any kind of considerations regarding its relation to the set's label; a common way to manage it is assigning a membership functionμ $\mu(x) \in [0, 1]; x \in X$ where X where X represents the universe of discourse of the measured variable. A different interpretation involves the set boundaries which, when fuzzy, can be told to be "elastic" [23]. It is similar to a blurry zone where included elements can still explain the set's meaning to some extent.

The usual language used to describe fuzzy sets has led to many misconceptions which have obscured its acceptance and usage. As said by Zadeh [24] "*…fuzzy logic is not fuzzy. Fuzzy logic is precise. Basically, fuzzy logic is a precise logic of imprecision.*" In this way, applying fuzzy logic to a control problem permits the designer to make precise decisions about imprecise data. As variables are not forcefully fitted into crisp sets, the consequences of wrong classification are minimized, so it alleviates problems due to noise, disturbance, and overall uncertainty. As fuzzy logic appeals to human reasoning, a mathematical approach will difficultly find its way to describe it. This makes FLC to seem heuristic and restrictive. As this problem has been mitigated due to the research efforts made during the past 30 years, fuzzy logic acceptance on various computer and control science areas keeps growing and expanding the potential of current proposed solutions.

A standard representation of fuzzy sets is done through membership functions mapped on a n-dimensional space, where (n−1) dimensions are devoted to elements' measured features and one extra dimension to depict their membership toward a given set. For elements described by only one feature, a 2-D mapping as shown in Figure 1 can be used. A fuzzy set is told to be standard whenever it is described by a normalized (with values ranging [0, 1]), convex membership function. Most commonly used shapes for membership functions are piecewise linear (triangular, trapezoidal) and continuous (sigmoid, polynomial, and Gaussian). There

are some works devoted to test and compare fuzzy systems built with different types of membership functions which try to elucidate the benefits and drawbacks of each one. Actually, there is not an "ultimate function" to describe memberships. Fuzzy systems are commonly very problem-dependent, and the main objective of placing a given problem in a fuzzy manner (at least for a non-model-based perspective) is to benefit from its uncertainty treatment and its linguistic inference relations. Both of the uncertainty treatment and linguistic inference relations are independent of the shape used.

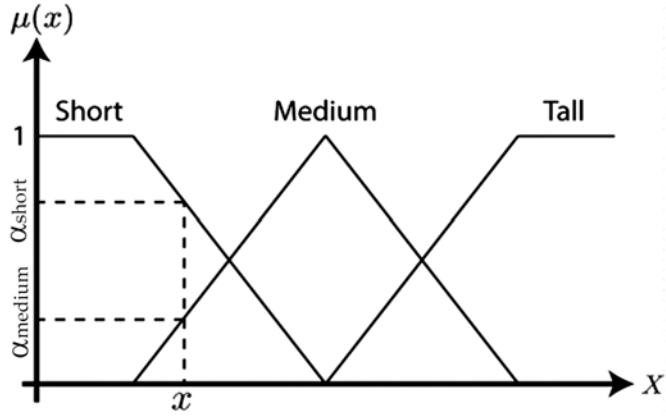


Figure 1: Standard representation of fuzzy sets.

A fuzzy inference system (the foundation of FLC) describes a relation between causes and consequences which follow from the inferential relation of (*n*-dimensional) input and output concepts. Each concept can be represented by a fuzzy set over a measurable feature in such a way that each input element is related to an output one, so a mapping is derived from linguistic rules. The linguistic rules have the following general form of an implication: $if\ x_1\ is\ A_i^1,\ \ x_2\ is\ A_j^2,\ \ \ldots AND\ x_n\ is\ A_k^n,\ \ then\ C_p^1,\ \ C_p^2,\ \ \ldots AND\ C_r^m\ are\ true.$ The preceding statement considers *n* input elements *x* classified over their own universe of discourse, each separated by any number of labeled sets A. On the other hand, there are *m* outputs, each containing any number of consequences of the statement. As a practical example, a statement about quadcopter control can be as follows: If "altitude" is "normal" and "z-direction" is "falling", then "motor1 speed" is set to "increase", "motor2 speed" is set to "increase", "motor3 speed" is set to "increase",

and "motor4 speed" is set to "increase". It is noteworthy that any amount of inputs and outputs can be incorporated to a fuzzy inference system, and depending on the desired precision, fuzzy sets can be added or removed from a specific universe of discourse, e.g., adding "rapidly falling" and "slowly falling" to "z-direction", or "increase a lot" to "motor speed". A figure showing the general scheme of fuzzy inference is shown in Figure 2.

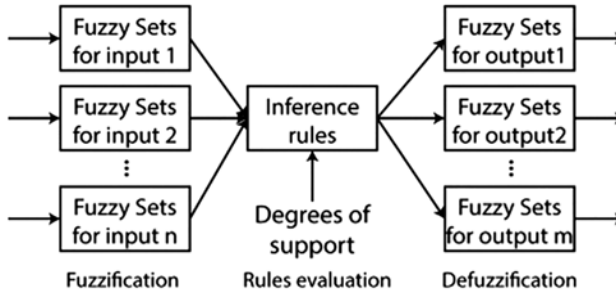


Figure 2: Standard Mamdani inference system.

A fuzzy inference system should never be seen as a set of binary conditionals. Many rules can activate at once (since set boundaries are not crisp, but fuzzy) with an individual rule-strength dependent on the membership values of each element to the labeled sets which compose the rule. A more adequate conceptual approach to fuzzy inference systems is understanding them as a nonlinear overlapping (blending, merging, weighing) of binary conditionals which result in a combined consequence. FLCs are fuzzy inference systems which commonly take the close-loop error as their input and provide a control signal as their output. The first approach of fuzzy logic to a control problem was developed by Mamdani [25] who controlled a steam engine by building the fuzzy inference machine, considering the output consequences to also be fuzzy sets. If consequences are also fuzzy sets, the general statement presented above implies that the control signal, found over a finite universe of discourse, will be also separated by fuzzy sets with meaningful labels. A FLC using this particular perspective about the controller outputs is normally referred as Mamdani-type fuzzy controller. Even if the actual numerical solution for a Mamdani FLC has not been given yet, there is one feature of this type of controllers which has no evident solution: the

controller output should not be a fuzzy set, so how can a crisp value be obtained from a fuzzy inference process?

Before answering the previous question, there is one different approach to look at which needs no fuzzy-crisp output conversion. When consequences are not fuzzy sets, but actual mathematical functions, the FLC is called to be of Takagi-Sugeno-type (TS), referring to the work of Takagi and Sugeno [26] who proposed this approach. Whenever the consequences are defined in this way, the whole FLC will work as a weighted nonlinear blending of those functions. The functions can grow in complexity from a simple constant to a dynamic model, so a TS-FLC is more general than a Mamdani one. It also expands fuzzy systems' potential as they could now perform gain-scheduling controllers or build fuzzy models for dynamic nonlinear systems, for example. Although a TS-FLC seems to absolutely outperform a Mamdani controller, it lacks of full linguistic interpretability. In consequence, the fine tuning of such a controller cannot be performed in terms of logical assumptions, and its construction would limit the fuzzy logic potential (in terms of artificial reasoning).

Flc Algorithm

As noted in the preceding description, most of the inference process can be assumed transparently. However, conversion between crisp and fuzzy variables has yet to be discussed. There are various valid ways to perform such conversion; still, the standard approach will be presented in a more formal manner. Any Mamdani controller will require three steps in the inference process: fuzzification, rules evaluation, and defuzzification as shown in Figure 2. The fuzzification process implies the conversion of crisp input values to fuzzy ones. Fuzzy values are obtained after evaluating the membership of a crisp value to all of the sets pertaining to its universe of discourse. All resulting values are important as they determine how strongly each rule should be executed. If more than one input is considered, there will be AND or OR operators along the inference rules' antecedents, so the evaluated membership of each input must be taken into account properly. Formally, for a universe of discourse where n fuzzy sets have been defined, the membership of an input

value x to the sets can be written as $\mu_{A_i}(x) \in [0, 1]; i = 1, 2, \ldots, n$. Commonly, μ_{A_i} can be used as a shortcut to express the membership value of a given input to the set A_i.

The rules evaluation is the core of inferential reasoning and it needs the values obtained in the previous step to correctly weight all of the rules in order to provide a logical response. Whenever a rule considers only one input, its triggering strength will be μ_{A_i} without any doubt. However, for rules with multiple inputs, there must exist some way to evaluate an AND operator for fuzzy values that are non-binary (OR operator can also be used, although it is not discussed in the present work). The different ways of determining the overall strengths of causes of inference rules are called "implication methods," and the work of Zhu et al. [27] can be reviewed for more details.

There are two main ways of evaluating the AND operator in fuzzy rules' antecedents. The first approach implies calculating the minimum of all the membership functions involved in the rule causes so $\mu_{A_i} AND \mu_{B_j} = \min(\mu_{A_i}, \mu_{B_j})$. The second approach uses the product of all rule causes as $\mu_{A_i} AND \mu_{B_j} = \mu_{A_i} \mu_{B_j}$. Both approaches are conceptually similar and their usage is mostly designer-dependent as there are no drastic differences between them. It is worthwhile to mention that the purpose of a binary AND operator is to provide a true output only when all its inputs are true. As inputs' validity is not absolute, but graded, both aforementioned methods provide a similar behavior. If only two inputs are being evaluated, the result of the AND operator will be totally true if and only if both inputs are totally true; whenever any of the two inputs is totally false, the AND result will be totally false. For all of the cases in-between, i.e., (0, 1), the resulting validity will be decimated depending on how false the inputs are.

The cogency of the rule's consequences will be as much as the result of the operated inputs, which determine the overall rule strength. So, each rule will output a certain set of weights related to a set of consequences. It is easy to see from this point that different rules can output different weights for a single consequence, so a way to solve this issue is needed. The fundamental principle behind consequences aggregation is that it

must satisfy all the rules which required it as an implication output. A simple approach would lead to take the maximum strength among the rules as it will surpass all needed values. From a different perspective, the aggregation can be seen as the sum of all related rules, limited to always be lesser or equal to one.

Lastly, the rules can be also weighted in terms of their importance to the problem. This is an additional weighting value called degree of support and is defined in a closed interval [0, 1]. Each rule can then be heuristically highlighted or obscured as desired. Actually, the tuning process can be based on the selection of proper degrees of support. Each consequence (fuzzy sets in this case) should be then lowered to meet the obtained overall weight. This process can be commonly driven in two different ways. The minimum method trims the membership function of the set by applying $\mu_{C_i} := \min(\mu_{C_i}(x), r_j) \forall\, x \in X$, where C_i is the consequent fuzzy set and r_j is the resulting overall strength, also called alpha-cut. The product method reduces the magnitude of the set by means of simple arithmetic, so $\mu_{C_i}(x) := r_j \mu_{C_i}$. Finally, the rule evaluation process can be divided in to three substeps: antecedents evaluation, which determines the rule strength due to inputs; rule implication, which logically links the antecedents to the consequences and adds the degree of support; consequences aggregation, which finally sets the overall rule strength and lowers the output sets. For the purposes pursued in terms of fuzzy implication, the resulting weighted consequences' union is the fuzzy output itself: A complex fuzzy set which represents the combination of all rules subjected to all inputs called the aggregated output fuzzy set. However, a controller cannot output a fuzzy set as a valid control signal, so an additional step is needed.

The conversion from a fuzzy set to a crisp value is commonly known as defuzzification. The most popular method used is the Centroid Calculation Method, which obtains a geometrical centre of the aggregated output fuzzy set with respect to the output universe of discourse. It is easy to find a conceptual support for this method as the whole output set represents all the values that are a valid output of the inference system, together with a measure of how possible it is they are the right output (their membership degree). The centroid method will find the weighted average of all of outputs' possible values in terms of their resulting

membership. Consequently, it will find the set's prototype value (a single value which effectively represents the whole set). The computation of this method is not different from a centre of mass calculation as shown in (1).

$$f(y) = \frac{\sum_{i=1}^{n} \mu_C(y_i) y_i}{\sum_{i=1}^{n} \mu_C(y_i)} \quad (1)$$

As can be noted above, the whole fuzzy inference system can effectively output a crisp value based on logic statements. The membership functions assigned to each set should effectively represent its meaning to guarantee that the process is consistent with reality or expected performance. Membership functions can be built in many different ways based on linguistic approaches, heuristic considerations, statistical consistency of data, or intelligently with the aid of an additional technique. Altogether, the adjustment of the design parameters presented above leads to a common tuning concept for fuzzy controllers. The number of sets to describe each universe of discourse, their membership functions, the rules assignments together with the methods chosen to evaluate the antecedents and consequences, the degree of support of each rule, and the defuzzification phase are variable parameters which lead to different performances (Fateh [8] shows the predominance of membership function shapes in tuning variations). Adjusting all these parameters in an analytical way or by an automatic process is very difficult, which somehow reduces FLCs acceptance, and their comparison and analysis potentials. Nonetheless, while a human logic-based approach to fuzzy tuning may be heuristic, it would effectively collect the desired features and specifications in a much easier way if compared with traditional approaches. "*Fuzzy control's main intent is to implement symbolic, linguistic control laws based on qualitative models of the plant, and control behaviours*" [12].

It is worthwhile to mention that a TS-FLC algorithm would follow almost the same steps, but will avoid the defuzzification process as its outputs are fully determined as functions. As functions are easier to manipulate through traditional mathematical well-known techniques, TS-FLCs are predominant in today's research trends and many hybrid techniques have been proposed to design, analyze, model, and tune TS-FLC ([4, 7, 6, 10]). On the other hand, improvements to the presented Mamdani's algorithm

have been also proposed. For example, Li and Ruan [4] propose a way for the controller to find the inference rules automatically and Kahn et al. [13] fully tune a Mamdani controller by using genetic algorithms.

QUADCOPTER MODEL

Quadcopters have built up much interest in recent years due to their physical characteristics and what their features allow them to do. As stated by Achtelik et al. [18], they can accomplish a range of tasks, including search and rescue, industrial inspection and observation, navigation and sensor data collection, and applications in the field of education and research. Additionally, they have virtually no legal requirements, and require minimal time and effort to begin a test or flight. We chose to analyze quadcopters because of the range of applications they contain, and because they allow us to show how a complicated multivariable nonlinear system (the quadcopter model) can be controlled by simple fuzzy logic to produce a valid output.

There are many physical variables involved in quadcopters' flight that make them mathematically complex. They are classified as unmanned aerial vehicles (UAV) and as vertical take-off and landing (VTOL) devices. Their movement depends only on four vertical throttle forces whose individual variations and overall momentum conservation can determine the six degrees of freedom (DOFs) which rule any quadcopter [11]. The control design for this device is complicated, as it is for most of flying robots. A quadcopter is an under-actuated system subjected to big dynamic changes related to little parametric variations.

The quadcopter is controlled by changing the rotation speed of the propellers, where two of the propellers are spinning clockwise (CW) and two counterclockwise (CCW). The angular momentum is balanced in all axes if all of the propellers are spinning at the same speed, due to the CW and CCW spinning propellers' counteraction. To rotate about the vertical axis (yaw), for example, the CW spinning propellers are decelerated and the CCW spinning propellers are accelerated. Keeping the overall thrust constant, the quadcopter will turn right as a result of changing angular momentum. The cross (pitch) axis and the front (roll) axis are not affected because the CW and CCW spinning propellers are mounted on opposite

sides. To rotate about the roll axis to the left side, for example, the right-side motors are sped up and the left-side motors are slowed down. Yaw is unaffected because of the balanced angular momentum about that axis. Accelerating or decelerating all motors equally results in ascending and descending, respectively, without affecting the pitch, roll, or yaw [18].

Because the quadcopter is complex and it is an under-actuated non-holonomic aircraft with fewer degrees of freedom than control variables, it is essential to simplify and extract the essential factors to create a kinematic model. Moreover, controlling this vehicle requires complex control algorithms, since the six degrees of freedom must be controlled only by four parallel force inputs [17].

The quadcopter model has many limitations that demand more precise control methods. While the model may roughly simulate the motion of the quadcopter, it is under-actuated, nonlinear, strongly coupled, and statically unstable. The model leaves air resistance, body gravity, driving force of propellers, and gyro force up to estimations by constants. This creates uncertainty in the model, which increases the difficulty in designing an accurate controller. Some components even lag or have delays while in use [5]. Additionally, quadcopters are typically propelled by brushless DC motors together with power electronics drivers, which are complicated to model. As a result, the model fails to account for the motor constants correctly [17]. These factors cause problems in modeling, as brushless DC motors, for example, are multivariable and nonlinear systems, where speed and position sensing of traditional machines with Permanent Magnet Brushless DC motors require a high degree of accuracy [11].

In a traditional model, all motor parameters would need to be detailed, making the model infeasible to replicate. In order to tackle power electronics and electric machinery uncertain and unknown behavior, a robust technique is needed. Given the limitations, an approximated non-parametric model which accounts for time-delays, bandwidth variations, and gain uncertainties was used as an alternative together with a quadcopter traditional model. In addition, we use fuzzy logic with heuristic input-output relations to handle these vague and complex situations.

Quadcopter Model

The specific kinematic model equations we will use in conjunction with fuzzy algorithms are from (2) to (7). A reference figure for equations consistency is shown in Figure 3.

$$m\ddot{x} = -k\sum_{i=1}^{4}\omega_i^2 \sin\theta\cos\phi - B_x\dot{x}\left|\sin\theta\cos\phi\right| \tag{2}$$

$$m\ddot{y} = -k\sum_{i=1}^{4}\omega_i^2 \sin\phi\cos\theta - B_y\dot{y}\left|\sin\phi\cos\theta\right| \tag{3}$$

$$m\ddot{z} = k\sum_{i=1}^{4}\omega_i^2 \cos\theta\cos\phi - mg - B_z\dot{z}\left|\cos\theta\cos\phi\right| \tag{4}$$

$$I_L\ddot{\theta} = -B_\theta\dot{\theta} + kl\left(\omega_1^2 - \omega_3^2 - \omega_2^2 + \omega_4^2\right)\cos\pi/4 \tag{5}$$

$$I_L\ddot{\phi} = -B_\phi\dot{\phi} + kl\left(\omega_1^2 - \omega_3^2 + \omega_2^2 - \omega_4^2\right)\cos\pi/4 \tag{6}$$

$$I_Z\ddot{\psi} = -B_\psi\dot{\psi} + b\left(-\omega_1^2 - \omega_3^2 + \omega_2^2 + \omega_4^2\right) + I_M\left(-\dot{\omega}_1 - \dot{\omega}_3 + \dot{\omega}_2 + \dot{\omega}_4\right) \tag{7}$$

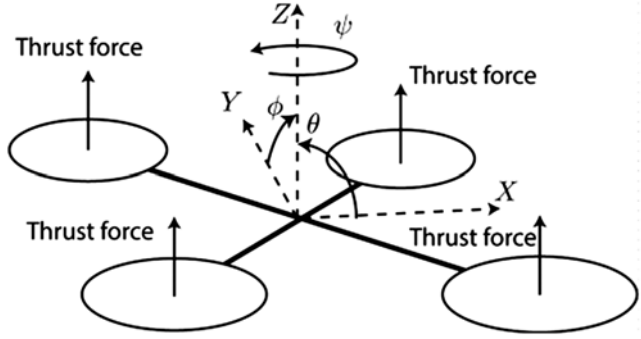


Figure 3: Quadcopter with its own reference frame.

where mm is the total mass of the system, ll represents the length of the arms, and each propeller speed is represented as ω_i and k is the lift constant. I_L stands for the moment of inertia of X and Y axes while I_Z is the moment of inertia with respect to the Z axis. The values B_i reprepresent the air-drag i direction, bb is the torque drag, and g stands for gravity. Please notice that all equations are given in terms of the quadcopter's reference frame so a tilt on the θ direction will directly modify the X axis. The model has not been referenced to ground as additional complexity

would be added to the model without really aggregating dynamical reality. As the model could be later referenced to earth by simple trigonometric operations, this step is omitted in this work.

TESTING VARIABILITY

The presented quadcopter model represents a perfect model of how it would respond if the motor constants, air drag, and other variables were estimated exactly. However, a perfect model does not provide a valid representation of the motion of a real nonlinear system. As noted in the aforementioned text, we deal with lots of uncertainty in which the expected model deviates from the actual behavior of the system. Regarding the quadcopter system, many components exist in lag or delays while in actual use, which contributes to the deviation from the model [5]. Aspects like motor torque and rotational speeds and thrust of the motors vary to some degree and are averaged using test bench data, despite being unequal for each motor [18]. Other methods have also been implemented to counter or reduce uncertainty in systems.

One plain way of battling uncertainty is through proportional-integral-derivative controllers (PID). They are commonly used and useful in control theory and technology because they perform well for a wide class of processes. They give robust performance for specific operating conditions, and are easy to implement with analog or digital hardware, not to mention they are very familiar to engineers. However, plants that have time delays cannot be controlled effectively by a simple PID controller. Fuzzy logic controllers outperform PID controllers because they have no integral accumulator to increase the error of the naturally delayed system [14].

The nonlinearities of a quadcopter, and even of a quadcopter model, are hard to control for a PID as it is a linear controller in nature. Any linear control will be only capable of providing linear control commands to nonlinear error variations, so its reach cannot be extended to the whole operating space of a given plant. Consequently, using a linear controller over a quadcopter will restrict the system to maintaining a smooth hovering undisturbed flight. An additional drawback is that different linear controllers will be needed, as a single tuning will not suffice

parametric inequalities among similar components of the quadcopter. This kind of consideration also increases the gap between simulation and actual implementation.

In order to face the difficulties exposed so far, the derived quadcopter model has not ignored relevant physical details apart from environmental wind speed and possible static parametric variations. Such uncertainty has a bigger impact if present at the propellers because controller's outputs are commonly given as thrust commands, assuming infinite bandwidth and no delay. As explained earlier, the on-board sensors and processing unit, the power electronics driver, and the electric machinery composing each propeller should not be simulated. Incorporating a precise simulation of such elements would immensely increase model's complexity, resulting on an infeasible testbed. Consequently, a simplified model of the propeller is needed which still incorporates time delay, limited bandwidth, and non-ideal gain. In order to account for this deviation and represent uncertainties, we propose using a First-Order Plus Dead Time (FOPDT) model to make the quadcopter simulation more realistic and non-ideal. In addition, a statistical variation of FOPDT parameters can be simulated so the robustness of the FLC is tested.

Similar approaches have been used among literature to simplify model processing while still keeping the desired characteristics. Precup and Preitl [7] represent uncertainties by using a simplified plant model where nonlinear servo systems were used in conjunction with a simplified linearized model of a controlled plant. The controller even includes an inserted variable to notify changes from the nominal expected behavior. Rather than a formal dynamic approach to the system, they use a simplified model similar to FOPDT, as we do instead of simulating power electronics formally. In testing the system, we use a nonlinear model, the opposite of Preitl and Precup [28], whose sensitivity analysis is done over linearized models of the controller. Our tests are not restricted by the simplifications or assumptions they used in their linearized model.

As the introduced variations will result on different operating conditions, the FLC can be measured to be robust to some extent, e.g., a percentage variation of FOPDT parameters. The testing conditions are to be kept the same for all variations so its sensitivity to those changes can be evaluated. Altogether, a simple FLC can be proven to face a complex nonlinear

system over a range of operating conditions for a tracking problem. It is clear that the usage of the FLC over the plant will describe an extended operating zone with tolerable performance. If the real plant is supposed to be within that zone, then the controller will be more likely to require minimum modifications for the implementation phase.

Robustness and Boundedness

In design of linear controllers, robustness is achieved when the compensator is designed for a consistent qualitative plant model that encompasses all specified plant perturbations or variations. It is important to recognize the trade-off between maintaining stability robustness and maintaining an increased tracking performance [12]. Among literature, it is possible to confirm that a robust control design will need a previous analysis of plant variations. Variations are commonly bounded within some margins which represent the worst case situations the plant can exhibit. An effective robust controller can manage the whole area described by these variations.

There are ways in which this problem has become more manageable. In [20], a fuzzy observer-based linear controller provides rough tuning to approximate the nonlinear control system, while an optimal H attenuation provides precise tuning to make the robustness optimal. Here, both advanced tracking performance and improved robustness are sought. The paper also illustrates the use of bounding matrices to fit a nonlinear system inside certain bounds through consideration of an approximate error. They also employ a bounded bandwidth to deal with robust performance control. To create the fuzzy controller, an optimization procedure uses the interior point method to minimize the quadratic boundary while testing stability, so that both controller is optimal and the boundary is minimal. The design of this controller allows the fuzzy algorithm to develop a robustness and function with a reduced effect of external disturbance [20].

In another example, robustness in the case of [4] is assumed to be better in FLC because the controller will adapt itself under varying conditions. However, here no expected performance is guaranteed. In [2], robustness is measured in terms of probability over an inference cell, based on the

magnitude of the change of the inference output and the variation of each membership variation, taking the derivative of the inference output with respect to the corresponding alpha cut. This is integrated over the whole inference cell to finally evaluate the robustness [2].

Because control error increases with more conservative bounds, solving the robustness issue implies bounding model parameters. Bounding model parameters means assigning an expected range to the performance of the parameter. Not just any bounds will serve; it is important to find meaningful bounds based on knowledge of the uncertainties and the modelled system. For the quadcopter application, the parameters should be based on simulations or experimental results [18].

Physical constraints can impose boundaries to the controller parameter, so the controller output should not surpass some allowed characteristic of the actuator. In [8], an output scaling factor for motor voltage control does not exceed the maximum voltage allowed for that motor. Ferrero et al. [1] conclude that even measurement uncertainties should be bounded. In [3], they assume their system parameters to be uncertain but bounded to 19% around the nominal value. In [7], the variations are arbitrarily limited.

For a system that is not totally known, a set of systems can enclose it. Preitl and Precup [28] derive sensitivity models related to the step function of the control system for sensitivity analysis. With the plants described in [3], the system is proposed as $A + \Delta$ where Δ is the expected variation of the matrix used. The graphs from [7] demonstrate limits for different design parameters. Additionally, in [22], boundaries are also established so that the model lies within an expected zone. The controller is also designed considering bounded conditions.

The main idea is that a controller which faces a system set will control anything in between. In [12], stability is tested for parametric bounded variations. In [7], two controllers are tuned: (1) a nominal PI controller with respect to the set-point, and (2) a PI controller with respect to the disturbance inputs of the control system. The goal in this research was to blend the controllers to permit a bump-free transfer from one PI controller to the next, and good behavior in the operating zones covered by such blending. This guarantees the achievement of desired control system

performance indices, overshoot, settling time, and robust stability [7].

SIMULATIONS AND RESULTS

The chapter intentions will be expanded for sake of clarity. There are no models which thoroughly represent a given plant. Such incompleteness can cause many problems which take the implementation far from the expected simulated results. However, going into deep detail about subsystems comprising a plant would be inefficient (or even impossible) due to increased complexity. To tackle this problem, such systems can be approximated by equations which exhibit a similar behavior. As a single equation would hardly fit the system's response, those relegated characteristics can be assumed to be contained somewhere between marginal cases of the simplified equation. In consequence, not a model, but a set of models is proposed to enclose the system reality. A controller can be robustly tuned to face the whole set of simplified systems providing at least two benefits: (1) The real plant can be controlled as long as its features are actually bounded by the set of models, and (2) the marginal control specifications are known from worst-case simulations, so the real model can be controlled inside those borders.

Intelligent controllers, specifically FLC, seem to be a good option when dealing with complex plants and uncertain conditions. Besides FLC being formally analyzed and having model-based solutions that can be easily found in literature, its more remarkable feature is the "translation" of linguistic fuzzy rules and measurements to a nonlinear mapping. A fuzzy controller can be tuned by means of practical observation or experience, almost disregarding the plant's complexity. In this spirit, a complex nonlinear plant was modelled and further variated to show the advantages of a simple heuristically tuned FLC in terms of stability and robustness.

A quadcopter is a UAV which incorporates sensors, a processing unit, power electronics drivers, and electric machinery. With its own complexity as a flying under-actuated device, its effective control is still a challenge nowadays. In this work, the quadcopter is modelled without the use of linearization processes, and a FLC is heuristically tuned to control it under ideal model conditions. In order to account for the

variability present in the control process, a set of FOPDT approximation models are used to curtail actuator performance. As the quadcopter model mainly depends on actuators' speed, many model's parameters are being considered uncertain by varying the FOPDT equation. The FLC original tuning (without variations) is preserved and its performance is analyzed toward percentage variations of motors gains, bandwidth, and discrete time delays. Altogether, a good performance of the FLC would move the process forward to a successful implementation process. Additionally, a simple approach to intelligent control design could be proven to be sufficient for such a varying complex plant.

Methodology

The whole testbed was programmed in LabVIEW 2015 platform. The quadcopter model was solved through a custom Runge-Kutta of 4th order so that its response can be evaluated step-wise. This numerical method was chosen as further implementation on a restricted-size FPGA is desired. The FLC was designed through the Fuzzy System Designer tool included as a part of the Control and Simulation toolkit for LabVIEW. The FOPDT model was discretized and solved as a recurrent equation dependent on the sampling time which, for all tests, was adjusted to 10 ms.

The ideal gains and bandwidths are set to 1 and 50 rad/s. They will be varied by a uniform random number generator limited to predefined relative limits of [0%, 2%, 5%, 10%, 15%] and [0%, 10%, 20%], respectively. The time delays will be managed as integer variations of sensor and actuator lags. For every simulated test, a time window of 20 s will be used and the squared error of all states will be measured. Each test will be repeated 200 times to allow the random generator to describe the variation uniformly and a final average will be computed per state.

A medium-sized quadcopter of 2 kg is considered. Its parameters are shown in Table 1 below:

Table 1: Considered quadcopter parameters

Constant	Abbreviation	Value	Units
Gravity	gg	9.81	m/s2m/s2
Arm length	ll	0.225	mm
X/Y moment of inertia	ILIL	4.856E-3	kgm2kgm2
Z Moment of inertia	IZIZ	8.801E-3	kgm2kgm2
Lift constant	kk	2.1E-4	kg m/rev2kg m/rev2
Torque drag	bb	1.14E-7	kgm2/rev2kgm2/rev2
X drag	BxBx	.25	kg/skg/s
Y drag	ByBy	.25	kg/skg/s
Z drag	BzBz	.25	kg/skg/s
θ drag	BθBθ	.01	kgm2/skgm2/s
drag	BφBϕ	.01	kgm2/skgm2/s
ψ drag	BψBψ	5E-3	kgm2/skgm2/s
Rotors' moment of inertia	IMIM	3.357E-5	kgm2kgm2

For control tuning purposes, quadcopter actuators are assumed to be of infinite bandwidth, equal gain (among all 4 motors), and to exhibit no delay. In Figure 4, four main blocks are shown: (1) fuzzy MIMO controller, (2) a converter from tilt to actual motor power, (3) the quadcopter model, and (4) the bounding conditions block.

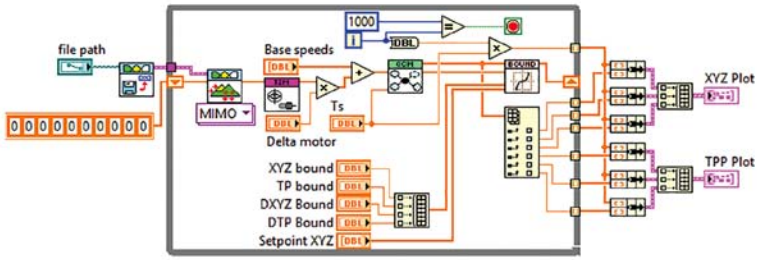


Figure 4: Testbed without FOPDT.

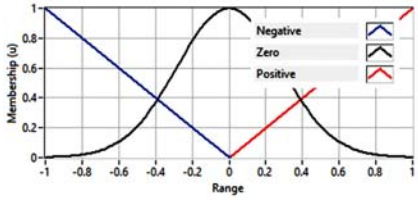
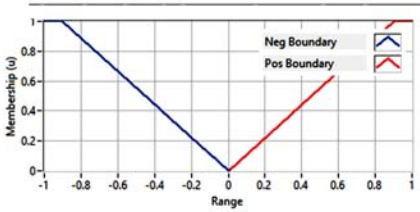
The FLC data are retrieved from a separate file and the control actions are executed in a black-box fashion. In search of a simple and logical controller, its output is designed in terms of forward tilt, right tilt, and overall thrust instead of individual motor power. It is clearer for a designer to identify whether the quadcopter needs to tilt rather than if an individual motor would provide the desired result; in addition, this simplifies the controller rules, as will be explained later. As the quadcopter still needs the individual motor power information, the second block converts the titling control signal into four separated increment or decrement actions. The number of fuzzy sets per input or output has been also arbitrarily determined to be of a maximum of three. The main interest here is showing a simple controller which is easy to understand despite possible better alternatives.

For improved versatility, all controller's inputs and outputs are normalized. This means that all considered universes of discourse have been limited to [−1, 1]. Pre- and post-processing scaling steps are needed to fit the actual needed intervals, and that is the main reason why the bounding block has been included. Having all the intervals normalized allows the designer to require a little effort in defining the membership functions as the scaling conditions will tune their reach. It is important that additional to scaling, a coerce condition is included so all the parameters can be represented within their universe of discourse. This implies that all the possible values are bounded (pre-known) by the designer.

In this case, the position control is attained by using one single FLC which requires the following inputs: X, Y, and Z error signals; X, Y, and Z speed signals; θ and φ angles; and θ and φ angular velocity signals.

These inputs can recreate a basic proportional-derivative FLC; however, instead of taking the error's derivative, the velocity measurements are used so the rules are clearer. All the inputs are presented in Table 2.

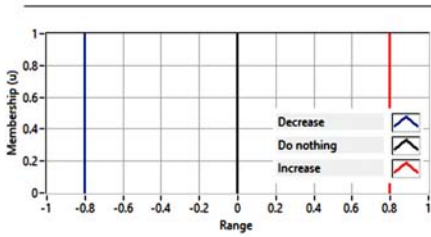
Table 2: Input membership functions

	Input membership functions for X, Y, and Z errors. The three of them have the exact same description.
	Input membership functions for: • X, Y, and Z velocities • θ and ϕ angles • θ and ϕ angular velocities They are meant to limit the speed of the quadcopter, so they are named as "boundaries". The seven of them have the exact same description.

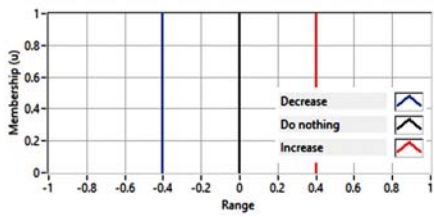
The outputs of the controller were also furnished to be similar among them and are shown in Table 3. The tilt information is divided into two as there are two angles of interest with respect to the quadcopter. An additional output named "all propellers" permits the system to perform homogeneous changes in the Z axis. All outputs' membership functions are defined using singletons; they are functions which only take the value of 1 at a particular point. As defuzzification is made based on weighing the influences of these functions, the resulting system is equivalent to a TS-FLC with constant outputs. Thus, each control signal will be a smooth transition between those constants.

As the motor inputs for the model are given on an interval [0, 155], the outputs of the FLC were multiplied by 10 and summed to a base speed. In this way, the fuzzy controller is providing correction variations to a predefined thrust which is close to the equilibrium force of the quadcopter. This computation permits the testbed to start from a condition where the vehicle is assumed to be already on flight.

Table 3: Output membership functions



Output membership functions for "forward tilt" and "right tilt". The two of them have the exact same description.



Output membership functions for "all propellers".

Despite of the number of inputs, only 15 rules are needed to set the necessary logic to control the quadcopter. Nine of them are of a compensating nature and 6 are restrictive:

- Compensating nature:
  - IF 'Zerr' IS 'Negative' THEN 'All propellers' IS 'Decrease'
  - IF 'Zerr' IS 'Zero' THEN 'All propellers' IS 'Do nothing'
  - IF 'Zerr' IS 'Positive' THEN 'All propellers' IS 'Increase'
  - IF 'Xerr' IS 'Negative' THEN 'Tilt Right' IS 'Decrease'
  - IF 'Xerr' IS 'Zero' THEN 'Tilt Right' IS 'Do nothing'
  - IF 'Xerr' IS 'Positive' THEN 'Tilt Right' IS 'Increase'
  - IF 'Yerr' IS 'Negative' THEN 'Tilt Forward' IS 'Decrease'
  - IF 'Yerr' IS 'Zero' THEN 'Tilt Forward' IS 'Do nothing'
  - IF 'Yerr' IS 'Positive' THEN 'Tilt Forward' IS 'Increase'
- Restrictive nature:
  - IF 'DZ' IS 'Neg Boudary' THEN 'All propellers' IS 'Increase'
  - IF 'DZ' IS 'Pos Boundary' THEN 'All propellers' IS 'Decrease'
  - IF 'DX' IS 'Neg Boundary' OR 'Theta' IS 'Pos Boundary' OR 'DTheta' IS 'Pos Boundary' THEN 'Tilt Right' IS 'Increase'
  - IF 'DX' IS 'Pos Boundary' OR 'Theta' IS 'Neg Boundary' OR 'DTheta' IS 'Neg Boundary' THEN 'Tilt Right' IS 'Decrease'
  - IF 'DY' IS 'Neg Boundary' OR 'Phi' IS 'Pos boundary' OR

'DPhi' IS 'Pos Boundary' THEN 'Tilt Forward' IS 'Increase'

- IF 'DY' IS 'Pos Boundary' OR 'Phi' IS 'Neg Boundary' OR 'DPhi' IS 'Neg Boundary' THEN 'Tilt Forward' IS 'Decrease'

The FLC tuning is done through a trial-and-error process over the scaling factors of all inputs and outputs. The system is then configured as shown in Table 4.

Table 4: Tuning parameters for the FLC

X, Y, and Z errors	0.5
θ and ϕ boundaries	0.08
X, Y, and Z speed boundaries	0.48
θ and ϕ angular velocity boundaries	0.3
All outputs	10

The resulting controller performance is shown in Figure 5 for set-point values of [0.4, 0.3, 0.2] for [X, Y, Z], respectively. The tests regarding FOPDT variability are done for a common set-point of 0 (for which the ideal model exhibits no error operation). All of the tests evaluate how well the system can hold the zero reference, so the computed error accounts for the variations allowed by the controller. The modified testbed is shown in Figure 6 and the error results in Tables 5 to 8, which include test conditions as follows:

- Bandwidth set to 50 rad/s, no sensor extra delay, no actuator delay
- Bandwidth set to 50 rad/s, one extra sensor delay, no actuator delay
- Bandwidth set to 50 rad/s, no sensor extra delay, one actuator delay
- Bandwidth set to 100 rad/s, no sensor extra delay, two actuator delays

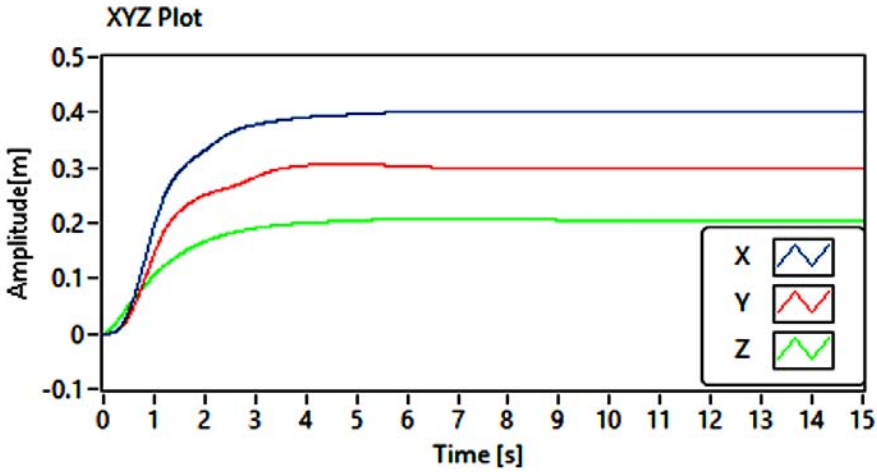


Figure 5: Test for tuned controller.

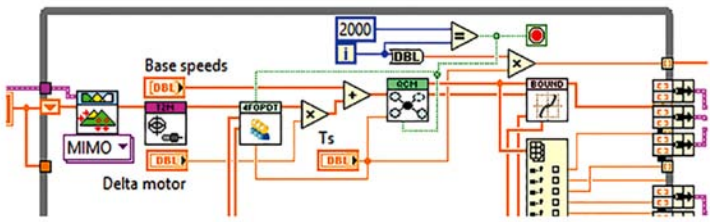


Figure 6: Testbed including FOPDT.

Table 5: Reference results for 0 delay conditions

Table 6: Results considering 1 extra sensor time delay

Table 7: Results considering 1 actuator time delay

Table 8: Results considering 100 rad/s bandwidth and 2 actuator time delays

ANALYSIS AND CONCLUSIONS

There are two things to comment about the controller before continuing with data analysis. It does not include an accumulator, so steady-state errors are expected. In addition, the scaling of X, Y, and Z errors could be constrained into a lower margin to force the controller to react toward smaller inputs.

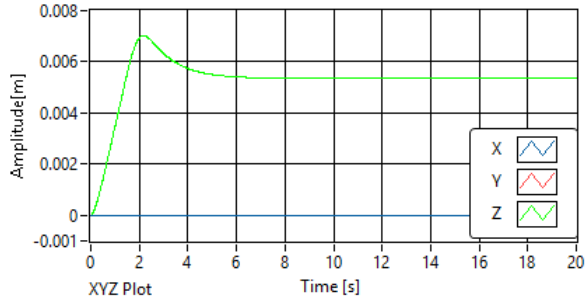


Figure 7: Reference test and steady state error of Z axis.

However, errors were assumed to be bounded on 0.05 m, so lowering this value would saturate the controller whenever higher set-points are requested. The quadcopter model is started with a base motor power of 76.5, equivalent to the 49% of the total thrust. This is enough to make the quadcopter to rise before the controller action compensates for the error. For ideal conditions and without the FOPDT model, the system response presents a steady-state error of about 5 mm as shown in **Figure 7**. As motors are assumed to be identical, no variations appear on X and Y axes. After performing all the tests with incorporated variability, the controller preserved stability in all cases, except for a 2 delay on the actuator side for which no data were collected. This particular case will be discussed afterwards. In order to ease analysis, four more tables (from **Tables 9** to **12**) are shown below. Each has the following rows: "Gain diff" measures the absolute difference in error calculation due to gain variations; "Col Avg" computes the average error value of a given state; "Delta State" compares each state with respect to the previous lower bandwidth test; and "Delta Ref" compares the "Col Avg" row with those of the test performed with no delays.

It can be seen that the uneven gain variation is responsible for the highest increase of error in all tests. On the other hand, bandwidth modifications do not generate an evident trend as error is sometimes even lower than previous ones. It is clear from this point that bandwidth unevenness is not quite relevant from a statistical point of view; however, angle variation shows an increasing error most of the time. This is due to a constant need to change the propellers' speed because command signals are not fully applied simultaneously. For strongly varying angles, an overall vibration effect will be visible on the quadcopter.

Table 9: Analysis for reference conditions.

It is worth to mention that the actuator delay will affect the controller performance more strongly than a sensor delay. Those actuator time-related issues may exist due to power electronic drives and integrated close-loops. They can also appear if the motors' information is not collected properly due to sensing or measuring problems on the inner loop and filtering delays. An additional feature observed throughout the simulations is that Z remains almost unaltered, mostly due to its greater independence to little angle variations.

Table 10: Analysis for first test

causes the controller signals to wait some iterations before their effect is fully applied. If the motors vary in bandwidth, some control signals will be delivered on time and some will not, increasing the error seen by the controller. This effect would lead to wrong compensation signals which, if delayed, will hardly keep a stable plant. Remember that the FLC tuning was not modified, so its success will depend on the quadcopter's overall bandwidth.

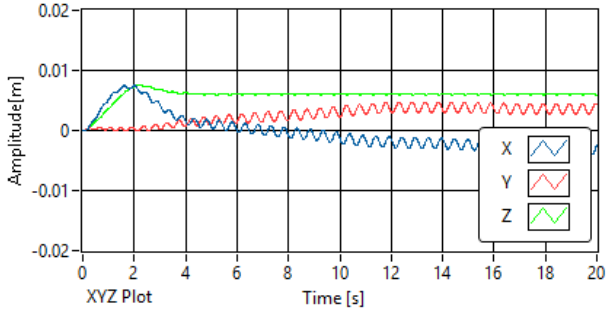


Figure 8: Chattering effect due to time delay of actuators.

It is also noteworthy that even if control signals are executed fast enough to keep stability, chattering may appear due to late compensation. This effect (show in Figure 8) can be incorrectly identified as noise, which can damage control performance.

A simple FLC has been proven to control a quadcopter nonlinear model subjected to variability (FOPDT) on its actuators. It is a very simple controller which seeks clarity and simplicity and that still exhibits robust performance when tested under model variations. The controller seems unimpaired by uneven gains and bandwidth variations among quadcopter motors, as well as single time delays present before or after controller block execution. It is possible to say that unevenness on motors' bandwidth does not have a drastic effect. However, an overall low bandwidth will greatly restrict the system's stability.

The controller allowed a maximum 15 mm absolute error among tests and kept the simulated quadcopter stable for motor-unbalanced variations up to 15% in gain and 20% in bandwidth. The controller is capable of dealing with time delay too. However, the actuators' response speeds seem to be a major restriction of this. This analysis permits the FLC system presented

to be considered as a simple option for actual implementation. Its tuning and further improvement through more dependable techniques can lead to a realizable controller which observes better specifications.

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CHAPTER 9

ALGORITHMIC DECISION-MAKING AND THE CONTROL PROBLEM

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ABSTRACT

The danger of human operators devolving responsibility to machines and failing to detect cases where they fail has been recognised for many years by industrial psychologists and engineers studying the human operators of complex machines. We call it "the control problem", understood as the tendency of the human within a human–machine control loop to become complacent, over-reliant or unduly diffident when faced with the outputs of a reliable autonomous system. While the control problem has been investigated for some time, up to this point its manifestation in machine learning contexts has not received serious attention. This paper aims to fill that gap. We argue that, except in certain special circumstances,

algorithmic decision tools should not be used in high-stakes or safety-critical decisions unless the systems concerned are significantly "better than human" in the relevant domain or subdomain of decision-making. More concretely, we recommend three strategies to address the control problem, the most promising of which involves a *complementary* (and potentially *dynamic*) coupling between highly proficient algorithmic tools and human agents working alongside one another. We also identify six key principles which all such human–machine systems should reflect in their design. These can serve as a framework both for assessing the viability of any such human–machine system as well as guiding the design and implementation of such systems generally.

INTRODUCTION

The recent trend toward automation by machine learning and artificial intelligence systems raises in a new guise old questions about the role of humans in human–machine systems (Johannsen 1982; Margulies and Zemanek 1982). The difficulties involved in sharing control with computer systems are of course familiar to industrial psychologists and systems analysts investigating the human operators of complex machines. In these contexts, the danger of human operators devolving responsibility to machines and failing to detect cases where they fail has been recognised for many years. The problem is that, as automation becomes smarter and cheaper, its operators have to assume an increasingly supervisory role (Meister 1999; Strauch 2018). In aviation, for example, the role of the pilot appears to have become easier, but a closer look reveals that the pilot's role has been transformed rather than simplified, with the pilot now performing a crucial monitoring function (Baxter et al. 2012; cf. Stanton 2015). Likewise in financial trading, "[t]he human trader's role is now largely one of setting strategies and monitoring their execution" (Baxter et al. 2012, p. 68). How does this shift from operator to supervisor affect the person who has undergone the shift, and the nature of the interaction between operator and machine?

What we shall term "the control problem" arises from the tendency of the human agent within a human–machine control loop to become complacent, over-reliant or unduly diffident when faced with the outputs of a reliable autonomous system. Although it might be thought innocuous, decades

of research confirm that the problem is actually pernicious, and perhaps even intractable (Banks et al. 2018b; Cunningham and Regan 2018; Greenlee et al. 2018). Somewhat alarmingly, it seems to afflict experts as much as novices, and is largely resistant to training (see Parasuraman and Manzey 2010 for reviews). Its effects may also be observed beyond the limits of strictly sociotechnical systems. For instance, it is well known that police officers, judges and jurors frequently overestimate the importance of forensic evidence—the so-called "CSI effect" (Marks et al. 2017; see also Damaška 1997).

Our interest is in how the control problem bears upon the proliferation of the newer types of machine learning systems. Machine learning is a form of data processing that extracts statistical patterns from large amounts of information. One of its more prominent applications is in the arena of decision support. State-of-the-art decision support systems are increasingly run on vast datasets (so-called "big data") and exploit an especially powerful form of machine learning known as "deep learning". Deep learning has two features worth noting here: first, as a form of machine learning, it is not in the mould of more traditional expert systems, which were programmed "by hand" to compute solutions to well-defined problems in a more or less deterministic manner; second, deep learning relies on a computational architecture modelled on the neurons and synapses of actual, biological brains—although obviously in a highly simplified form. These features are worth drawing attention to because they underscore how sophisticated the autonomous systems under human care can be; and system complexity has been an abiding theme of research into the control problem from its beginning.

While the control problem has been investigated for some time, up to this point its manifestation in machine learning contexts has not received serious attention. This is significant, not because the problem necessarily has any distinctive characteristics in a machine learning context, but because there is a risk that lessons learned elsewhere will go unheeded in this new arena—an arena we have every reason to believe brings with it all the psychological pitfalls of earlier systems of industrial-scale automation. This paper aims to fill that gap by offering a critical analysis of the problem in light of the advent of sophisticated machine learning techniques. As a recent French report into artificial intelligence notes, "it is far easier for a judge to follow the recommendations of an algorithm

which presents a prisoner as a danger to society than to look at the details of the prisoner's record himself and ultimately decide to free him. It is easier for a police officer to follow a patrol route dictated by an algorithm than to object to it" (Villani 2018, p. 124). And as the AI Now Institute remarks in a recent report of its own: "[w]hen [a] risk assessment [system] produces a high-risk score, that score changes the sentencing outcome and can remove probation from the menu of sentencing options the judge is willing to consider" (AI Now 2018, p. 13). The Institute's report also offers a sobering glimpse into just how long such systems can go without being properly vetted. A system in Washington D.C. first deployed in 2004 was in use for 14 years before it was successfully challenged in court proceedings, the authors of the report attributing this to the "long-held assumption that the system had been rigorously validated" (AI Now 2018, p. 14). In her book, *Automating Inequality*, Virginia Eubanks (2017) notes the complacency that high tech decision tools can induce in the social services sector. Pennsylvania's Allegheny County introduced child welfare protection software as part of its child abuse prevention strategy. The technology is supposed to assist caseworkers deciding whether to follow up calls placed with the County's child welfare hotline. In fact, however, Eubanks relates how caseworkers would be tempted to adjust their estimates of risk to align with the models. The proliferation of advanced machine learning tools in both government and private sector agencies clearly behoves us to examine the control problem in the unique context in which it now arises.

In addressing the problem, we have drawn on the literatures of both industrial psychology/engineering on the one hand—primarily "human factors" research (see below)—and artificial intelligence on the other. We argue that, except in certain special circumstances (in which great care must be taken), algorithmic decision tools should not be used in high-stakes or safety-critical decisions unless the systems concerned are significantly "better than human" in the relevant domain or subdomain of decision-making—a position towards which an increasing number of human factors experts have somewhat reluctantly been driven: see e.g. Banks et al. (2018b), Cunningham and Regan (2018), Walker et al. (2015), Cebon (2015). More concretely, we recommend three strategies to address the control problem, the most promising of which involves a *complementary* (and potentially *dynamic*) coupling between highly

proficient algorithmic tools and human agents working alongside one another. For any complex task, the choice between using a sophisticated system that makes only occasional errors but which reduces the human role to that of a monitor, and a simpler system that is reliable effectively 100% of the time but requires ongoing human participation to get the job done, can only be resolved on a case-by-case basis. In high-stakes settings, however, it is generally not advisable to choose the more sophisticated system unless it makes considerably fewer errors than a proficient human expert. Even though no technology is really 100% reliable, the dangers posed by human complacency diminish practically to zero the moment a system approaches a certain (admittedly very high) threshold of reliability. How many sophisticated systems actually reach this threshold is another question. For example, as at the time of writing, autonomous vehicles do not approach this level of capability (Banks et al. 2018a, b), but many subcomponents within standard (nonautonomous) vehicles clearly do, such as automatic transmission, automatic light control and first generation cruise control (Walker et al. 2015).[Footnote1] In more typical decision support settings, arguably diagnostic and case prediction software are approaching this better-than-human standard. There are at present AI systems which can spot early-onset Alzheimer's disease from control patients with over 80% accuracy up to a decade before the first appearance of symptoms, a feat vastly outperforming the ablest human pathologist attempting anything similar (Amoroso et al. 2017).[Footnote2] In the legal sphere, advances in natural language processing and machine learning have facilitated the development of case prediction software that can predict, with an average 79% accuracy, the outcomes of cases before the European Court of Human Rights when fed the facts of the cases alone (Aletras et al. 2016). Most impressively, a similar system had better luck in predicting the rulings of the US Supreme Court than a group of 83 legal experts, of whom almost half had previously served as the justices' law clerks (60% vs. 75% accuracy) (Brynjolfsson and McAfee 2017). If the disparity between the performance of such systems and that of well-trained and experienced human professionals widens any further, presumably it will not much matter if humans perfunctorily adhere to whatever these systems decide or advise in a particular situation.

BACKGROUND TO THE CONTROL PROBLEM

A human–machine system (HMS) may be defined as the synthesis of a biological–psychological system and a technological-mechanical system characterized by functional interdependence (Johannsen 1982). The object of any HMS is to provide a "function, product or service as an output with reasonable costs, even under conditions of disturbances influencing man, machine or both" (Johannsen 1982, p. xiii). Importantly, it is has long been recognized as ideal for the human element in this system to be satisfactorily absorbed in the role being played—to reach an adequate level of job satisfaction (Moray 1979)—even if this conflicts with the overall aims of the HMS (e.g. in providing a service at reasonable cost).

HMSs were first investigated in relation to predominantly manual control tasks, initially in aircraft piloting, but then later in ship steering, car driving and industrial process control (see Kelley 1968; Edwards and Lees 1974; Sheridan and Ferrell 1974 for early reviews). This research continues today under the branch of psychology known as "human factors". Human factors research draws on various strands of inquiry, including sociology, physiology, control theory, systems engineering and cognitive science, the latter a branch of (cognitive) psychology that investigates mental processes through the use of models inspired by computer science (Newell and Simon 1972; Rouse 1982). Apart from providing models of cognitive processes, computers have been a common denominator in practically all HMSs from the time they were first studied, with human–computer interaction (HCI) a key focus from the start (Pazouki et al. 2018). Here the standard topics have concerned optimal task allocation, interface design and software ergonomics generally (Rouse 1981; Hatvany and Guedj 1982; Williges and Williges 1982). Computer-aided decision-making, which is our concern here, can therefore be considered a special branch of HCI and human factors research.

When we talk about "control" of HMSs, we are using the term in a broad sense—broader than the sense typically understood in control theory and human factors—encompassing tasks which have traditionally been regarded, strictly speaking, as distinct from control, such as problem-solving (see e.g. Johannsen 1982). Thus by "control" we understand both *fault diagnosis and management* (solving problems as they

occur in real time, with a view to restoring normal operation) as well as *planning* (anticipating future problems and devising appropriate strategies to combat them). The control problem was arguably first identified in papers by Wickens and Kessel (1979) and Wiener and Curry (1980), but it did not receive its definitive and celebrated formulation until Lisanne Bainbridge (1983) paper came along with the succinctly telling title: "Ironies of Automation". The chief irony with which her paper grappled is "that the more advanced a control system is, so the more crucial may be the contribution of the human operator" (1983, p. 775). Although writing at a time before deep learning had anything to do with algorithmically automated decision tasks, what she had to say about the role of the human monitor in a HCI is as salient today as when the paper first appeared:

if the decisions can be fully specified then a computer can make them more quickly, taking into account more dimensions and using more accurately specified criteria than a human operator can. There is therefore no way in which the human operator can check in real-time that the computer is following its rules correctly. One can therefore only expect the operator to monitor the computer's decisions at some meta-level, to decide whether the computer's decisions are "acceptable". (1983, p. 776, emphasis added)

As we see things, this residual monitoring function of the human operator generates at least four kinds of difficulties that should be treated separately. The first relates to the cognitive limits of human processing power (the "capacity problem"). Its statement in Bainbridge followed directly on from the italicized portion of the preceding quote:

if the computer is being used to make the decisions because human judgement and intuitive reasoning are not adequate in this context, then which of the decisions is to be accepted? The human monitor has been given an impossible task. (1983, p. 776)

Humans are often at a severe epistemic disadvantage vis-à-vis the systems they are tasked with supervising. This can be seen very clearly in the case of high frequency financial trading. It is impossible for a monitor to keep abreast of what is happening in real time because the trades occur at speeds that simply exceed the abilities of human monitors to keep track. As Baxter et al. (2012, p. 68) point out, "[i]n the time it takes

to diagnose and repair [a] failure…many more trades may have been executed, and possibly have exploited that failure". Analogous problems arise in aviation with respect to the use of autopilot systems (Baxter et al. 2012). Cebon (2015, p. 10) notes that autopilot systems are becoming "…so sophisticated that they only fail in complex 'edge cases' that are impossible for the designers to foresee. Consequently pilots cannot be trained to handle them". Along with the attentional problem (see next paragraph), cognitive constraints account for the main difficulties operators experience in reasserting control of a HMS when the system malfunctions. While one may question whether the opacity of a system impedes its intelligibility quite as much as the capacity problem seems to imply (see e.g. Zerilli et al. 2018), the capacity problem presents a formidable HCI challenge regardless. Today, even a fully proficient software technician would be loath to understand the multi-vector logic governing the generation of a neural network's outputs.

The second difficulty relates to the *attentional* limits of human performance (the "attentional problem"):

We know from many "vigilance" studies…that it is impossible for even a highly motivated human being to maintain effective visual attention towards a source of information on which very little happens, for more than about half an hour. This means that it is humanly impossible to carry out the basic function of monitoring for unlikely abnormalities…. (Bainbridge 1983, p. 776)

Automation has a significant impact on situation awareness (Stanton 2016). This is perhaps most clearly illustrated in respect of autonomous vehicles. Inattentive drivers operating a vehicle while it is in autonomous mode are less able to anticipate takeover requests and may be ill-prepared to resume control in an emergency (Stanton 2015; Cunningham and Regan 2018; Banks et al. 2018a, b). Instantaneously transitioning from low to high workload poses great difficulties for most people (Walker et al. 2015). The third difficulty relates to the *attitudes* of human operators in the face of sophisticated technology (the "attitudinal problem"). Except for a few brief remarks (Bainbridge 1983 p. 776), this problem was not really addressed in Bainbridge's paper (cf. Wiener and Curry 1980). It has, however, been the subject of active research in the years since (see e.g. Skitka et al. 2000; Parasuraman and Manzey 2010; Pazouki et al. 2018). Here the conundrum is that as the quality of automa-

tion improves, and the human operator's role becomes progressively less demanding, the operator "starts to assume that the system is infallible, and so will no longer actively monitor what is happening, meaning they have become complacent…[T]he operator assumes that the system is reliable and therefore failure detection deteriorates" (Pazouki et al. 2018, p. 299). There is some evidence that complacency is worse under conditions of multiple task load, "when manual tasks compete with the automated task for the operator's attention" (Parasuraman and Manzey 2010, p. 387). In other words, "[t]he operator's attention allocation strategy appears to favor his or her manual tasks as opposed to the automated task" (Parasuraman and Manzey 2010, pp. 387–388). While this makes it sound as if complacency is an attentional issue, in truth it is an attitudinal one because (so it seems) the monitor only risks being "distracted" by other tasks when they believe the system is reliable enough to be left alone. When the system is not regarded as reliable in the first place, the effect does not occur. (As we discuss later, the control problem arises only from the use of highly reliable but imperfect systems: it does not arise from the use of less reliable systems). This very likely explains why the effect is reversed when the operator monitors a less reliable system, which predictably elicits higher vigilance (Parasuraman and Manzey 2010; Banks et al. 2018a, b). Related to automation *complacency* is automation *bias*, occurring when human operators "trust the automated system so much that they ignore other sources of information, including their own senses" (Pazouki et al. 2018, p. 299). Both complacency and bias "describe a conscious or unconscious response of the human operator induced by overtrust in the proper function of an automated system" (Parasuraman and Manzey 2010, p. 406).

The fourth and final difficulty relates to the *currency* of human skills (the "currency problem"):

Unfortunately, physical skills deteriorate when they are not used….This means that a formerly experienced operator who has been monitoring an automated process may now be an inexperienced one….[With regard to cognitive skills] efficient retrieval of [process] knowledge from long-term memory depends on frequency of use….[T]his type of knowledge develops only through use and feedback about its effectiveness. People given this knowledge in theoretical classroom instruction without appropriate practical exercises will probably not understand much of it,

as it will not be within a framework which makes it meaningful, and they will not remember much of it as it will not be associated with retrieval strategies which are integrated with the rest of the task. (Bainbridge 1983, pp. 775–776)

These four problems may be seen as four distinct but interrelated aspects of the one control problem. For example, the capacity problem can be expected to intensify the human tendency towards overestimating the value of a machine's outputs, thus compounding the attitudinal problem. In this paper we shall follow the trend of most human factors research since 1983 by confining our attention primarily to the attitudinal problem. Although the problems are distinct, their very interrelatedness means that prescriptions regarding one may go some way towards alleviating (some of?) the others (e.g. see our discussion of the value of *dynamism* in HMSs, in Sect. 5).

Locating the Control Problem Within the Landscape of Control-Related Issues

The control problem is nestled among a set of (at least) six interrelated questions about HMSs. Identifying the main questions together enables us to situate the control problem within a broader framework of inquiry into human control in HMSs. In this section we say something brief about the first four questions. In the following two sections, we pursue answers to the final two questions at comparatively greater depth. The questions we have identified are as follows:

1. What is meaningful human control of a HMS?
2. Is human control, so understood, always necessary within a HMS?
3. Can the role of the human operator be safely reduced to that of monitor alone?
4. If not, why not?—What is "the control problem"?
5. When, or under what conditions, does the control problem arise?
6. Can the control problem be solved?

Regarding (i), a system for us is under "meaningful human control" when, *at a minimum*, it behaves the way it should, i.e. in accordance with the wishes of its operators (cf. Santoni de Sio and van den Hoven 2018). For a system to be under meaningful human control, however, also implies that it is under *effective* control, such that its operators have the wherewithal to correct the system or abort its operations in sufficient time

to avert the worst effects of its deviance. This is why we stated earlier that our notion of control extends to fault diagnosis and management (resolving problems with a view to restoring normal operation) as well as planning (devising strategies to deal with contingencies). Regarding (ii), we assume that it is always desirable for a HMS to be under effective human control.

Our discussion of the control problem already signals a negative reply to question (iii) whenever high-stakes or safety-critical decisions are involved: humans perform very poorly at prolonged monitoring tasks (Molloy and Parasuraman 1996; Banks et al. 2018a). Human attentional resources typically "shrink to fit" task demands (Walker et al. 2015). The attitudinal and attentional effects of the control problem combined are sufficiently detrimental to explain why a HMS that reduces the human controller to a monitor of displays or passive recipient of outputs is necessarily hazardous. However, because the effects of complacency can be reversed by replacing a reliable system with a less reliable system, some purely monitor-based setups do seem to avoid the problem (note: they *avoid*, rather than *solve*, the problem). And of course systems that approach better-than-human reliability do not pose a control problem as such (e.g. automatic transmission, case prediction software, etc.).

Because we have already defined the control problem (iv), all that remains is for us to elaborate on the answers we have intimated to the final two, most important, questions, i.e. (v) and (vi). We address these in the following two sections.

WHEN, OR UNDER WHAT CONDITIONS, DOES THE CONTROL PROBLEM ARISE?

The conundrum of control is that the more reliable a system becomes, the more difficult it is for a human supervisor to maintain an adequate level of engagement with the technology to ensure safe resumption of manual control should the system malfunction. In relation to current "Level 2" autonomous vehicles (see below)—which allow the driver to be hands- and feet-free but not *mind-free*, because the driver still has to watch the road—Stanton (2015, p. 9) puts the point vividly: "even the most observant human driver's attention will begin to wane; it will be

akin to watching paint dry". This is a manifestation in manual systems of a more general problem of control over automated decision support systems, viz., the tendency to defer to systems that approach (but do not reach) very high reliability and predictability. Conversely, *decreases* in automation reliability generally seem to *increase* the detection rate of system failures (Bagheri and Jamieson 2004). Starkly put, automation is "most dangerous when it behaves in a consistent and reliable manner for most of the time" (Banks et al. 2018b, p. 283). Decades' worth of research in aviation, shipping, driving and industrial process control supports this assessment. The only options to deal with the predicament therefore appear to be (at least in high-stakes or safety-critical contexts):

(a) The use of less reliable systems for tasks whose execution may be more expedient when automated to any standard of proficiency than when not at all, since less reliable systems do not pose the control problem;
(b) To implement only *partial* automation through *task decomposition* (see Sect. 5); and
(c) To wait for a system to reach near perfect (better-than-human) reliability before deployment.

Options (a) and (c) are self-explanatory. We shall discuss (b) in greater detail in the following section (as well as a few other strategies, such as "catch trials", in Sect. 7). For now we note that (b) and (c) are not mutually exclusive: any decision task that has automatizable subcomponents may employ near-risk-free technology working alongside an active, purposefully-engaged human operator, with human and machine fully autonomous within their particular spheres of operation. Furthermore, options (a) and (b) are not mutually exclusive either: any decision task that has automatizable subcomponents may likewise employ patently *suboptimal* technology working alongside an active, purposefully-engaged human operator (although here the machine will obviously *not* be fully autonomous within its sphere of operation). Because it may seem counterintuitive, we shall justify the inclusion of option (a) (and (a + b)) as part of our menu of options in the following section.

Since decision tasks can be cut more or less finely [as option (b), above, assumes], one might wonder whether the control problem presents quite

the same challenge when the situation involves the automation of a few subcomponents of a decision, in contrast to the automation of an entire decision. We could assume, for instance, that *border control* is one big decision—i.e. whether to admit, or not admit, persons moving between state boundaries—involving customs clearance, passport verification, drug detection, and so on. When the *entire* process is automated by one large, distributed border control software package, and this system works reliably well most of the time—but still requires human monitors to invigilate display panels and the like—is the control problem any worse than it would be when some automatizable subcomponents of the overall decision are carved out for discrete automation (and automated, once again, by *mostly*, but not completely, reliable systems)?

Currently, of course, border control decisions are only partially automated in this sense: SmartGate allows for fully automated electronic passport control checks, but customs officials and sniffer dogs still litter most immigration checkpoints, and their job is to handle such parts of the overall decision task as cannot be effectively automated. The same issue arises in automotive engineering. The Society of Automotive Engineers (SAE) framework, running from Level 0 (no automation) to Level 5 (full automation), classifies vehicles in accordance with the degree of system functions that have been carved out for automation (SAE J3016 2016). Tesla Autopilot and Mercedes Distronic Plus (Level 2) require the driver to monitor what is going on throughout the whole journey, while Google's self-driving car does everything except turn itself on and off. The thought is that if an actively engaged human is retained somewhere in the control loop, contributing purposefully to the decision task, the human may be less susceptible to automation complacency and bias than when their only role is monitoring. But actually the research we cited earlier suggests that matters are not quite so simple. Complacency appears to be *worse* under conditions of multiple task load so long as the automated subcomponent, being reliable most of the time, engenders misplaced trust in its ability to be left alone. Crucially, this effect can be reversed if the system is replaced with one that does not engender the same degree of confidence—i.e. a less reliable system (Parasuraman and Manzey 2010, pp. 387–388). These findings indicate that the control problem is not necessarily affected by the size or share of the automated subcomponent relative to the whole decision procedure. As long as the

autonomous system in question is more reliable than not, the control problem rears its head, with the only options available for remediating its effects being the three outlined above.

On the other hand, this is not to deny that differences between partial and full automation may extend to differences in how human operators typically *perceive* the respective capabilities of these systems. There is evidence that operator trust is positively related to the scale and complexity of an autonomous system. For instance, in low-level partially automated systems, such as SAE Level 1 autonomous vehicles, there is "a clear partition in task allocation between the driver and vehicle subsystems" (Banks et al. 2018b, p. 283). As the level of automation increases, however, this allocation gets blurred to the point that drivers find it difficult forming accurate assessments of the vehicle's capabilities, and on the whole are inclined to overestimate them (Banks et al. 2018b). Counteracting this effect may be the greater readiness to believe that a smaller, less sophisticated device—with fewer working parts and opportunities for system glitches—will be compensatingly less temperamental. In fact we suspect that this presumption is probably justified in the case of decision subsystems in SAE Level 0 vehicles such as automatic transmission, automatic light control and first generation cruise control (Walker et al. 2015). These subsystems may be so reliable, approaching near perfect (better-than-human) dependability, as to effectively neutralize the control problem's sting in most cases. So in the end, it seems, larger and more sophisticated technologies that are mostly reliable *probably do* pose a greater control problem than smaller ones.

CAN THE CONTROL PROBLEM BE SOLVED?

If the question is interpreted literally, the answer to "Can the control problem be solved?" appears to be straightforwardly negative: the control problem cannot *literally* be solved. There is nothing we can do which *directly* targets, still less *directly* alleviates, the human tendency to fall into automation complacency and bias once an autonomous system operates reliably most of the time, and when the only role left for the operator is to monitor its largely seamless transactions. However, by accepting this tendency as an obstinate feature of HMSs, we may be able

to work around it without pretending we can alter constraints imposed by millions of years of evolution.

The insights of human factors research is instructive here. There is no reason to suspect that machine learning and other state-of-the-art decision support systems are less likely to induce complacency effects than other forms of automated effort (e.g. Cummings 2004; Edwards and Veale 2017, p. 51). With this in mind, one important human factors recommendation is to foster mutual accommodation between human and computer competencies through a *dynamic* and *complementary* allocation of functions that optimally preserves attentional resources (Stanton and Marsden 1996). Ideally, only those parts of a decision should be automated that leave the human operator with something vital and absorbing to do (Bainbridge 1983). Optimal workload, moreover, would prevent demand explosion in scenarios where the operator must intervene quickly to rectify a situation—effective intervention can be enormously difficult when the operator has to shift from low to high level cognitive effort within a very short window (Walker et al. 2015).

Let us call this the "dynamic/complementary allocation of function" (DCAF) approach. DCAF assumes that human performance can be enhanced when automation *augments* rather than *replaces* human skills. It need not, however, assume that augmentation is always preferable to replacement. In fact, for the DCAF approach to work, some systems clearly need to replace the human agent and be left to operate autonomously. Human–machine decision systems that contain automated subcomponents work best when the human operator is allowed to concentrate their energies on the chunks of the task better suited to human rather than autonomous execution—a setup which only avoids the control problem if the automated subroutines are handled by systems approaching near-perfect (better-than-human) dependability. Otherwise the autonomous parts might work very well for the most part but still require a human monitor—and it is clear where *this* path leads. Indeed one of the advantages of complementarity is precisely that, by carving up a big decision into smaller and smaller chunks, the more likely it will be that better-than-human systems can be found to handle them.

Complementarity between human and computer is crucial. In a passage worth citing in full, Pohl (2008, p. 73) notes that

…intelligent software systems can be particularly helpful in complementing human capabilities by providing a tireless, fast and emotionless problem analysis and solution evaluation capability. Large volumes of information and multi-faceted decision contexts tend to easily overwhelm human decision-makers. When such an overload occurs we tend to switch from an analysis mode to an intuitive mode in which we have to rely almost entirely on our ability to develop situation awareness through abstraction and conceptualization. While this is perhaps our greatest strength it is also potentially our greatest weakness, because at this intuitive meta-level we become increasingly vulnerable to emotional influences.

The capabilities of the computer are strongest in the areas of parallelism, speed and accuracy. Whereas the human being tends to limit the amount of detailed knowledge by continuously abstracting information to a higher level of understanding, the computer excels in its almost unlimited capacity for storing data. While the human being is prone to impatience, loss of concentration and panic under overwhelming or threatening circumstances, the computer is totally oblivious to such emotional influences. The most effective implementation of these complementing human and machine capabilities is in a tightly coupled partnership environment that encourages and supports seamless interaction. (emphasis added)

At the same time, DCAF emphasises that the allocation of functions in a HMS should be flexible enough to support *dynamic* interaction, with hand-over and hand-back for shared competencies (as occurs when a driver disengages cruise control and thereby resumes control of acceleration). Of course dynamism will be dangerous if there is hand-over between agents that are ill-matched in their competencies. Dynamism will only work in circumstances where the human and machine are nearly equivalently proficient (with the machine perhaps only marginally better than the human). Apart from anything else, dynamic interaction allows the human to maintain their manual control skills, and so may go some way towards alleviating the currency problem.

It should be clear that DCAF falls under option (b) in our three-item menu of options for managing the control problem. It should also be clear that, as we presaged in Sect. 4 (and explained in the preceding paragraph), DCAF (b) will almost always employ near-risk-free technology (c)—so

that (b) and (c) are not mutually exclusive. For example, in relation to autonomous vehicles, Stanton (2015, p. 9) describes the DCAF challenge as follows: "We need to design vehicle automation to have graduated and gradual hand-over and hand-back tasks if it is to successfully support human drivers. Vehicle automation needs to work towards providing a chatty co-pilot, not a silent auto-pilot!" For this to be the case, however, the driver cannot worry about whether what the "chatty co-pilot" is saying is true. In the DCAF approach, the human *is* a co-pilot of sorts, with real work to do, so that the fidelity of their autonomous counterpart/s needs to be assured.

What if this fidelity cannot be assured? We have said that *as a rule* a decision tool should not replace a human agent in a high-stakes/safety-critical setting unless the tool reaches a certain crucial threshold of reliability; and we have applied this recommendation iteratively, carrying it over to DFAC decision contexts in high-stakes/safety-critical settings such that, for any automatizable *subcomponent* of a decision procedure, a tool should not replace the human agent responsible for that (sub)decision unless the tool meets our very high (better-than-human) standard. But what if this standard cannot be met? Can less-than-reliable systems be deployed here? In other words, are there exceptions to the general rule we have defended, or special circumstances where the general rule gives way? The short answer is: yes. As we have explained, the control problem does not arise from the use of patently suboptimal automation, only from *generally* dependable automation. Therefore, depending on the exact nature of the HCI at issue, a *less*-than-reliable system might safely replace the human agent charged with deciding some matter within a larger decision structure, for example, passport verification within the larger border control decision structure. The use of less-than-reliable systems is of course option (a) in our menu, and as exhibited in this example, nested within a broader decision structure consisting of subcomponents, as predicated by (b) (i.e. (a) and (b) are not mutually exclusive, again as we noted in Sect. 4). But now, why *would* a patently suboptimal decision tool be deployed here at all (or anywhere else, for that matter)? It is one thing to say that it avoids the control problem. It is quite another to say that a system which is so suboptimal it does not engender human confidence should *for that very reason* be used to assist human decision-makers. Clearly we owe our readers an explanation for

including option (a) within our menu of strategies for dealing with the control problem.

We think deployment of suboptimal tools may still prove useful in circumstances where the tools have access to information to which the human does not, or otherwise "decide" things in ways that humans generally *cannot*. Such systems very literally augment human capacities: human and machine in effect *share* control. The clearest examples of this form of technology are recidivism risk prediction tools used in law enforcement. Not all such instruments come with the problematic biases of PredPol (used in so-called hot-spot policing) and COMPAS (predicting the likelihood of offender recidivism) built into them. Some may be genuinely useful in reducing crime at the same time as *reducing* the prison population (see e.g. Kleinberg et al. 2018). These systems answer questions of the form: How should we distribute police officers over a locality having such and such geographical characteristics? What is the likelihood that this prisoner will reoffend if released on parole? And so on. Consider how these systems decide such matters. Often they use logistic regression or more advanced actuarial techniques to mine patterns from very large databases. This is not a feat unaided humans can hope to match. There are also some phenomena within human decision-making that algorithms can help to counteract—e.g. decision fatigue and decision inertia, of which some of the classic studies actually involve judges' parole decisions (e.g. Danziger et al. 2011).

Be that as it may, however, we would still urge that great caution be exercised before any form of suboptimal automation is used in high-stakes/safety-critical settings. Many of these systems (like COMPAS) are after all tools which have attained notoriety for their problematic biases and inherent technical limitations (e.g. Blomberg et al. 2010; Larson et al. 2016; Dressel and Farid 2018). And as some of these systems gradually begin to overcome their limitations, our worry is that the control problem will gradually re-emerge, taking human operators unawares and decision subjects along with them. It will be all too easy for a judge with decision fatigue, for example, to simply rely on what a predictive risk instrument "objectively" recommends. It may turn out that guidelines recommending, for example, that decision-makers consult their own judgment first before consulting an algorithm, using the algorithm merely as a check on their intuitions, could assist in offsetting some of the effects

of automation complacency and bias. (Note that this would come close to telling decision-makers *not* to use the algorithm—hardly a "solution" to the problem). The Wisconsin Supreme Court, when discussing protocols around judicial use of the COMPAS recidivism algorithm required that sentencing judges be given a list of warnings about the tool as a condition of relying on its predictions. More empirical research is required to see whether such approaches really do work.

To conclude our analysis of option (a), some of these features of suboptimal decision systems should be stated more explicitly. Option (a)—whether or not combined with option (b)—always represents a specific type of HCI. It is noteworthy that whenever a patently suboptimal tool is used, the human agent does not readily stumble into the control problem, and may therefore be assured of an active and meaningful role working alongside it (assuming a certain level of diligence, aptitude and motivation on the part of the human). But the interaction here will not quite be the same as that envisaged for HMSs under the DCAF approach. Under DCAF, the allocation of functions is complementary. This will not generally be the case under option (a). Assume that a decision, D, comprises the (sub) decisions d_0, d_1, d_2 and d_3. Under DCAF, the human will take care of (let us say) d_0, d_1 and d_2 while the system will take care of d_3. This means the human can concentrate their energies *entirely* on d_0, d_1 and d_2 and essentially *ignore* d_3, because the system is superior in making decisions of the type d_3. This cannot happen when suboptimal software is used. In such cases, it is not as if the human can take care of d_0, d_1 and d_2 while the system takes care of d_3; the human must *also* take care of d_3, albeit with the *assistance* of a suboptimal decision tool. Both human *and* machine participate in d_3 (i.e. human and machine effectively *share* control). Indeed, in light of what we said earlier, in many cases both human and machine may aptly be described as doing (or deciding) the same thing in different ways: for the system may be trying to answer the same question as the human (will she reoffend if released on parole? etc.), only with access to information which the human does not have, or in ways (or at speeds) which humans are unable to match. So there need be no complementarity of *functions* here, as both human and machine may be performing the *same* function (viz., d_3), albeit distinctly—a classic case of "multiple realization" (Zerilli 2017). We might even say that instead of a complementary coupling of skills between human and computer, what

we have under option (a) will often be a *supplementary* coupling—where each agent adds something unique to the decision problem in point of how the agent goes about resolving it (somewhat analogous to the role of an expert witness who "assists" the judge in determining the appropriate sentence for an offender).

Table 1 summarizes the logical space of decisions that may be automated, in whole or in part, and our recommendations for whether or not they should be. Figure 1 depicts both the presence and danger of complacency as a function of system reliability. Notice that at a certain point of reliability, the presence of complacency no longer matters. Notice also what the figure does not capture: it does not tell us what over-reliance on an algorithm looks like, or otherwise calibrate for a healthy or sceptical level of dependence on an algorithm.[Footnote3] This—which could well be called the measurement problem—is the subject of separate research in human factors, although it is probably fair to say that most design interventions and optimal task allocation and HCI paradigms are about preventing over-reliance rather than detecting it, no doubt (at least partly) because the hallmarks of over-reliance will differ from system to system and context to context (see e.g. Endsley 2017).

Table 1: The logical space of automatizable decisions and their attendant control problems

	For any decision D: { d_0, d_1, d_2 ... d_n}	
Option (a) Patently suboptimal system D (whole decisions)	Option (b) Decomposition/allocation d_0, d_1, d_2 ... d_n (semiautonomous decisions)	Option (c) Better-than-human system D (whole decisions)
Supplementary coupling/ human in the loop e.g. medical diagnostic tools **Proceed with caution**	Complementary coupling/ human in the loop (b + c) (DCAF) e.g. ACC (below) **Recommended** OR	No human in the loop e.g. SAE Level 5 AV (eventually); case prediction sofware **Recommended**

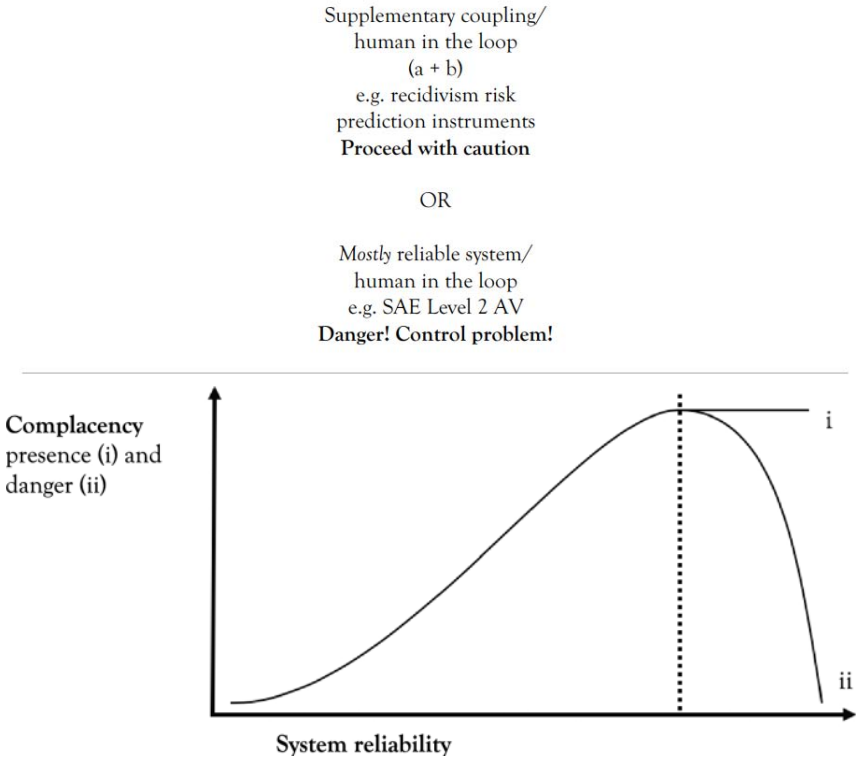


Figure 1: Presence (i) and (ii) danger of complacency as a function of system reliability. The dashed line represents near perfect (better-than-human) reliability.

System Reliability

The DCAF approach might be thought of as a variant of the "Privacy by Design" (PbD) approach—something like "Control by Design". PbD proponents want data protection principles taken into account throughout the whole lifecycle of information systems development (Bygrave 2017). Analogously, one could say that the DCAF approach seeks to "hardwire" human factors considerations into the development of HMSs from the earliest stages of modeling. For algorithmic decision support tools, we would suggest that the following six principles can serve as a framework both for assessing the viability of any such human–machine system as well as guiding their design and implementation:

- *Division of labour* Decisions with automatizable subcomponents should reflect a clear allocation of responsibilities between the human- and computer-operated parts of the decision.
- *Complementarity* The allocation of responsibilities should proceed in such a way that those subcomponents better suited for human handling are not automated, and those better suited for computer handling are not manually controlled. While an unhelpful aversion to algorithms can be reduced by giving users power to adjust a decision system's outputs (Dietvorst et al. 2016), human interference also tends to introduce errors (Fildes et al. 2009). Humans should stick to what they do best, such as communication, symbolic reasoning, conceptualization, empathy and intuition—provided these are the skills actually required for a particular decision (Pohl 2008). Intuition may be excellent in some decision contexts (who will be the best actor for this part?) but the last resort of a scoundrel in other contexts (what is the likelihood that this brown-skinned man with a history of mental health issues and no priors will re-offend?). A related point is that what may count as a virtue in a human may well count as a vice in a machine. "Graceful degradation" has long been regarded as one of the advantages of humans over machines (Fitts 1951), but as Bainbridge (1983, p. 777) pointed out, "[t]his is not an aspect of human performance to be aimed for in computers…automatic systems should fail obviously."[Footnote4] In short, complementarity means humans and machines have clearly defined and clearly separated roles, where the human is effectively barred from interfering with the machine's outputs and perhaps in many cases even knowing what the outputs are. Breaking the task up in this way also increases the chances of finding optimally reliable software to handle the automated parts of a decision.
- *Dynamism* The allocation of responsibilities should incorporate hand-over and hand-back protocols where this flexibility contributes to optimal performance. This assumes that some decisions can be safely handled by both humans and computers, i.e. where humans and computers have shared competencies within particular subdomains. Hand-over and hand-back may

also go some way towards alleviating the currency problem, as operators are thereby afforded an opportunity to practice and maintain their manual control skills (Bainbridge 1983).

- *Co-evolution* User requirements co-evolve over time, and decision support tools should reflect this. Decision support tools within HMSs should be designed for adaptability and change. This means designers should not over-specify how a system will work, but allow its users to tailor the system so that it best meets their particular needs (Walker et al. 2015, p. 201).
- *Pragmatism* Decision support tools "should be congruent with existing practices which may on occasion appear archaic compared to what technology now offers" (Walker et al. 2015, p. 201). When cell phones first appeared, people did not throw out their telephone directories and address books in short order. The older technology held on for a while longer until mobiles were subsumed into the Internet of Things. As new decision software gets tested and then rolled out, we think the same approach is advisable.
- *Context-sensitivity* Each decision tool, situated within its own unique decision context, may prioritise these principles and negotiate their various trade-offs differently.

We now turn to consider an algorithmic decision tool that exemplifies several of these principles in its design.

CASE STUDY: NEW ZEALAND'S ACCIDENT COMPENSATION CORPORATION (ACC)

Since 1974, New Zealand has run a universal no-fault accident compensation scheme for personal injury. Because the scheme is compulsory, all citizens/residents (or temporary visitors) who have suffered personal injury can expect to be covered regardless of whether or not another party is at fault. Most of the ACC's payments cover treatment/medical costs, but they also regularly cover lost earnings and home and/or vehicle modifications for those with more serious injuries. The ACC processes around 2 million claims per year, of which (on average) about 96% are accepted (ACC 2018).

Over the years, the ACC has largely relied on manual control for processing claims. In the past this has involved ACC staff members sorting through and assessing individual claims one by one. Even with improvements to case handling procedures over the years, such as technology allowing electronic submission, *all* claims have required some degree of manual processing (ACC 2018). At the time of writing, the ACC plans to introduce an improved claim registration and cover assessment process by the end of 2018. It aims to make the claims approval process quicker and more efficient, removing the need for manual control in standard cases altogether. The ACC hopes that by harnessing the power of big data—12 million claims submitted between 2010 and 2016—it can both reduce the wait time for approvals as well as more efficiently distribute the more complex claims to ACC teams for final determination.

There are two key features of the new claims handling process. First, the ACC's machine-learning algorithm (developed in-house) has been designed to identify such characteristics of a claim as are strictly relevant to whether it can be accepted. Thus, "[s]imple claims—where the information provided shows that an injury was caused by an accident—will be fast-tracked and immediately accepted" (ACC 2018). For example, the system would fast-track "someone going to the emergency clinic to have a cut stitched," but not someone presenting with "multiple severe injuries" (ACC 2018). Claims that are not accepted at this step will be passed along to ACC teams for manual processing. Second, the system is not able to *decline* claims—it can only *accept* claims that show up as straightforwardly involving accidents based on information provided by the claimant. In giving the tool this limited jurisdiction, its designers have ingeniously converted what is potentially a high-stakes decision into an extremely low one: for the tool cannot decide adversely, only inclusively.

The process runs as follows. Each claim moves through a series of automated system checks. At each "checkpoint," one of two things can happen: the claim passes, or it does not. If it passes, it proceeds to the next checkpoint. If it does not pass, the system flags it for manual processing. There are three checkpoints: one for *validation and eligibility*; a second for *accident description*; and a third for *cover decision* (final determination). At the validation and eligibility checkpoint, the system checks that the claimant has provided all essential information (e.g. location and date of accident, type of injury, healthcare provider,

claimant's employment and residency status, etc.). If the information is complete, the system passes the claim on to the accident description checkpoint. If the information is incomplete, the system flags it for manual processing. At the accident description checkpoint, the system attempts to categorize the claim in accordance with a predetermined taxonomy of claim types ("fall," "rugby accident," etc.). The system searches the claim form for words that correlate with recognized claim types. If the claim can be categorized in this way, it is passed on to the final checkpoint for determination. If it cannot be categorized, it is flagged for manual processing. At the final checkpoint, two statistical models are employed:

The "Probability of Accept" model is informed by a statistical model that uses data from 12 million previous, anonymised claims to calculate the probability a new claim should be approved. Each claim is then given a score, and ACC sets a threshold for scores that will be automatically accepted or not. A claim that scores above the threshold set by ACC will be automatically accepted for cover.

A claim that scores below the auto-acceptance threshold would then be run through the "Complexity" model, which categorises the claim on a scale of low-complexity through to high-complexity. Each claim is then given a complexity score, and ACC sets a threshold for complexity scores that will be automatically accepted or not. A claim that scores below the threshold set by ACC will be automatically accepted.

A claim that scores above the auto-acceptance threshold for complexity would then be referred for further manual processing by an ACC staff member.

Example: If a client submits a claim for treatment relating to multiple severe injuries and post- traumatic stress following a motor vehicle accident, their claim is likely to receive a high complexity score and would be referred for handling by ACC teams. (ACC 2018)

How well does the ACC tool incorporate the six human factors principles we outlined in the previous section? We think it performs commendably on at least three of our stated principles:

- *Division of labour* There is here a clear allocation of responsibilities between the human- and computer-operated parts of the decision regarding whether to approve claims.
- *Complementarity* The allocation of responsibilities proceeds in such a way that those subcomponents of the decision better suited

for human handling are not automated, and those better suited for computer handling are not manually controlled. Human controllers do not interfere with the automated parts of the process, which are therefore left to operate as essentially risk-free zones of automated decision-making. Humans are not able to perform such aspects of the "accident description" and "cover decision" subcomponents of the decision as are handled by the algorithm either as *accurately* or as *quickly* as the algorithm. In the ACC model, humans only intervene at the point where the algorithm reaches the limit of its competence to determine a claim.

- *Context-sensitivity* The allocation of responsibilities does not incorporate hand-over and hand-back protocols (i.e. it is not *dynamic*), but in this particular setup, such flexibility would not contribute to optimal performance. This means that the ACC tool has been deployed in a context-sensitive manner, *dispensing with* or *trading off against* principles that are not especially salient in the specific circumstances of deployment.

ARE THERE OTHER WAYS TO ADDRESS THE CONTROL PROBLEM?

Earlier we mentioned that the control problem appears to be resistant to training, and that experts are as prone to complacency as novices. Before concluding, we should say a little about some of the other commonly suggested strategies for overcoming the control problem.

First, there is some evidence that increasing accountability mechanisms can have a positive effect on human operators whose primary responsibility is monitoring an autonomous system. In an important study, Skitka et al. (2000, p. 701) found that "making participants accountable for either their overall performance or their decision accuracy led to lower rates of automation bias". This seems to imply that if the threat of random checks and audits were held over monitors, the tendency to distrust one's own senses might be attenuated. What effects these checks could have on other aspects of human performance and job satisfaction is a separate question, as is the question of how accountability mechanisms affect *complacency* (as opposed to bias). Parasuraman and Manzey (2010, p. 396) also warn that the results of this study are not conclusive. But clearly auditing

protocols, and perhaps more creative accountability measures, such as "catch-trials"—in which system errors are deliberately generated to keep human invigilators on their toes—could be quite useful in counteracting automation bias. Catch trials look particularly promising. While more research on their efficacy is needed before concrete guidelines can be promulgated recommending their adoption, they do seem to offer a viable means of getting humans more actively engaged in the control task. Footnote5 But in any case, much like other touted solutions to the control problem, they do not offer a *literal* solution: rather, they render systems that are mostly dependable (but not better-than-human) *less reliable by stealth* (as it were), capitalizing on the premise that less reliable systems do not induce the same complacency and bias that attend more reliable systems. Thus catch trials really fall under option (a) in our menu of strategies above.

Second, might having a *group* of humans in the loop, working together and able to keep watch on one another, alleviate automation bias? Apparently not:

Sharing monitoring and decision-making tasks with an automated aid may lead to the same psychological effects that occur when humans share tasks with other humans, whereby "social loafing" can occur—reflected in the tendency of humans to reduce their own effort when working redundantly within a group than when they work individually on a given task….Similar effects occur when two operators share the responsibility for a monitoring task with automation…. (Parasuraman and Manzey 2010, p. 392)

Finally we should note that Parasuraman and Manzey (2010, p. 387) added these observations in connection with the effects of training regimes: ***Although extended practice does not eliminate automation complacency, other training procedures may provide some benefit. In particular, given that complacency is primarily found in multitasking environments and represents attention allocation away from the automated task, training in attention strategies might mitigate complacency.***

We are not aware of research empirically substantiating this latter claim, but would anyway caution against task allocations that reduce human agents to monitors of largely static displays of information (if that is the implicit proposal here). Other studies cited by the authors, albeit in the

context of automation bias, indicate that even explicit briefings about risk factors in HCI do not mitigate the strength of automation bias, and this seems to be true in both multitasking and singletasking environments. An idle mind is not an empty mind, but rather a wandering mind, and when the stakes are high, the risk of complacency is still too great to be managed by rubber-stamp training interventions that make only a questionable difference to deep-seated psychological propensities. Perhaps there is then reason to be sceptical about the effectiveness of "warnings" or other guidelines about how best to use decision tools in judicial settings (as we mentioned earlier in regards to COMPAS). But it is a live research question.

CONCLUSION

Automation introduces more than just automated parts: it very often also transforms the nature of the interaction between human and machine in profound ways. One of its most alarming effects is to induce a sense of complacency in its human controllers. To date, little has been said about whether and to what extent the same problem arises from the use of ever more sophisticated algorithmic decision tools, including those exploiting cutting-edge machine learning techniques such as deep learning. We have endeavoured to show how insights from human factors research have great relevance to policy specialists working in AI regulation and policy. Among the factors which should be considered in the decision to automate any part of an administrative or business decision is the tendency of human operators to hand over effective control to an algorithm just because it works well in most instances. We argue that, except in special cases, whenever an automatizable decision is high-stakes or safety-critical, the decision support tool under consideration should not be deployed unless it has genuinely earned its keep. Failing that, a dynamic and complementary allocation of functions between actively engaged human operators and simpler but more nearly perfectly reliable autonomous systems should be considered the safest course.

Notes

1. Notice, incidentally, that it is therefore not just when a decision tool is architecturally opaque that a human operator should potentially be retained in the decision control loop, as is already

widely appreciated (e.g. IEEE 2017; House of Lords 2018). Even a fully technically transparent decision system may enjoin human agency to a greater or lesser extent.

2. The AI system in this case computed measures of structural brain connectivity from fMRI brain scans, and used these as inputs to a classifier. Accuracy was computed on unseen brain scans; the classifier's performance was significant at the $p < 0.001$ level. More generally, assessing the accuracy of machine learning systems can be a complex task, but suffice it to say that more meaningful accuracy rates would need to consider base rates, which are not always cited in the relevant studies. It is well known that when a base rate is lower than the false positive rate of a test, false positives will exceed true positives even for an extremely accurate test (the so-called "false positive paradox"). Stepping back a little, however, because our point here is just that in some highly formulaic and process-driven domains it appears that machines perform better than humans, the underlying base rates will not be strictly relevant. So long as machines perform better than humans in these domains (as our examples illustrate), these results should hold regardless of base rates.
3. We owe this point to an anonymous reviewer of the journal.
4. This is not always true. An object classifier should tell you how much a given object is like a chair, rather than move discretely from "chair" to some other category of objects: to that extent, classifiers certainly *are* designed with a view to graceful degradation.
5. Catch trials might not be such a good thing if case workers came to think that "odd" looking cases were "probably not real".

ACKNOWLEDGEMENTS

The authors wish to thank the participants of two roundtables, one held in Oxford, November 23-24, 2017, in partnership with the Uehiro Centre for Practical Ethics, University of Oxford, the other in Dunedin, December 11-12, at the University of Otago.

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CHAPTER 10

DIAGNOSTIC DECISION SUPPORT SYSTEM IN DYSMORPHOLOGY

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INTRODUCTION

Dysmorphology is the aspect of clinical genetics concerned with syndrome diagnosis in patients who have a combination of congenital malformations and unusual facial features, of- ten with delayed motor and cognitive development [1]. Making a diagnosis for a dysmorphic patient requires a high degree of experience and expertise [2] since many dysmorphic diseases are very rare. The human brain possesses a remarkable ability to recognize what is familiar or unfamiliar in a face. The general public can recognize the face shape of individuals with Down's syndrome and experienced clinical geneticists develop this innate skill to such a degree that they recognize subtle facial features associated with several hundred dysmorphic syndromes [3]. In some areas of the world, however, genetic

diagnosis is generally performed by general practitioners, dermatologists or pediatricians, not particularly trained in dysmorphology, rather than trained geneticists due to the lack in the numbers of geneticists. Dysmorphologic diagnosis is usually performed by referring the images or terms standardized and specified in some limited number of catalogs and databases. However, not being very familiar with the terminology, especially for practitioners in rural areas, is an important handicap to dig into the right diagnosis. This can lead to diagnostic inaccuracy which in turn curtails both the right cure of patients that will best suit their particular needs and the right guiding of their parents who may be at risk of having a new dysmorphic child. The whole process of reaching a genetic diagnosis can be very lengthy and entail struggling with referrals to numerous medical professionals and waiting for appointments. Throughout this process, parents find themselves dragged from one medical professional to another until discovering the accurate diagnosis of their child. These parents often experience high levels of burdensome anxiety and frustration. Moreover, delay in diagnosis may also delay access to critical services such as clinical trials and a patient's referral to supportive services including early intervention, physical or occupational therapy. Syndrome recognition and diagnosis is of clinical importance for several reasons according to Smithson [1]: first, it influences patient management because awareness of the pattern of anomalies associated with a particular syndrome highlights the investigations that need to be undertaken; second, diagnosis provides information about the long-term prognosis and may help to identify options for treatment: for example, bone marrow transplantation or enzyme re- placement therapy can now be offered for some inborn errors of metabolism (e.g. in Fabry disease); third, the diagnosis determines what genetic advice can be given, including an estimation of genetic risks and possible means of prenatal diagnosis. Thus, delays in early treatment can have a miserable impact on the patient's health and can dramatically influence the chances of the child catching up to his/her peers and leading to a normal life. Therefore, reaching a thorough genetic diagnosis at an early stage is crucial. Not only does this affect the choice of cure for the patient, but it also enables the proper guidance, counseling and support for the parents to ensure an overall improvement in the patient's quality of life and care. Most physicians, neurologists or pediatricians are capable of noticing these early signs in a child, but are not equipped to perform a precise genetic

diagnosis on their own especially for very rare diseases. Since there are thousands of possible genetic conditions to be taken into account and each condition is in itself very rare, a specialist's evaluation generally seems the best path to ensure a proper genetic diagnosis is reached though it is sometimes very difficult even for geneticists to diagnose these orphan diseases.

The face is widely recognized as an attribute which best distinguishes a person, even at first glance. Facial features give lots of clues about the identity, gender, age and ethnicity. The face develops under the influence of many genes and in many cases a face provides important information to diagnose a syndrome. Thus, facial appearance can be a significant hint in the initial identification of genetic anomalies generally associated with cognitive impairments. There are specific properties, especially for facial dysmorphology caused by genetic syndromes and these properties are used by geneticists to pre-diagnose even before a clinical examination and genotyping are undertaken. Analyzing of properties in faces is sometimes sufficient to diagnose for some cases, however, it is necessary to analyze other specific properties of the body such as the structure of the skeleton and the characteristics of speech produced for some other cases. Diagnosing of genotype-phenotype correlations correctly among many syndromes seems beyond the capability of human especially for very rare dis- eases. Most of the genetic diagnostic decision support systems (DDSS) have been applied in terms of the anthropometry and more specifically craniofacial anthropometry including stereophotogrammetry1 so far. It might be possible to diagnose a good number of syndromes correctly by using computer-assisted face analysis DSS as asserted by some scientists such as Farkas [4], Loos [5], Boehringer [2], and Hammond [6, 7]. Farkas [4] pioneered techniques for studying facial morphology using direct anthropometry for nearly 40 years ago [4]. His approach, using a ruler, calipers, tape measure and protractor, has been applied widely in the analysis of facial dysmorphology [7]. Many clinicians undertake such a manual craniofacial assessment and compare a patient's phenotype to the norms of a control population of comparable age and sex [7]. A most recent study of Hammond [7] has re- viewed the surface-based image capture in 3D in syndrome delineation and discrimination, in the categorization of individual facial dysmorphology and in phenotype–genotype studies which is a very complex implementation of dysmorphological diagnosis

process in a clinical environment. For dysmorphic syndromes with known genetic causes, molecular and/or cytogenetic analysis is the appropriate route of investigation in order to confirm a diagnosis. However, applying right analysis method throughout many probable analyses is very much dependent to the accurate diagnosis considered before genotyping is undertaken. The aim of this chapter is to propose a new methodology by observing the characteristic key components of facial dysmorphology associated with genetic disorder to indicate the right diagnostic criteria.

Douglas [8] has stated that classification of faces based on facial patterns in isolation is un- likely to be accepted by dysmorphologists unless the mathematical features extracted and identified by feature selection algorithms to be discriminatory can be related to facial appearance. Principal component analysis (PCA), independent component analysis (ICA), kernel principal component analysis (KPCA), local feature analysis (LFA), probability density estimation (PDA), multi-linear analysis (MLA), elastic graph matching (EGM), kernel discriminant analysis (KDA), support vector machine (SVM), Gabor wavelet and Fischer's linear discriminant analysis (LDA) exist to analyze the features of a face. Among them, the methods of PCA using eigenface, elastic graph matching, Gabor wavelet and Fischer's LDA are popular for face recognition. PCA can be computed as an optimal compression scheme that minimizes the mean squared error between an image and its reconstruction [9] as well as it may achieve good results of up to 96% recognition under ideal conditions [10] which can be provided with either capturing images in ideal environments by having a good illumination and using a good capturing device or preprocessing of images with several image processing techniques before extracting features. PCA using eigenfaces have been identified as computational efficient on even reduced hardware [11]. Additionally it is used for dimension reduction as in our study from 2D to 1D to ease and speed up the calculations. That is to say, the dimensionality of the required space for all images can be reduced to the number of input images instead of the pixel count that all images have in total.

City block distance, Euclidean distance, sub/space method, multiple similarity method, Bayes decision method and Mahalanobis distance are known typical distance functions [9]. Kapoor [9] highlights that the Mahalanobis distance is the most effective of the typical evaluation

distance-based approaches that calculate the distance from a point to a particular point in the data set. We have tested the Mahalanobis distance and Euclidean distance in our study to find the genotype-phenotype correlations. The well/known Mahalanobis distance classifier2 is based on the assumption that the underlying probability distributions are Gaussian [9]. Kapoor [9] indicates the difference such that Mahalanobis distance is a distance measure based on correlations between variables by which different patterns can be identified and analyzed. It is a useful way of determining similarity of an unknown sample set to a known one. It differs from Euclidean distance in that it takes into account the correlations of the data set and is scale-invariant, i.e. not dependent on the scale of measurements. In our study, the well-known Euclidean distance matching process outperformed the process of Mahalanobis distance. Thus, we chose this matching technique in our study.

Hammond [7] pointed out that in terms of future technological support, two (2D) or threedimensional (3D) models of facial morphology are showing potential in syndrome delineation and discrimination, in analyzing individual dysmorphology, and in contributing to multi-disciplinary and multi-species studies of genotype–phenotype correlations. Our study is an example of substantiating this potential. We have developed a real-time computer sys- tem that can locate and track a patient's head, and then recognize the patient by comparing characteristics of the face to those of trained individuals with classified dysmorphic diseases. In this study, in terms of both the feature extraction and helping non experienced practi- tioners in diagnosis process as well as to support experts in their decisions, we established an application to ease the process and we refer to our method as "Facial Genotype-Phenotype Diagnostic Decision Support System (FaceGP DDSS) in Dysmorphology". Up to date, no complete solution has been proposed that allow the automatic diagnosis of dysmorphic diseases from the raw data (live camera, video or frontal photographs) without human intervention. The FaceGP DDSS aims not only to ease the required on-site expertise, but also to eliminate the time consuming catalog search of practitioners and geneticists to diagnose facial dysmorphic diseases through approximately 4.700 known dysmorphic diseases3 automatically, no intervention from the user such as preprocessing of images. The FaceGP DDSS methodology can be implemented on any site easily. In the methodology, reference images or

reference patients on live subjects having the specific dysmorphic diseases are used as a guide for identifying the facial phenotypes (the outward physical manifestation of the genotypes) to train the system. Digital facial image processing methods are employed to reveal facial features with disorders indicating dysmorphic genotype-phenotype interrelation. A great number of genetic disorders indicating a characteristic pattern of facial anomalies can be classified by analyzing specific features (eigenfaces) with the aid of facial image processing methods such as PCA. Distance algorithms such as Euclidean, Mahalanobis are used to construct the correlation of the input image with the trained images in matching. Some image enhancement methods such as histogram equalization and median filter are implemented on detected images to capture better features and compensate for lighting differences. This study proposes a novel and robust composite computer-assisted and cost-effective method by merging several methods in the characterization of the facial dysmorphic phenotype associated with genotype, in particular a method relying primary on face image capture (acquisition from either camera, video or frontal face images) and manipulation to help medical professionals to diagnose syndromes efficiently.

METHODS

The FaceGP DDSS methodology has been established in C++ programming language. We benefited OpenCV4 library. The application can function on any present computer, not re- quiring much CPU and memory while processing thanks to the easy implementation of PCA. The methodology comprises several main modules, namely face detection and image ac- quisition, image processing, training and diagnosis/recognition module, and these main modules are divided into several sub modules as illustrated in Figure1. Functions of these modules are explained in following subsections in detail.

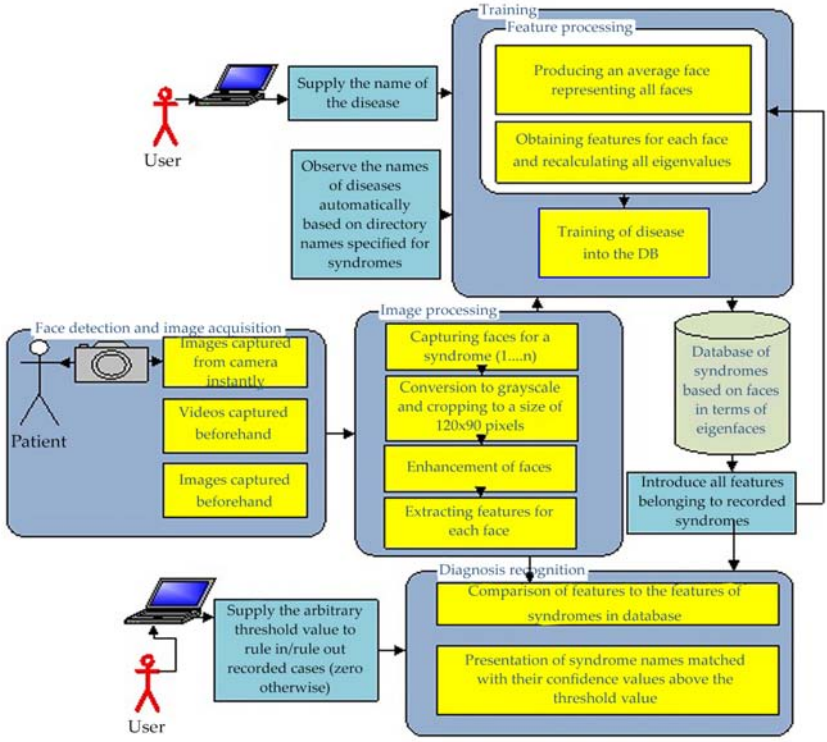


Figure 1: 1. Overall architecture of the methodology: the system consists of four main modules; face detection and image acquisition, image processing, training and diagnosis/recognition module. These modules are divided into several sub modules that are delineated in the specified sections of the modules.

Face Detection and Image acquisition

The patient images can be captured from several different environments: they can be cap- tured from softcopy images stored in a disk, it can be observed from hardcopy pictures or real-time images which can be detected simultaneously from patients by a camera attached to the computer. The images can be automatically captured on an ordinary high-resolution digital camera (e.g. 8 megapixels) mounted across the patient (no matter what the distance is), provided that a frontal face is detected (to prevent motion artifacts). Natural movements of the body at rest (e.g., breathing), and a person's inability to sit motionless result in

no problem as the camera detects and acquire images in a short period of time. Time of capture per image is 0.2s which is triggered by the system automatically excluding time for not ac- quiring frontal faces. Capturing images is so instantaneous that it may be more suitable for imaging children with mental retardation who are unable to hold a pose for long and poten- tially uncooperative. Images not including a proper frontal face are not captured and the ap- plication is idle during this time, especially when the head turning to sides, up and down. Frontal faces are the essential components of our data preparation and model building. In other words, the process of capturing images is just performed if the application detects an acceptable frontal face. The application is able to capture sufficient number of frontal images in real-time, which is required to train the system for subsequent analyses.

Image Processing

Capturing faces for a specific case

Images of patients are acquired for a specific syndrome either to train or to diagnose in terms of the function triggered by the user. The functions of the implementation are explained in the next section. The system activates the diagnosis function as it detects the images of patients if this function is triggered. Otherwise, it expects user interference to activate the training function in order to make sure that the procedure of capturing all required frontal face images for a specific syndrome is finished.

Conversion to grayscale and cropping of images

After images of patient are acquired, they are converted to grayscale and cropped to include just faces by relying upon the face outline, forehead, two eyes, cheek, chin and mouth. This stage is finalized by normalizing the image with a size of 120x90 pixels. Processing of this phase as depicted in Figure 2 ensures that all face images are exactly positioned the same regarding a proper rotation. A background removal algorithm is not implemented due to the cropped face in which there is almost

no background and the rest of the image is re- moved before feature extraction.

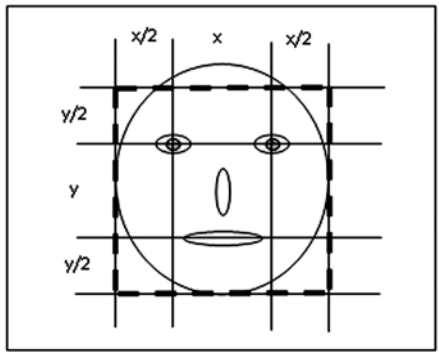


Figure 2: Delineation of cropping a dysmorphic face.

Enhancement of face images

The face images are standardized by employing two essential image enhancement methods, namely histogram equalization and median filtering to remove illumination variations in or- der to capture better features. Histogram equalization employed on an image is known to provide better extraction of features [14]. Histogram equalization is applied on too dark or too bright face images in order to enhance image quality and to improve diagnostic performance, thus, facial features become more apparent by enhancing the contrast range of the image. Median filtering is very effective to enhance images especially obtained from a cam- era without losing information [15]. There is no preprocessing of frontal images manually.

Feature extraction

Extraction of facial features is implemented in this sub module. After automatic image preprocessing is employed on raw image data, the feature extraction is implemented on the normalized face image to reveal the key features that are used to classify and recognize dysmorphic diseases. The FaceGP DDSS methodology is designed for modeling and analyzing large sets of face images. Whichever method is used, the most

important problem in face recognition is reducing the dimensionality in terms of easing computational complexity. We haven't used craniofacial landmarks or extracting feature graphs5 . Instead; we performed principal component analysis (PCA) which is a very effective method at classifying face images in the sense of reducing computational complexity. PCA which evaluates entire face is implemented to extract the features of dysmorphic faces in terms of its simplicity, learning capability and speed. PCA may be defined as the eigenvectors of the covariance matrix of the set of face images, meaning an image as a vector in a high dimensional space. It classifies the face images by projecting them to the 2-D space which is composed of eigenvectors obtained by the variance of the face images. These eigenvectors are a set of features that characterize the variation between face images. In other words, the features of the images are obtained by looking for the maximum deviation of each image from the mean image. Each image location contributes more or less to each eigenvector, so that it is possible to display these eigenvectors as a sort of ghostly face image which is called an "eigenface". Eigenfaces can be viewed as a sort of map of the variations between faces. PCA reduces the dimensionality of the dataset. Thus a face of 8-bit intensity values can be represented by an ordered sequences numbers in a vector, one dimensionally with PCA. This is a huge data compaction, as in our case reducing the representation of a face surface from 10800 dimensionality space (120x90 2D points each with x and y coordinates) down to 1 per image. Each face can be regenerated from eigenvalues using a linear weighted sum of the PCA modes in return. The most relevant information contained in a dysmorphic face image is extracted by PCA6 . Briefly, after capturing sample dysmorphic images and normalizing them following some automatic image processing methods, eigenfaces are generated and saved. An eigenface keep values that make a dysmorphic image unique.

Training

The eigenfaces, eigenvalues and average image generated by PCA are stored in XML file as Haar-like features7 together with their labeled diagnosed names. The methodology has the ability to store and read data in XML format. The number of generated eigenfaces (n-1) is almost equal to the number of input images (n) in our study. Classifiers are

trained with those features extracted by feature extraction module. As new dysmorphic diseases are trained, the eigenfaces and eigenvalues are recalculated.

Users can easily add new dysmorphic diseases by using their archives in which there are several sample images representing other diseases not defined in the system one by one as well as more than one disease once by the help of the utility provided by the system.

Diagnosing/Recognition

The trained classifiers are employed for prediction in this sub module. Diagnosing/recognition process is a pattern recognition task. The prediction of the diagnosis of a patient re- quires the detection of frontal face from a camera or a file, normalizing and processing of face with techniques mentioned in Section 2.2 and extraction of facial features for comparing the trained classifiers. A dysmorphic face image captured and processed is transformed into its eigenface components and then these components are compared to those of predefined labeled classes. There are a number of algorithms in the literature that can compare faces to look for a match. A simple and intuitively appealing way to compare an individual face with two sets of faces is to calculate how close for which a method is a nearest-neighbor classification, how close are they in terms of the Euclidean distance. Once a face has been detected and extracted from an image it is ready to be compared against known/trained syndromes to see if there is a similarity. The captured face image compared to all the syndromes trained in the database one by one for similarities to make sure all similar faces above the threshold value are found in terms of the Euclidean distance. The role of Euclidean distance comparison for image recognition is not much different in that it tries to capture how similar or different a test object is from training objects in terms of the 50 or so mode values, that face surface is to the average face surfaces of each set. Whichever of the average faces is closest determines the classification of the individual. In other words, during the recognition stage, when a new image is input to the system, the mean image is subtracted and the result is projected into the face space. The best match is found for the identity that minimizes the Euclidean distance. For example, for a particular syndrome, the features obtained from the PCA is compared to

the trained faces in the database using an Euclidean distance comparison to calculate how close it is to the features of faces in the Database. The similar faces above the threshold value supplied by the user are probable diagnoses displayed to the user. Confidence values can be defined as the resemblance or degree of proximity of eigenface values (how near they are) between two sets of eigenface values obtained from the values of the trained diagnostic images and the identified image to be diagnosed. These values are used for assessing the reliability of the proposed diagnostic inference by the system.

Diagnosis is where the system compares the given patient's face features to all the other trained face features in the database and gives a ranked list of possible matches with respect to the confidence values above the threshold value. In our system, probabilities of similarities in diagnostic process are revealed to the user in a decreasing order rather than either "known" or "unknown" outputs as in face recognition systems, after comparing an undefined dysmorphic face with recorded defined dysmorphic faces that are diagnostically classified. That is to say, our system is not a face recognition system; rather, it is how much a disease is similar to the diseases classified in the database as ruling in or ruling out diseases in terms of the threshold value supplied by the user. This cost effective diagnosis methodology could then help to determine subsequent investigations including more appropriate genetic testing, and possibly even avoiding or delaying the need to undertake some of the more expensive genetic tests.

Interface and the Functions of the Methodology

A screen shot of the implementation is presented in Figure 3. The main utilities of the implementation are explained in following sub-sections.

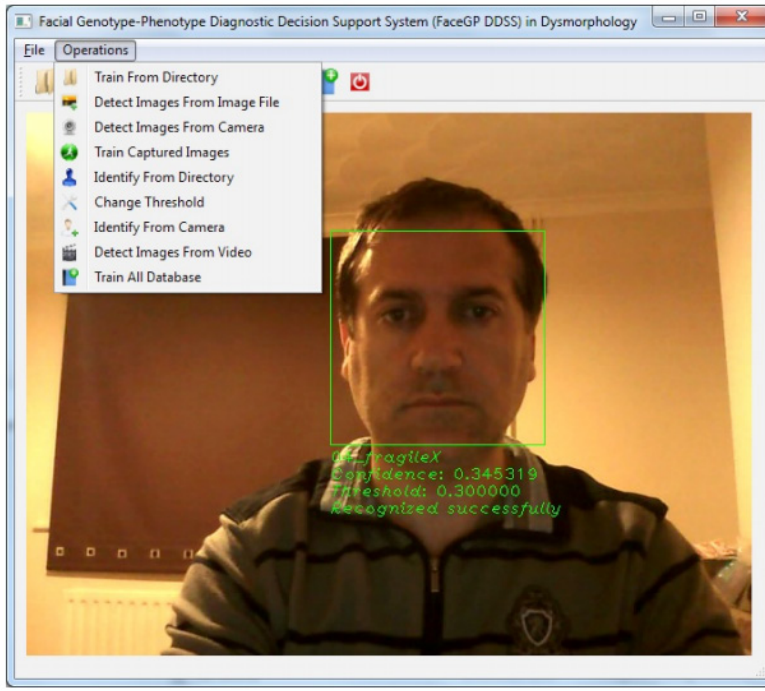


Figure 3: An example for the diagnosing process via camera: Four messages are displayed; the name of the probable diagnosis (e.g. Fragile X), the degree of proximity to that diagnosis (e.g. 0.345319), the threshold value entered by the user (e.g. 0.30), the message about whether a probable disease is found or not as "recognized successfully" or "un- known disease". The messages change if other diseases are found above the threshold value to reveal them on the screen. All the time required to search through 7 trained identified diagnoses that include 34 eigenfaces and find the nearest diagnoses in respect to the threshold value is few seconds.

Detect images from image file:

This utility detects faces from the images displayed on the screen where images are brought from the chosen directory automatically. Detection stops and training process begins when the user clicks the utility "train captured images". The name of the disease is entered by the user.

Detect images from camera:

This utility detects face appearances on live camera from a patient or patients who are diagnosed with same dysmorphic disease. Detection stops and training process begins when the user clicks the utility "train captured images". The name of the syndrome is supplied by the user.

Detect images from video:

Face images of a patient or patients who are diagnosed with same dysmorphic disease are detected from a video or several videos. Detection stops at the end of video and training process begins when the user clicks the utility "train captured images". The name of the syndrome is presented by the user.

Train captured images:

Detected face images from either a directory or a live camera are processed to be classified into the database.

Train from directory:

A directory in which there are several images of a specified disease is chosen and the name of that syndrome is entered by the user. All necessary algorithms are run through training of the diseases automatically. Diseases can be trained one by one by this utility.

Train all database:

All labeled diseases in a directory are processed by "face detection and image acquisition" and "image processing" modules respectively and automatically. Then, processed cropped frontal face images are trained into a database without user intervention by training module. In other words, all modules in Figure 3 are employed automatically. The system accepts the directory names where the dysmorphic images are as the names of the syndromes while training the datasets. The only thing expected from the user is to specify the folder where the datasets are.

Change threshold:

The user can specify the threshold value to rule in or rule out diseases during the identification process. The greater the threshold value is, the less the number of probable diagnoses is proposed, vice versa, the less the threshold value is entered, the greater the number of diagnoses is revealed to the user together with confidence (probability or proximity) values.

Identify from a directory:

Several images in a directory can be chosen at once and these images can be compared to the labeled syndromes stored in the database. A video that has dysmorphic patients can be chosen to diagnose probable diseases as well.

Identify from a camera:

A patient can be captured from a live camera mounted to the computer to diagnose a syndrome stored in the database.

Evaluation of the Methodology

A case study has been carried out to evaluate the methodology. We have analyzed 2D frontal face pictures of patients, each being affected with one of the syndromes. The scope and the design of the case study are presented in the following subsections. The findings of the study are presented in the next section, results.

Study sample

The study sample was composed of 7 syndromes comprising 35 individual frontal faces (5 for each) of patients that are included from Boehringer's study [2]. These diseases depicted in Figure 4 are microdeletion 22q11.2, Cornelia de Lange, fragile X, Mucopolysaccharidosis III, Smith–Lemli–Opitz, Sotos and Williams–Beuren. The patients for each syndrome are

more or less the same age, but, in different genders (10 females and 25 males) for 5 syndromes that are microdeletion 22q11.2 (3 F: Fmales, 2 M: Males), Cornelia de Lange (2F, 3M), Smith–Lemli–Opitz (2F, 3M), Sotos (2F, 3M) and Williams–Beuren (1F, 4M).



Figure 4: Seven syndromes: each row comprises one syndrome; microdeletion 22q11.2 (3 F: Females, 2 M: Males), Cornelia de Lange (2F, 3M), fragile X (5M), Mucopolysaccharidosis III (5M), Smith–Lemli–Opitz (2F, 3M), Sotos (2F, 3M) and Williams –Beuren (1F, 4M).

Study design

7 syndromes were trained by the utility named "Train all database" mentioned previously. The system could build a training set for 7 syndromes that have 34 eigenfaces for 35 faces less than one minute. The mean face and all 33 eigenfaces are displayed in Figure 5 and Figure 6 respectively. The first four images from the syndromes were used as a testing set to measure the recognition/diagnosis success. All these test images were put in a directory and each test image was compared to other trained 34 images in the database to measure how close it is on the vector space to others by using the utility of "identify from directory". All recognition process lasted about 1 minute in terms of pairwise comparison. This utility produces confidence values in a table and diagnose regarding these values above the threshold value entered by the user. In our case study we have aimed to find the probable diagnoses in the sense of rule-in 1, rule-in 2 and rule-in 3 diagnoses respectively by adjusting the threshold value for each person. Then, the success rates of these n-rule-in observations were obtained.



Figure 5: Mean face for 7 dysmorphic diseases generated by the system.

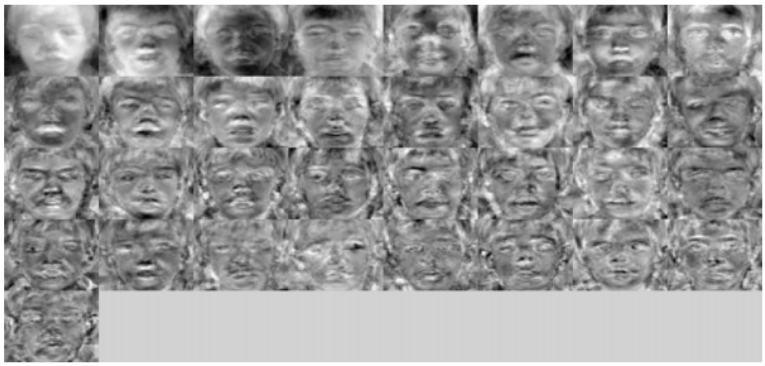


Figure 6: Eigenfaces of 7 dysmorphic diseases that comprise 35 frontal face images.

RESULTS

The threshold value entered by the user increases or decreases the possible number of diagnoses, the less the threshold value is entered, the more diagnoses are proposed; vice versa, the less diagnoses are included to be examined by the medical professionals. Pairwise analysis of 28 patients in 7 different syndromes is depicted in Table 1 regarding the confidence values. Each column corresponds to an individual patient's comparison to other patients one-to-one on the vector space of eigenfaces. The greater the value a column, the greater the probable proximity it has corresponding to that row whose syndrome indicates the probable diagnosis. The threshold value for each column is adjusted to rule in one, two and three diagnoses respectively. The results of three diagnoses for each tested patient are presented in Table 2 in which the gray cells correspond to the right diagnoses. Ruling in one, two and three diagnoses yields 21, 26 (extra 5 to rule in one) and 28 (extra 2 to rule in two) correct diagnoses among all 28 tested patients respectively. Ruling in one, two and three diagnoses designates the success rates of 75, 94 and 100 percent respectively as well. The diagnostic success rates are depicted in Figure 7

Table 1: Pairwise comparison: Each column corresponds to an individual patient's comparison to other patients one-to-one on the vector space of eigenfaces in terms of the proximity. The greater the value a column has, the greater the probable proximity it has corresponding to that row whose syndrome indicates the probable diagnosis. First column together with first row corresponds to the syndromes (e.g. 1 corresponds to microdeletion 22q11.2). Second column together with second row indicates the number of the images in the specified syndrome in the first column or first row

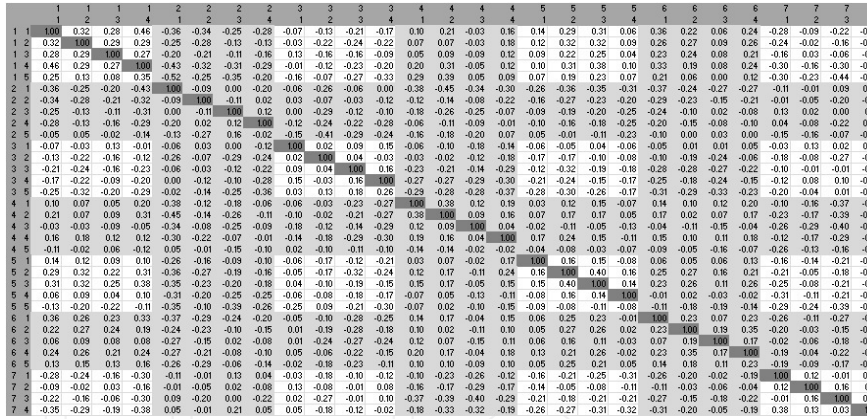


Table 2: Ruling in one, two and three diagnoses regarding the greatest values in columns of Table 1: the grey cells correspond to the right diagnosis. Ruling in one, two and three diagnoses yields 21, 26 and 28 correct diagnoses with success rates of 75, 94 and 100 percent among all 28 tested patients respectively. For instance, the value, 0.464, is observed from the cell where the syndrome name is coded as 1 and the frontal face is coded as 4. This indicates that the frontal face which is coded as 1 in the syndrome list of 1 is the most proximate with a confidence value of 0.464 that is the greatest value in that column

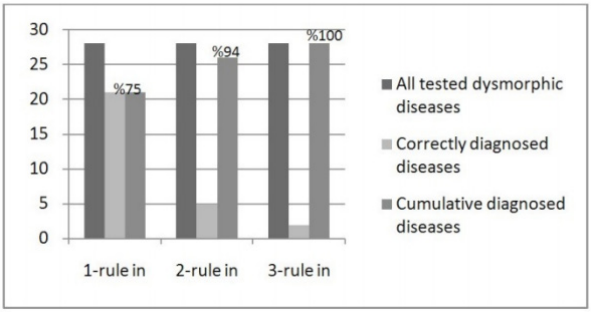


Figure 7: Graphical representation of success rates with respect to ruling in one, two and three diagnoses concerning the values in Table 2. Ruling in one, two and three diagnoses yields 21, 26 (including 5 more) and 28 (including 2 more) correct diagnoses among all 28 tested patients respectively. This designates the success rates of 75, 94 and 100 percent respectively as well.

DISCUSSION

Main Findings

FaceGP DDSS methodology has a success rate of 75%, 94% and 100% in terms of ruling in one, two and three diagnoses respectively. The results show that FaceGP DDSS methodology is able to make a biometric identification among syndromes successfully and efficiently based on the features of the patients' frontal faces, even though, the methodology has been tested by a limited number of 7 syndromes. Diagnosing syndromes correctly among many syndromes can be eased by the methodology provided that it is trained with those syndromes. One specific result of the study is that all test frontal faces of three syndromes that are microdeletion 22q11.2, fragile X and Williams–Beuren are correctly diagnosed in ruling in one diagnosis. Ruling in two diagnoses covers the 5 syndromes correctly whereas the ruling three does all seven syndromes. From these results we can conclude that the implemented methodology especially can guide medical professionals to employ correct cyto- and/or molecular genetic analysis that is the appropriate route of investigation in order to confirm a diagnosis with known genetic causes by ruling in probable diseases. Even with adequate knowledge, there remains the problem of

reconciling sometimes imprecise descriptions of dysmorphic features in the literature with a personal and potentially subjective examination of an individual patient [7].

Preliminary results indicate that the application can be trained with many syndromes in several minutes and syndrome recognition can be established in few seconds either from an attached camera or from a file. We expect that the performance of the system doesn't degrade as the syndrome number grows owing to the computational efficiency of PCA. Moreover, multiple diagnostic as well as multiple training of syndromes effectively and efficiently can be employed easily with the implementation which will attract medical professionals most. During training process, the larger the training dataset per syndrome, the better the success of syndrome recognition is, thanks to the pair wise comparison in our study, regarding different characteristics even in same syndromes such as Down syndrome that has three subtypes9 and cri du chat syndrome that has several variations in the feature10. Our implementations may be used to assist in diagnosing and defining facial phenotypes associated with syndromes in different ethnic groups and in different age groups provided that these kinds of cases are included into the training process of a specific syndrome.

Comparison to Other Published Studies

Hammond [7] has pointed out that there are well documented approaches to recording craniofacial dysmorphology in a more objective fashion. Moreover, he [7] has asserted that international experts in dysmorphology are currently developing standardized terminology to address issues of imprecision and inconsistency. Most genome-wide association studies to date have focused on a limited number of specific diseases or traits to test whether a computer can classify syndromes and then recognize them when compared to new cases. There have been successful discrimination studies using images of children with a limited number of dysmorphic syndromes [2, 5, 6, 16]. Some robust composite computer assisted decision support systems are needed to be established not only for practitioners but also geneticists to support their decisions through thousands of dysmorphic diseases. FaceGP DDSS methodology is aimed to serve several needs of medical professionals who work in dysmorphology. This study presenting

the FaceGP DDSS methodology contributes to the medical environment in several aspects. One of which is the support of general practitioners or pediatricians in the rural areas rather than trained geneticists as well as making easy of works for geneticists throughout thousands of dysmorphic diseases defined in some catalogs and databases. The other one is that a limitless number of dysmorphic diseases can be trained and tackled with FaceGP DDSS methodology in diagnosing process simultaneously. On the other hand, other similar studies having a fixed number of syndromes up to 10 in number are implemented to reveal the potential rather than to be an application to serve medical professionals for their everyday needs. Right diagnosis and consequently right treatments can influence progression of disease, especially in term of removing the effects of environ- mental factors11. For instance, when you supplement a patient having a syndrome with hormone, the patient may get better. The FaceGP DDSS methodology is designed primarily for investigators who wish to diagnose their patients with dysmorphic diseases quickly, effectively and successfully. Furthermore, it aims to support scientists for their studies who do not have expertise in the particular domain of dysmorphology. A new understanding of ruling in/ruling out diseases in our methodology can be very helpful for geneticists who wish to employ cyto- and/or molecular genetic analysis for their cases to confirm probable diagnoses. Moreover, the application is ready to be used with a user friendly interface when implemented at any site. Our methodology, noticeably different from others, doesn't require any manual intervention or preprocessing of images by users, rather, all necessary algorithms have been embedded into the methodology.

Medical professionals may construct their own databases in terms of their own dysmorphic facial findings, thus facilitating incorporation of their findings into the examination as well as may add their special cases into a formerly constructed database. In addition, these data- bases, later, can be shared in a web environment, can be easily used as plug-and-play separately and furthermore, valuable databases can be united in a unique database after their evaluation by an expert group to be served to the knowledge of the scientific community. This opens the door to cross-study analyses of not only the primary genotypes-phenotypes dysmorphological diseases (prevalence < 1/25.000) but also secondary genotypes-phenotypes syndromes (prevalence < 1/25.000, maybe

1/100.000). However, probable specified genotype-phenotype diseases should be trained before presenting the application to the use of the medical professionals to gain their support.

Users could benefit the methodology with a user friendly interface without any manual intervention which may cause the users to avoid the use of any system. These findings refute the notion presented in several studies that manual steps cannot be excluded entirely from any dysmorphic facial analysis software that intends to extract as much information as possible.

Limitations of the Study

There are several concerns that we should keep in mind while implementing these kinds of studies. Some genetic dysmorphic diseases could not be brought into scientific literature for especially two reasons. One of which is that many cases are lost before birth and nobody doesn't have any incentive to investigate the reason and eventually no one knows the cause; the other and the most important one is that families facing nonspecific cases don't permit the geneticists to investigate the cases, even though the investigation would help the families greatly for their future decisions12 and consequently babies or fetus are buried with their genetic secrets in the sense of the ethical rules. On the other hand, in practice, some genetic dysmorphic diseases that are very rare (e.g. prevalence 1/100.000) are not globally defined and they are stored in the local Electronic Medical Records (EMRs) or research databases across different medical institutions without any common data structure or representational format. These data elements are needed to be presented to the knowledge of the genetic communities on behalf of the current and future healthy population. Our ability to fully understand the genetic basis of common diseases is significantly hindered by the inability to precisely specify the phenotypes and in particular, identifying and extracting phenotypes at large varies greatly between different medical specialties and institution, and lacks the systematization and throughput compared to large-scale genotyping efforts [22]. Beyond these clinical aspects, dysmorphology has contributed much to current understanding of the genetic basis of human development [1]. Moreover, imprecise and nonstandardized nomenclature, especially of facial features, places a major difficulty for the communication between clinical geneticists [2]. It

has to be noted that neither 2D nor 3D methods have direct applicability in clinical practice yet, as the number of specified syndromes is still very small [2].

As Boehringer [2] emphasize, database support with respect to facial traits is limited at present to apply similar studies as we do to establish better applications. Distinctive dys- morphic frontal faces specific to dysmorphic genotype-phenotype diseases are needed to train the system. Currently, in our study, a very limited number of dysmorphic genetic dis- eases by using frontal faces have been trained for further recognition process. There are sev- eral genetic databases such as eMERGE (Electronic Medical Records and Genomics) and PhenX (Consensus Measures for Phenotypes and Exposures), Dysmorphology Database in Oxford Medical Databases (OMD) and OMIM. One of which named OMD is more appropri- ate for our study, because it is better prepared to reveal genotype-phenotype associations in terms of images and taxonomy of dysmorphology, although it has very limited number of frontal faces for syndromes. One of the reasons that we work on frontal 2D image analysis is that this prominent database (OMD) that we aim to include into the study contains 2D genetic dysmorphic images rather than 3D videos by which the number of frames are captured and recorded. Moreover, most of the geneticists studying on dysmorphic diseases usually keep 2D images of their patients in their databases. The main drawback of the majority of 3D face recognition approaches is that they need all the elements of the system to be well calibrated and synchronized to acquire accurate 3D data (texture and depth maps) [19]. That will make it easier for investigators to collect and analyze the 2D dysmorphic data associated with genotypes. Whereas capturing of 3D information results in a richer data set and al- lows for excellent visualization despite the difficulties in possessing the technology and in detecting 3D as mentioned by Kau [13]13, 2D analysis has several advantages in practical use: equipment is cheap and it is easy to handle [2]. Conventional and digital two-dimensional (2D) photography offer rapid and easy capture of facial images. 3D analysis of syndromes would sure give better results as depicted in Hommond's study [6]. However, the lack of available data in 3D invalidates any methodology implemented for the near future.

Of course, recognition of face shape does not imply a diagnosis. A

diagnosis is made by an appropriately trained clinician backed up, whenever possible, by genetic testing. For some dysmorphic syndromes there is no definitive genetic test and a clinical diagnosis has to suffice. For others, for example Noonan syndrome, a number of important genes may have been identified, but mutations for those genes may not be found in some children for whom there is a compelling clinical diagnosis [3].

A masking is not applied to remove the background of the cropped faces in our study. By employing a background mask, which simply provides a face shaped region, the effect of background change would be minimized and diagnosing success would be better which is going to be an improvement as a further study. Furthermore, we couldn't reach the raw material of 7 syndromes in which the photos we utilized in our study are not in good condition in terms of their appearances. Moreover the patients are not same ages and same sexes for each syndrome. The results would be better if better images were utilized and if the patients were in similar age group and sexes in the study. The more faces bearing the characteristics of any syndrome included in the training, the better the recognition of that syndrome will be.

CONCLUSION

In terms of future technological support, two (2D) or three-dimensional (3D) models of facial morphology are showing potential in syndrome delineation and discrimination, in analyzing individual dysmorphology, and in contributing to multi-disciplinary and multispecies studies of genotype–phenotype correlations [7]. Our study is an example of substantiating this potential. We describe a new approach to syndrome identification by merging several algorithms. The algorithms that we included in our study are not novel. They have been utilized in many studies so far. However we included most essential ones in a robust composite understanding in a way to serve the everyday needs of the medical professionals who work in dysmorphology. The preliminary results indicate that computer based diagnostic decision support systems such as the one we have established might be very helpful to assist medical professionals in genotype-phenotype dysmorphic diagnosis. The study reveals that the differences between facial regions such as facial

landmarks, eyebrows, hair, lips, and chins can give the possibility of predicting the diagnosis of syndromes. It may contribute to the medical professionals in several aspects. Some of these are:

- To support medical professionals who do not have expertise in the particular domain of dysmorphology such as general practitioners or pediatricians in rural areas,
- To support geneticists throughout thousands dysmorphic diseases, most of which are very rare and difficult to memorize,
- Generally to support investigators who wish to diagnose their patients with dysmorphic diseases quickly, effectively and successfully,
- To support investigators who strive to expand their studies by including their cases into the system with the implementation whose database is able to be broadened dynamically and easily, which provides them to keep and deal with their data more efficiently.
- To guide geneticists to employ correct cyto- and/or molecular genetic analysis that is the appropriate route of investigation in order to confirm a diagnosis with - known genetic causes by ruling in probable diseases.
- No preprocessing of data manually that may cause the users to avoid the utilization of any system is required.
- FaceGP DDSS methodology can provide genetic screening which is a preliminary process of applying standard analysis to large populations to pick up underlying symptoms of genetic disorders. Genetic screening is not a diagnosis, but can produce a differential diagnosis which would lead to a definitive diagnosis and hence to early intervention and treatment.

The hope is that the FaceGP DDSS methodology will be widely adopted by the scientific community, fostering a new era of cooperation and collaboration and facilitating crossstudy. Based on user feedback, we expect to continue to update the functionality of the methodology. As the data gathering for age groups and ethnic groups becomes more standardized and evolved internationally in the sense of dysmorphology, general implementations valid for everybody will be more possible.

Future Work

Further improvement in diagnosing/recognition seems to be possible by integrating a background cropping mask algorithm that simply provides a face shaped region and minimize the effect of background change [15].

The dysmorphic faces from main databases as well as from individual databases referring to the names of the diseases should be both categorized and trained by the application for further better diagnostic decision support. This is a huge time consuming and challenging process needed to be done in the near future for the easy acceptance of the methodology by the scientific community. We intend to extend this work to a wider environment by including domain experts from academic and government institutions by deploying the methodology at sever- al sites including as possible as many syndromes. Furthermore, 3D image processing and fetus image analysis in dysmorphology is going to be the subject of our future study.

ACKNOWLEDGEMENTS

The authors are very grateful to TÜBİTAK (The Scientific and Technological Research Coun- cil of Turkey) for sponsoring the study.

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CHAPTER 11

DECISION-MAKING IN COMPLEX DYNAMIC AND EVOLUTIVE SYSTEMS: THE NEED FOR A NEW PARADIGM

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ABSTRACT

For contemporary psychology, decision-making represents behaviours, which are very different from automatic responses. They are developed by implementing integrative cognitive functions adapted to the finalities sought and the situation to treat. Through the diversity of epistemological choices for instance, research in previous decades focused on the individual choices expressed by situations or contexts with a stable structure. The new problems of life in today's society lead to making decisions on societal problems (climate, energy, etc.), which bring into play systems and no longer variables. This chapter has four aspects. After having characterised the decision-making process as a cognitive behaviour (1), having recalled the best known traditional models (those of Economics and Psychology) (2), this chapter deals with the properties of complex systems (globality, interactivity, dynamism, and scalability),

which render decision-making difficult (3), and concludes with the necessity of a change of paradigm by pointing to paths to follow (4).

Keywords: dynamic complex systems, cognition and complexity, complex decisions, errors of decision, paradigm change

INTRODUCTION

For a long time, before using electronic devices of navigation, sailors used to check their progresses using points of interest (POIs) as marks of their journey. These were particular points rich in information (a cape, an island ….) allowing the sailors to reduce uncertainty about its position. This is a typically cognitive process which allowed the sailors to mark out their route and see how they were progressing. Metaphorically, the term may be used in the study of decision-making to describe the cognitive work of the decision maker watching out for indications to ensure that his line of thought progresses in such a way as to enable him to make a final choice: that of deciding the course of action to be embarked upon.1

This chapter sets out to analyse several strategies or several models drawn up to give an insight into the decision-making process which, by definition (since several choices are possible), always takes place in a context of uncertainty. A large part of the cognitive activity of the decision maker is directed at lessening this, by processing the information available in various ways. It is structured in four parts. The first part presents decision-making as a form of conduct and behaviour, so enabling it to be studied from the point of view of psychology. The second part, for the benefit of readers who are unfamiliar with these questions, analyses two commonly used decision-making models which, notwithstanding their differences, have this much in common: they make it possible to give an account of individual decisions. The third part, in a more innovative way, undertakes to study a very particular type of super-individual decision that concerning groups of human beings exposed to risk situations. How do those responsible for safety, whatever their particular role, take their decisions to avoid the generalisation of harmful consequences? Their ways of approach, very different from individual strategies, open up new perspectives. Situations like this have two advantages for researchers: (1)

substantive (i.e. do the actions carried out lead to satisfactory responses to the critical case?); (2) epistemological (i.e. how does one represent or conceptualise these situations?). The fourth part attempts to analyse the consequences of a development of this kind. The epistemological questions they give rise to are so important that they radically change the traditional decision-making models. This being so, there is a need for a changed paradigm amounting to no less than a "scientific revolution" of the kind described in Kuhn's famous work.

TAKING A DECISION: A COMPLEX AND INTEGRATED FORM OF CONDUCT

For psychologists, more than just behaviour—a term which might suggest a certain automatism of response—decision-making is a specific form of conduct. First of all, the choice of this term underlines the fact that such processes must not be reduced to the extremely visible and observable aspects of the explicit choice of one course of action in preference to other (often many other) possible ones. Secondly, it introduces a constructivist option. The decision is constructed progressively and that which marks its culmination (the choice of the course of action to be embarked upon) is necessarily preceded and justified (sometimes in an approximate or erroneous way) by phases implying cognitive information-processing activities (perception, attention, memory, etc.) which "explain" the choice arrived at. Decision-making is also a process which presupposes freedom of choice, which is defined in time and consists of several stages. The two principal operations are the search for information and the assessment of its importance, which we will call weighting.

An Initial Definition

One of the best known definitions of the entire process of decision-making is that of MacCrimmon [1], characterised by the accumulation of stages identified in his account of the subject. A decision maker "observes a gap between an existing state and a desired state and has the motivation as well as the potential to reduce this gap, while more than one possibility of action exists which may not be immediately available, a

kind of action requiring an irreversible allocation of resources [cognitive in this case], and while the benefits [consequences] associated with each choice are completely uncertain" [1]. Each choice consists, according to him, of resolving a problem (MacCrimmon uses the expression "decision problem").

Different Perspectives

A definition is rarely neutral, and this one, formulated with members of the managerial class in mind, is characterised by a series of operations to be carried out successively, therefore presupposing the existence of a (meta-) process of control and integration, and of verification by retrospective loops, not mentioned in the formulation but nonetheless indispensable to ensure the validity of the whole construct.

It is not surprising that MacCrimmon's definition does not totally suit psychologists who are more interested in the previous stage: knowledge of the mental processes and the choice of the strategies planned by the decision makers. Among them, there are some who will criticise this definition for being too segmental, cumulative and prescriptive, and for its failure to give a more important place to the conditions of the time (in economics), the physical environment of the time (in the determination of risk-management strategies), social dimensions (judicial decisions), the pressures of the world of the time (political decisions) which have a determining influence on choices. Strictly focused on rationality, a definition of this kind leaves little room for motivation, sensitivity, desire, emotions, not to mention pleasure, and so on.

Constructing a Decision: what are the processes?

We will consider two principles as being justified both by the evidence and by observations so that the analytic processes may continue to have an acceptable level of general applicability. Decision-making takes place: (1) in an environment or context which is an integral part of the problem but of which the role is too often minimised if not totally hidden; (2) epistemologically, decision-making is constructivist in nature, which means that it progressively develops and becomes more refined on the

basis of representations of the world which become all the more operative as the occasions multiply and the information becomes more diverse. Decision-making in this perspective is therefore an illustrative example of a type of conduct resulting from the putting into play of dynamic processes [2].

Managing the Decisional Space

We owe the introduction of the topological dimension in decision-making to Lewin (1890–1947) and his field theory [3, 4]. The characteristics present in the field are a component to be taken into consideration, and this leads to a very broad view of the decision which cannot be limited to dealing with certain intangible visible indications or to reproducing learning processes. In elaborating any concrete decision, the information is extracted from a context, and some of this information, according to its nature or intensity, will be accepted as valid by the decision maker on a cognitive basis. Each piece of information used must be assessed in accordance with the context and, where applicable, with the framework in which it happens to be inserted [5]; these two characteristics give it a "salience" [6] of variable intensity. As Lewin has shown, the field which contains all these pieces is not homogenous; it has hills or rough areas which are characteristic points because they are the cause of certain dynamisms.

TWO TRADITIONAL MODELS OF DECISION-MAKING

With regard to decision-making, the two most well-known models (among the various existing) are summarised here: that of the economic decision and that of the behavioural decision [7].

Economics

Economics was the first discipline to formalise decision-making in the full meaning of the term, that is, by establishing a binding axiomatised system [8]. We shall limit ourselves here to indicate in a summary

way the salient elements of a branch of study which is still extremely active. The economist's problem consists of assessing among **n** mutually exclusive actions $\{\mathbf{a}_1 \ldots\ldots \mathbf{a}_n\}$ that will give the greatest satisfaction in a given situation, on the one hand, and to a specified decision maker, on the other hand. Therefore, the objective consists of ordering the outcomes (**1**) according to the preferences of the decision maker ($a_3 > a_8 > a_1$, etc.). To do this, the decision maker constructs a "decision tree" containing "routes" and "stages" (called knots) which represent possible pathways to be followed. At each knot, the decision maker must opt for a way which will bring him to the next stage and so on to the end (to the "leaves") which indicates the expected consequences of each action. (For a more complete presentation, see [7] Chapter 2). Each of the end points is evaluated numerically taking its frequency into account [assessment of the probability (p) that it will take place taking uncertainty into account] and the subjective value (i.e. for the decision maker concerned) of the utility **u** of the consequences attached to it. It should be noted that, even though the context is that of economics, the consequences are not determined in monetary amounts (objective references) but in subjective units of utility (u) [the satisfaction it can afford]. The value attached to the same sum of money varies in fact according to the individual fortune already possessed so that utility is a more general reference than monetary value. The two indices are combined in a multiplied form, that is, p*u. The outcome (leaf) which has the highest p*u numerical value is that deemed to constitute the best consequence. Climbing the tree in reverse therefore makes it possible to determine the "best" action to be executed. This model, known as subjective expected utility (SEU), therefore refers to a numerical validation criterion ultimately obtained by the observance of axiomatic properties.

Psychology

Psychology was the second discipline to set itself the task of modelling decision-making. Although it took the preceding concepts as a basis, this school of thought has led to a very different model form. In 1953–1954, the psychologist Ward Edwards [9, 10], applying the validation methods used in psychology, in particular predictive validity, installed a

team of researchers in a Las Vegas casino to study the decision-making of professional players. These persons who live off gambling takings consequently on decisions made in a context defined clearly by rules (those of the game) but where chance also plays a part represented an appropriate sample of decision makers who have, in a short time to decide and to assume the effects of their choices. The initial objective of the team of psychologists was to verify the SEU theory, but it became apparent that the players' decisions were not based on any of the axiomatic elements necessary for the determination of p*q and consequently were not related to the SEU criterion. The decisions taken were based on behavioural information processing in which knowledge, learning and intuition seemed to play an important role. A new investigational pathway was therefore opened up under the name of Behavioural Decision-Making (BDT) [11].

Very soon, Simon [12] underlined the fundamental differences existing between these two conceptions of decision-making, that of economics, which is axiomatic and organised with a view to attaining an end (maximise p*u), and that of psychology, which also identifies an objective to be achieved but sets out to achieve it in a procedural way (implement relevant information-processing procedures). These procedures, which would later be called cognitive, were to lead to new modelling forms [13] used even in economics with behavioural economics [14]. The frontiers between the disciplines had therefore become permeable, a very welcome development.

Managing an Intermediate System

Schematically, the decision-making process consists of transforming all kinds of semantic units present at the mechanism entry point into behavioural forms of action choosing which mark the outcome of the process. Between these two extreme points, there is an organised network of information which will undergo processing. Seen from the topological point of view only, the decision consists of processing an intermediate system which is a generalisation of the notion of intermediate variable (or intervening variable or mediating variable) often used in psychology and defined as "a hypothetical variable postulated to account for the way in which a set of independent variables control a set of dependent

variables".2 The notion of an intermediate system is nothing other than the generalisation of that of the intermediate variable with the retention of the epistemological notions of postulated and hypothetical entities (based on the decision maker's knowledge), on the one hand, and causality, on the other hand (i.e. the incoming variables influence the outgoing ones and so produce effects). Functionally, this intermediate system, which from the methodological point of view is a construct, constitutes a reserve of informational resources organised in the form of networks or "dormant" information clusters. When judiciously activated by the decision maker, these networks make more effective decision-making possible.

This is demonstrated by work in the area of Management Science on the complex entities constituted by enterprises in which the "right" decisions make it possible to achieve competitive advantages and the blossoming of the company. It has been shown in [15] that the management of an intermediate system in American small and medium enterprises (SME) enables this enviable objective to be achieved. At this point in our account, we may consider the decision maker as an agent who picks and processes information from a system at a half-way point between perception and action, a kind of reservoir holding pertinent indications drowned in a mass of information items most of which have no causal relationship with the question under consideration. Such a task can only be difficult.

The Cognitive Difficulties of Decision Makers and their Reactions

There are many works dealing with the difficulties, mistakes, false ideas, shortcuts and approximations affecting the action choices of decision makers [6, 13, 16], leading them to making poor-quality decisions. Therefore, as not to over-encumber this account, we will not list all these but rather classify them under three headings: structural difficulties, information-picking difficulties and processing difficulties, each category being illustrated by a single commentary. Structural difficulties are those corresponding to inaccurate or erroneous mental representations of the global organisation of the intermediate system, more often than not implicitly considered as being simpler than it is in reality. This is the case when the decision maker (cognitively) elaborates a decision tree which

is not exhaustive and when (in the actual situation) he finds himself confronted with the task of implementing real eventualities but ones not forming part of the initial plan. The decision tree has two functions, one to classify, and the other to predict. Used principally in Economics and Biology [17], it is the forerunner of classification algorithms and has a predictive value with regard to the choice of action, for any new observation.

Information-picking difficulties are frequent. The information items of use for decision-making are not, in real situations, isolated and salient as they might be in a laboratory experiment. To use them, the decision maker is obliged to search for them on the basis of their salience (or saliency), which therefore entails the necessity of a prior mental representation. Salience is a function of the purposes assigned to the action. The point is to pick salient information for a very specific decision and not to decide by using the most obtrusive (visible) elements in a given field. This latter strategy leads to a decision bias called salience bias [6, 7, 8, 9, 10, 11, 12, 13] consisting of processing extremely visible information items but ones not relevant to the question under consideration. Processing difficulties become sensitive at the junctions of the different cognitive operations implemented in succession to determine the action chosen. Three principal difficulties become evident: (1) the very poor cognitive capacities of human beings in assessing and processing uncertainty, an unavoidable element in decision-making situations. Seen as disconcerting and subversive, it is often excluded from the process, something which leads to an "over-confidence" bias [6]. This bias is noticeable in the assessment of risks (generally under-estimated) quite as much as, in the opposite direction the possibility (overestimated) of winning the jackpot in the lottery.

DECISION-MAKING IN COMPLEX DYNAMIC SYSTEMS

Epistemological Reductionism

The decisions presented in the preceding sections are characterised by

having been taken in a stable, defined informational context, that is, invariable throughout cognitive processing and ending in the choice of a single action, a behaviour marking the end, satisfactory more often than not, of processing operations. These situations are modelled on a limited number of variables, the pertinence of which is based on laboratory studies, sometimes of an experimental kind, but which have always undergone epistemological reductionism [18] guaranteeing their permanence and high level of general applicability. All other variables, particular or inconstant, are removed from the model.

Complex and Dynamic Decisions

There are decisions of another kind, which one could describe as super-individual as they concern at one and the same time a great number of persons, which must be taken in very different conditions. They cannot be processed in a laboratory nor reduced to a few variables, so they must be considered as global in nature and their complexity must be taken into account. Unlike the laboratory strategy where variables are isolated, the entity being studied can only be seen in a global way and cannot be reduced epistemologically without distortions. Another distinctive feature: the entities under study become modified under the influence of the processing operations, giving rise to a temporal dimension (evolution capacity) and a high degree of lability in the choice of "active" variables liable to be used in taking the decision. In such cases, therefore, momentary characteristics are what one is trying to define. One of the examples (and a very recurrent one in the summer period) which best illustrates this conjunction of complexity and dynamism can be found in the management of forest fires. These phenomena give rise to management difficulties linked to the difficulty of anticipating developments (uncertainty) and the unstable components of the fire (changes in intensity and direction). The decisions regarding the actions to be taken to contain and manage the fire and extinguish the flames are very difficult cognitively. A new element has been introduced into the situation: that of the interactions at all levels between different variables; interactions of a kind and extent which develop with time, the progress of the event and the measures undertaken at the previous stages by the action teams. The intensity of the wind, its direction, the degree of dryness of the ground, the nature of

the forests, and so on determine the characteristics of the fire and the way it will develop. The interpretation in substantive terms (i.e. in terms of the present situation) of the interactions is cognitively difficult, and the decisions taken as a consequence may be qualitatively poor [19].

An Epistemological Turnaround

The finding of identical difficulties in very different contexts (political, legal, economic, environmental, technological decisions, etc.) where human beings perform poorly must lead one to consider the various perspectives applied to studies on decision-making. The necessary and legitimate search for the most efficient action to solve a problem, as discussed by MacCrimmon, has led researchers to design research plans inspired by the exact sciences (e.g. physics and chemistry) or disciplines, such as biology, which verify their hypotheses concerning certain very specific variables, in an appropriate place perfectly protected against external influences: the laboratory. The history of Science, in its present state, shows in fact that for certain situations (but not all), such a choice produces the safest information. Such an approach, while being perfectly scientific, cannot be implemented in a generalised way to all the psychological problems of decision-making. Certain very recent decisions, such as those concerning climate change (cf. Section 5.1) or the management of industrial or ecological disasters, cannot usefully be subjected to epistemological reduction, a crucial process in laboratory studies. In other words, it is no longer possible to isolate certain variables and manipulate them to verify their causal status.

Must one then search for other scientific approaches? If so, there will have to be a turnaround in epistemology too. The phenomena under review will have to be assessed as global entities (holistic option), to be considered in their natural state rather than in a laboratory, in the conditions in which they actually occur, and if possible in *statu nascendi* (at the moment in which they occur). The management of maritime disasters with the threat of pollution require urgent decisions. These two recommendations are in line with the principles defined by Gestalt psychology in the first half of the twentieth century [3]. These were advanced over and over again at the time but could never be measured or assessed for want of methodological options other than experimentation. The epistemological

change which will make it possible, in part, to overcome this difficulty consists of conceptualising the situation being studied as a dynamic complex system.

Dynamic Complex Systems

In 1968, the biologist Ludwig von Bertalanffy (1901–1972) published a work in which he presented the notion of a "system" as a very extensive holistic entity [20]. "Systems everywhere around us," he observed. Only the analytical traditions inherited from previous centuries prevent us from seeing them and approaching research questions by including this aspect of globality rather than destroying it at the outset by concentrating on certain variables.

This original contribution, which highlights the potential richness of the systemic way of thinking, has been completed by the work of Cilliers on the functioning of systems [21] and on the epistemological characteristics arising out of them [22]. For this author, a complex system is an entity presenting ten specific characteristics [21]. Among the most important, we would instance the presence of numerous interacting variables where the interactions are not linear. This means that proportionality is no longer the rule so that even a very small variation introduced into the system may have major effects when exiting. This corresponds to the case found in 1972 by the meteorologist Lorenz known as the "butterfly effect", thus opening the way to new forms of non-Newtonian determinism.

Let us also consider certain characteristics of the system itself, independent of the decision maker who can only take note of them and include them in his decision. The system has a history, it is composed of networks which reflect it, it has resources available to it which in the absence of human intervention determine its "behaviour", it is usually open to the environment, has self-organisation capacities and can regulate itself because of the existence of control loops. One could say that it is endowed with an "epistemological personality", so that the decision maker is first of all an analyst and a manager of both the resources of and directions taken by the system, before being able to choose the appropriate action.

THE NECESSITY FOR AND CHARACTERISTICS OF A NEW PARADIGM

Up to the present day, very wide sectors of scientific psychology have chosen to apply the experimental paradigm in their research practices as a guarantee of the validity and replicability of their conclusions. This is, of course, not an erroneous choice, but it has now become apparent that its application is impossible in certain situations where nonetheless the intervention of psychologists is required.

Complex Systems and Psychology: the Case of Global Warming

The most illustrative case of conceptualising psychological issues in terms of complex systems is that of climate change. Climate is a complex system, it possesses all the properties defined in [21] characterising this type of organisation. The global state of the system depends on multiple interacting variables most of which are nonlinear, climate evolves, "integrates" characteristics which cause it to organise itself, to change its "behaviour" and global configuration. Among these factors for change, the production of carbon dioxide by human beings is one of the best identified factors (even if still the subject of ideological disputes) in global warming. Although human beings have no variable available to them which would enable them to act directly (as would an independent variable) to limit the harmful effects of global warming as required, they must nonetheless take decisions to influence its future course, and with regard to this, the contributions of psychologists are welcome.

The very well-known American Psychological Association (APA) has set up a task force which in 2008–2009 worked on the problem of "global climate change" and all its individual and collective psychological consequences. The objective was therefore much broader than decision-making, as is shown in the final report on the work of this commission which appeared in a special number of the American Psychologist [23]. Questions concerning the forecasting of the development of climate and the perception of risks are considered but, although it underlies many points in this work, the complex system notion is not explicitly

mentioned. The phrase "addressing a multi-faceted phenomenon and a set of challenges" present in the title is, however, entirely consistent with the spirit of complex systems.

Functions of the paradigm

Putting psychological objects into perspective by reference to complex systems opens up the way to a new paradigm. The old experimental-type paradigm, as we have seen, cannot account for certain important decisions. The new paradigm must enable a better understanding of them. It would seem that we are at present on the threshold of a "scientific revolution" [24, 25] made all the more apparent by this necessary change.

A paradigm is defined as "a philosophical and theoretical framework of a scientific school or discipline within which theories, laws and generalisations and the experience performed in support of them are formulated".3 The function of a paradigm, as this definition highlights, consists of ensuring the required coherence of the research approach and verifying the compatibility between the different components necessary for scientific knowledge (the hypotheses, the data observed, the methodological tools applied to process them and the theories constructed on the basis of the results, respectively). A paradigm is the overall structure containing compatible entities.

Certain Major Properties Characterising the New Paradigm

As emphasised in [21], thinking in terms of complex systems implies avoiding the "reductionism" linked to the initial choice of certain variables forming part of a greater complex. In the experimental paradigm, only those initially considered relevant will be used and where applicable verified. This choice being initial, even if supported by hypotheses and observations, is a determining factor in the construction of knowledge. In addition, the said variables are tested in an isolated way one from the other and then put into use "artificially" outside their natural environment. This procedure eliminates from the field the knowledge produced by a great number of interactions, which could prove decisive. The paradigm

of complex systems is a complete change of perspective. The decisions studied with a view to their consequences are studied globally, on the ground, in their natural environment and in specific circumstances. The importance of the results obtained is a function of the activity of networks which, as for the nervous system, become observation "units."

This approach does not set out to establish general conclusions (conclusions applicable in all circumstances) regarding decision-making, since to do this, it would be necessary to ignore many specific items of information, which exist and are active in the specific situation to be dealt with and which in fact are often decisive in the taking the decision.

The Search for Assessment Indicators

How should one assess, measure, or quantify the activity of a complex system with a view to predicting its development and being able to decide accordingly? Physicists, the first to deal with this question when it had to be answered in their discipline, refer to the laws of thermodynamics (particularly the second law) regarding energy. This energy dimension, present in all systems, makes comparisons possible by calculating, for each system, its level of entropy. The size of the latter was for a long time interpreted as a degree of disorder, but, unlike in the experimental approaches which scrupulously avoid it, systemic disorder can here have a positive connotation. It is considered as a possible generator of further states differing one from the other while order, once it has been determined, is immutable and results in one state only.

The transposing of the laws of thermodynamics into psychology has made it possible to highlight their relevance but at a meta-psychological level: that of the global psychological development of human beings [25] and this direction is too general to characterise a particular system. Researchers should therefore direct their efforts to looking for multiple indicators. Since this work has been published, the needs for identifying patterns of information have been emphasised as a heuristic way to manage complex systems [26]. For instance, artificial intelligence and human cognition ("humanised computing") are articulated to create tools either for treating psychological disorders [27] or allowing recognition of psychological entities (emotions) using non-linear relationships [28].

The Use of Icons

The educational system as a vector of knowledge and the diversity of the contributions it makes to different pupils is an example of the differentiated functioning of a complex system, which produces measurable effects, satisfactory or otherwise. How should such a system be characterised based on the observable results it provides? In particular, when a country applies one and the same generalised system to pupils belonging to different cultures (so-called "minority" groups), what can be said of the performance of the system where total assimilation on the one hand and extreme diversification on the other hand must both be considered as mistakes? The functioning of the educational system of Chile with regard to a "minority" group with a strong attachment to its land, culture and identity (the Mapuche) was studied in an initial contribution [29]. This highlights the importance of teachers possessing the two cognitive registers (that of the "minority" concerned and that of the "majority"). Considered more globally, this conclusion illustrates the arguments advanced above on the management of the intermediate system (cf. Section 3.3).

A second contribution [30] deals with the use of icons to assess how a system (school system in this case) functions with regard to the different demands represented by different groups of pupils. The term icon was chosen to stand for homogenous configurations of information which appear at the "surface" of the system and which indicate how it functions with regard to the diverse needs of users. Let us suppose, for example, that one of these icons includes several items of information signalling a lack of mastery of the written language, the decision maker, after analysis, can then proceed to choosing the action most suitable for the sub-groups concerned.

The fact that these icons are products of the systems and not just observations or perceptions differentiates them from the normal function of icons, which is pictorial in kind. Systemic icons, it is true, also "represent" but, as they are produced functionally, they do much more than this and can justifiably be described as cognitive icons as they enable knowledge. In short, while physicists referred to the energy of systems in order to differentiate them, the Human Sciences refer to

cognition as a global act making it possible to assign significance to subsets of information (icons) which therefore draw their significance from the totality of the system while at the same time participating in it.

CONCLUSION

Changes in society today are leading psychologists to deal with the management of complex situations which are very different from those that traditionally formed part of their area of activity. Two major developments characterise contemporary psychology: (1) new fields of activity (perception of risks, management of disasters or traumatic events, climate change, etc. (2) The importance of a global reference both in the definition of the phenomena studied and at the level of the people who find themselves involved (often large groups of the population). These changes must logically lead to an adaptation of the research and intervention strategies because the experimental method, so useful in the study of certain problems, is no longer applicable while the reliability it provided with regard to its conclusions still remains an imperative.

This chapter has attempted to present a difficult but promising approach: that of the use of dynamic complex systems to construct adaptable, appropriate, and evolutive decisions. It emphasises the necessity, once certain situations have presented themselves, of a change of paradigm so that complexity is recognised as a component in research as it already is in the forms of conduct being studied, rather than being somewhat ineptly eliminated from the start. Epistemological and methodological advances are necessary in order to develop the paradigm of complex systems in psychology, a paradigm which is already a reference in other branches of the human sciences.

Notes

- For stylistic reasons and to simplify writing, the masculine form is used in this chapter. This does not imply preference or discrimination. What is said is equally applicable to male and female decision makers.
- Collins English, 12th edition 2014, Harper Collins Publishers.
- Merriam Webster Dictionary.

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Automated Problem Solving and Decision Making: Key Trends

The day-to-day work of business professionals requires solving problems (or assessing opportunities) and making decisions. Decision making is a core activity for professional regulators. However, high-impact regulatory decisions are often made in an uncertain environment affected by resource constraints, individual biases and time pressures. Regulators can draw on a range of tools and techniques to strengthen their organisational decision making processes to address these challenges. The decision making process of many operations are dependent on analyzing very large data sets, previous decisions and their results. The information generated from the large data sets are used as an input for making decisions. Since the decisions to be taken in day to day operations are expanding, the time taken for manual decision making is also expanding. In order to reduce the time, cost and to increase the efficiency and accuracy, which are the most important things for customer satisfaction, many organisations are adopting the automated decision making systems.

Consequently, the purpose of this book is to introduce you to methods and techniques that will help you solve problems and make decisions. This book presents insights about the technologies used for automated decision making systems and the areas in which automated decisions systems works more efficiently and accurately. The Automated decision making systems are mainly used in business analytics and informatics. The decision making systems can be automated by applying certain business rules which are generated and operated by business analytics. The decisions taken by the automated decision making systems are part of the business informatics. This book provides the wide—ranging coverage to the challenges and perspectives of decision making from a computational perspective. This book will serve as valuable tool for directors, policy staff and operations staff, as well as to researchers and practitioners working within the field of organisational decision making. It is also of relevance to other regulatory bodies with an interest in the findings and conclusions from the work.

C. R. Larsenhas extensive experience as a software consultant. He has written several articles and research papers on theory of human decision making, management techniques, and personnel policies. He also focuses on design and develop integrated models that would coordinate management functions and information system components as an integrated process. He is author and co-author of more than 30 works in national and international journals, conference proceedings and book chapters.

ISBN 978-1-98465-323-9

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