Use of the motivation-expectation space to communicate strategies in a joint cognitive system

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2011

Li, A. S. T. (2011). Use of the motivation-expectation space to communicate strategies in a joint cognitive system. Doctoral thesis, Nanyang Technological University, Singapore.

<https://hdl.handle.net/10356/46487>

<https://doi.org/10.32657/10356/46487>

USE OF THE MOTIVATION-EXPECTATION SPACE TO COMMUNICATE STRATEGIES IN A JOINT COGNITIVE SYSTEM

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A thesis submitted to the Nanyang Technological University
in partial fulfillment of the requirement for the degree of
Doctor of Philosophy

2011

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Acknowledgements

During the course of my research, I met Emeritus Professor Christopher Wickens. He was a great source of inspiration. His sharp critique added depth to this research and made me examine the research from new angles.

I would like to thank Drs. Lionel Lee, Kenneth Kwok, and Soh Boon Kee from the DSO National Laboratories for their support in this undertaking. I would like to express my gratitude to my work colleagues Shuli, Andrea, Kenny, and Kok Leong, who had helped to cover my work duties while I was on leave for setting up the simulation used in the experiment.

In conducting the experiment, I was fortunate to meet Assoc Prof Lee Yong Tsui and technicians in the Centre for Human Factors and Ergonomics and Computer Aided Engineering. They kindly supported my study by providing experimental facilities. I like to thank Waiteng and Kee Jin for their patience and dedication in helping me develop the software and material for the study. My pilot participants, Rain, Yangxi, and Ben too gave me valuable suggestions that improved the quality of the experiment.

I would also take this opportunity to apologize to my family and friends who were neglected when I was struggling between work, studies, and family. Sorry to Rose, Sulis, June, Chanel, Yvonne, Huiting and many more. I will make it up to you when I am done. Special thanks to Wei Tiong and his family for their care and concern; it made my day-to-day routines much easier.

Most importantly, I would like to thank my advisor, Prof Martin Helander who has a strong belief that I am made for bigger things. His support and encouragement were very important.

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List of Abbreviations

ADH	Abstraction Decomposition Hierarchy
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis

Abstract

When humans and automation work together, the human typically takes a supervisory role and rely on the automation to complete certain tasks. However, there are times when the human supervisor cannot understand what the automation is doing. This is complicated by the fact that automation can sometimes fail, which makes the actions of the automation difficult to comprehend. This thesis presents information for calibrating operator's trust and dependence on automation for improving decision performance.

The Motivation-Expectation Space (MES) representation is proposed as a tool to aid the monitoring of automation. The literature review suggested that the four components in the MES (goals, means, causes, and effects) are fundamental in how people naturally strategize decisions. The review also revealed that the MES can support most of the information requirements needed for bridging automation trust and dependence.

A case study was performed to demonstrate how data obtained through a cognitive task analysis (CTA) could be translated to the MES representation. This was previously demonstrated in a petrochemical context where work constraints are limited primarily to the laws of physics (e.g. temperature). In this thesis, the translation was repeated for an in-car navigation task to gain insights in the MES application for a context with intentional constraints. The case study concluded with (1) a specific definition for each relation depicted in the MES, and (2) the design of the MES representation for an in-car navigation aid.

A three group between-subject experiment was conducted to test the effectiveness of the information and orthogonal structure in the MES. The information in the MES was presented in either the orthogonal MES format or textual formats. The results showed that the decision performance of both experimental groups who received the information performed significantly better than participants in the control group. There were, however, no

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differences between the two formats in improving dependence, and performance. The main advantage of the orthogonal structure over plain text was time. Participants who received the MES took a shorter time to interpret the automation strategies than participants who received the automation strategies in the textual format.

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1 Introduction

A Joint Cognitive System (JCS) comprises of multiple entities which, when put together, are able to modify the JCS's behavior to adapt to novel situations (Hollnagel & Woods, 2005). Cognitive Systems Engineering deals with the design of artifacts for JCS. Artifacts are designed with specific objectives to aid humans who assume the role of adaptive users of these artifacts. For example, a handwritten note is a simple artifact that aids our limited memory capacity, and a cellphone that stores birthdays is a more sophisticated memory aid.

Hollnagel and Woods (1983) made the analogy that Cognitive Systems Engineering is akin to new wine in new bottles. Technology and humans adapt in turn and become more sophisticated. In recent years, computers can be equipped with cognitive abilities. They are able to analyze the constraints in an environment, and perform resource planning typically with a goal specified by their human counterparts. Some are capable of adapting system's goals to changes in the situations. They are fundamentally artifacts that are in themselves cognitive systems. The interaction between human and these sophisticated systems is much more complex than interaction with artifacts that do not possess cognitive capabilities. The advent of artificial cognitive systems hence brought new challenges and designers of man-machine systems increasingly faced more difficulties.

One way to have individual cognitive systems (either man or machine) contribute harmoniously to the JCS is to align their goals (Potter & Rousseau, 2010). A driver using a Global Positioning System (GPS) to navigate constitutes a JCS where the two components (the driver and the GPS) share a common goal. The GPS tracks the location of the vehicle and updates its position on a map. The GPS, coupled with a navigation software, can direct the driver to his destination. Reaching the destination is naturally a joint goal of the driver and his GPS. The GPS suggests a route which the driver may or may not agree with. The driver makes the final decision and controls where the vehicle goes.

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However, there are times when the GPS gives suggestions that cannot be understood by the driver. Sometimes, we do not understand the basis of the suggestion; why does the GPS tell us to turn left (away from the destination)? The suggestion may be flawed as we are aware that automation is not always reliable. It can also be because the JCS (the driver and the GPS) is in a situation which is atypical. Perhaps there is a traffic jam, roadwork, or bad weather in the typical best path. The GPS, thus, gives the next best solution. How will the driver judge the suggestion?

The GPS and driver example is an illustration of a JCS where the automation and the human jointly made decisions that address their common goal in navigating to their destination. Automation has become ubiquitous, and many functions are masked in current automation systems. In oil refining, a large number of sensors are used to monitor the state of the processing plant. The information is displayed in a control room where technicians can get an overview of the plant state. Many decisions that pertain to safety are automated (Perry, Wears, & Cook, 2005; Tan, Helander, & Ho, 2007). Technicians need to interpret the situation, as well as the behavior of the automation equipment. They need to understand what the automation is trying to achieve, as well as the effects of the automated actions.

What do operators do when they do not trust the automation? Do they comply blindly or do they go with their experience and ignore the messages? When a driver does not know the rationale for a suggestion to take a certain route, he will not be confident of his decision. Likewise, when the technician in a processing plant is unaware of the rationale and mechanisms behind an automated action, he will not be able to diagnose the situation. The problem is that the invariant goal of reaching the destination can be achieved through a number of sub-goals (minimizing time, fuel efficiency, etc.) and means (route and direction) (Vicente, 1999). Usually, the automation is communicating only the low-level details –

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directions and actions. The changing goals and sub-goals are typically not communicated to the human operator.

Before we get overwhelmed by the number of options and abilities of automation, it is important to address the issue of trust and how the communication gap between automation and users can be bridged. The human operator, who understands how the automation comes up with the solution, is able to quickly recover from automation failures. This thesis proposes the use of Motivation-Expectation Space (MES) as a potentially suitable tool for bridging the communication gap. In particular we focus on the following aspects of the MES:

1. Assess the value of MES in communicating automation strategies to human operators. Section 0 presents a review of how human and organizations may strategize and evaluate the effectiveness of the MES in communicating automation strategies to human counterparts.
2. Assess how the MES can be used in calibrating trust for and dependence on decision automation. Section 1.3 examines the effectiveness of the MES in addressing factors that are utilized for calibration of trust and dependence on decision automation.
3. Determine if the use of MES can be extended to scenarios where work constraints are not limited to the laws of physics (e.g. temperature). MES was first developed for process control, where the work is mostly bounded by constraints in temperature and pressure (Tan, et al., 2007). Chapter 2 demonstrates the feasibility of applying the MES for an in-car navigation aid where decisions are guided by intentional constraints which changes depending on one's preference.
4. Determine if
 - a) information delivered in the MES aids decision making
 - b) information helps human operators recover from automation failure
 - c) orthogonal structure of the MES aids communication

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These issues were tested using the MES representations developed in Chapter 2 and reported in the experiment presented in Chapter 3.

1.1 Motivation-Expectation Space

The Motivation-Expectation Space (MES) is a network of orthogonally-arranged information where one can trace where things are going, and analyze plans of actions that take into consideration the goal of the system as well as the sequence of events (Tan & Helander, 2006). Figure 1-1 illustrates the basic blocks in MES. There are two orthogonal dimensions in the MES: motivation and expectation.

Figure 1-1 The Motivation-Expectation Space (MES) has four relations arranged along two orthogonal. The vertical presents the why-what-how relations. Traversing up, one finds the motivation for performing an action. The horizontal illustrates the cause-effect relations. This is the time sequence of events that have happened or is expected to happen.

The vertical motivation dimension captures the goal-directed behavior in a joint cognitive system, where human and machine work together to achieve common goals (Hollnagel & Woods, 2005; Lintern, 2009; Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999). The goal (why) in the situation is represented at the top of the vertical link and the possible solutions (how) are represented at the base of the vertical link.

The horizontal expectation dimension describes the sequence of events that has happened or is expected to happen. On the left is the cause, which is a

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problematic situation that has happened. On the right is the effect, which is the solution that the automation has taken to rectify the problem.

It is important to differentiate the cause-effect from the means-ends relation. The cause-effect relationship is driven by expectations while the means-ends relationship by goals and motivations. Operator's decisions are guided by both the goal for the task, as well as the technological progression and his belief of the system state.

1.1.1 Theoretical foundations from Cognitive Task and Work Analysis

The MES was proposed by Tan and Helander (2006) as a tool for incorporating knowledge into the *Abstraction Decomposition* Hierarchy (ADH), a fundamental representation in Rasmussen's *Cognitive Work Analysis* (CWA). It was developed while applying the *Cognitive Task Analysis* (CTA) with CWA in a study that elicits the cognitive process used in troubleshooting a petrochemical plant (Tan, 2007b). CTA focuses on how tasks are performed, rather than the steps in which the tasks are carried out (Klein, 1995; Vicente, 1995). CWA in contrast does not have a specific elicitation tool but it is better known for its rich representations (Helander & Tan, 2006; Rasmussen, et al., 1994; Vicente, 1999).

The Critical Decision Method (CDM) was the CTA technique used in the 2007 study. It was the most widely used and best known CTA technique (Roth, 2008). CDM is an empirical approach where experts' knowledge and skills needed for performing a task are elicited in a naturalistic environment (Klein, 1989). Typically, experts are asked for a challenging decision that they made in the past. A set of semi-structured questions are then used to probe their cognitive processes and expertise. There is no formal representation tool. The data is usually first recorded in a Cognitive Demands Table and later translated to other usable formats (Crandall, Klein, & Hoffman, 2006). Usually the data collected relates to decisions

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made, the cues that led to the decision, the strategies that were used, and the difficulties in making the decisions.

CWA, on the other hand, is a formative approach, where information is analyzed and represented in five stages (Vicente, 1999). Rasmussen developed the CWA framework based on his observations of expert operators who controlled nuclear power plants. The CWA analyses and representations hinge on the concept of letting the operators finish the design. CWA takes into account that the human operator is adaptable and that system design should support rather than restrict the operator's span of control. It accounts for the variability in behaviors caused by differences in knowledge and cognitive strategies (Vicente, 1999).

The five analyses in CWA are: Work Domain Analysis, Control Task Analysis, Strategies Analysis, Social-Organizational Analysis, and Worker's Competencies Analysis. The Work Domain Analysis generates the ADH representation, which maps the work constraints and activities (Vicente, 1999). The analysis can be difficult, and the generated ADH can be controversial. The MES was proposed as a tool for transforming the elicited knowledge into the ADH format (Tan & Helander, 2006).

With the ADH, the analyst can select pertinent activities and perform a Control Task Analysis using a ladder diagram to identify requirements that support expert behavior. A Strategies Analysis is then undertaken to identify the various ways that the activities can be performed. The Social-Organizational and Cooperation Analysis focuses on examining how workers and automation can be organized and governed to facilitate communication, cooperation, and ultimately improve system performance. The Worker Competencies Analysis summarizes the requirements derived from the first five stages with the purpose of proposing a coherent system that complements human capabilities and limitations.

The CWA is tedious to perform; there are many CWA research articles that focus on the Work Domain Analysis and Control Task Analysis but only a

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few studies analyze the remaining three stages. Examples include petrochemical industry (Burns & Hajdukiewicz, 2004), virtual private network (Burns, Barsalou, Handler, Kuo, & Harrigan, 2000), design of product accounting equipment for retail chain shop (Rasmussen, Pejtersen, & Schmidt, 1990), hydro scheme control (Sanderson, Wong, Choudhury, & Memisevic, 2003), and Navy Surface Combatant (Bisantz et al., 2003). The only study that covered all five stages was for the design of an online bookhouse (Pejtersen & Rasmussen, 1997).

1.1.2 MES in bridging the gap in Cognitive Task and Work Analysis

In a previous study, the author tried to identify a common ground for CTA and CWA (Tan, 2007a). Using the Critical Decision Method, operators were asked about their thought processes when troubleshooting failures in petrochemical plants. The results were analyzed using a CWA framework and some parallels between the two methodologies were observed. Three dimensions which are emphasized in CTA can be mapped onto the CWA (Helander & Tan, 2006):

1. goals elicited maps to Work Domain Analysis;
2. expert-novice differences maps to the Control Task Analysis; and
3. strategies maps to the Strategies Analysis.

In CWA, there are generic representations, ADH and ladder diagrams, for performing the Work Domain Analysis and Control Task Analysis respectively. However, Rasmussen did not develop a context-free representation for his Strategies Analysis (Vicente, 1999). Rasmussen developed four information flow maps for the strategies that nuclear power plant experts exhibited. Vicente critiqued that these representations were not context-free and used operations research models instead in his Strategies Analysis (Vicente, 1999). He also commented that a taxonomy of

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elements on adaptive decision-making such as the Payne's Elementary Information Processes would be useful (Payne, Bettman, & Johnson, 1993).

The MES may be appropriate for these purposes since it (1) was derived from two powerful techniques in Cognitive Systems Engineering, and (2) possesses features that are in Rasmussen's Cognitive Work Analysis. It retains the functions which were conceptualized from the ADH in CWA (Rasmussen, et al., 1994). Similar to the ADH, the MES has a why-what-how structure, where the system's goals are listed at the top-most hierarchy. In the ADH, two dimensions for classifying data are used; abstraction level and decomposition level. Navigating vertically provides the why-what-how and explains the functionality of the system, while navigating horizontally displays the spatial relationship between objects in the systems: system to sub-system to components. The MES retains the vertical navigation and highlights it as the motivation dimension. Unlike the ADH, it does not mandate five abstraction levels and therefore is seemingly more flexible.

The horizontal dimension in MES, instead of representing spatial relation, is used to represent causal relationships between components, known as the "expectation" in the system. In analyzing the interview notes, the author noted that the operator's reasoning revolves around his goals in operating the plant and the causal relationship between plant components (Tan et al., 2007). Cause-effect phenomena have been used in many other evaluation schemes including: cognitive maps, cause maps, information maps and belief nets (Boland, Maheshwari, Te'eni, Schwartz, & Tenkasi, 1992; Ford & Hegarty, 1984).

The MES structure seems to be a convenient format for illustrating human decision strategies. An investigation on decision strategies is performed in this thesis to strengthen the argument that the structure in MES is how a person naturally rationalizes a decision.

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1.2 Decision strategies

Decision strategies have been widely studied in warfare, business, systems engineering and artificial intelligence. The concept of strategy first appeared in *The Art of War* (Sun Tzu, 500bc cited from Gagliardi, 2006). In ancient Chinese wars, scholars were appointed as military strategists to plan the movement of troops and resources into favorable positions. Sun Tzu's philosophy and methodology in managing military actions has since been widely studied and applied. His strategies ranged from short term plans of attack to long term planning of food and shelter for the soldiers.

In business management, Grant (2007) defined strategy processing as a dynamic shifting between the external and internal environment. A team of business analysts gathers information from the external world (competitors and environment) and internalize the information (company's resources and capabilities) into useful knowledge to make a decision. Payne had similar ideas; he viewed decision strategies as sequences of mental and effector operations that are used to transform an initial state of knowledge into a final state of knowledge (Payne, et al., 1993).

In system engineering, Rasmussen analyzed decision-making from a systems perspective. He stated that mental strategies are used to bring situation assessment, diagnosis and planning into action (Rasmussen, et al., 1990). Again, a decision strategy is about comprehending the situation and understanding one's resources making a plan of action. In short, strategies are "process descriptions of how something can be done" (Ahlstrom, 2005, p. 161).

Closer to our focus on automation, Gordon (2003) analyzed planning strategies in ten domains to develop artificial intelligence (AI) that could incorporate common-sense strategies. Gordon's approach to strategies was different, since it emphasized how strategies are employed rather than how they should be employed. He defined planning strategies as "recognizable abstract patterns of planned behavior". Using a bottom-up approach, he

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analyzed 372 strategizing behaviors to identify common components. Interestingly, he reported *means*, *ends*, *cause*, and *effects* as four fundamental elements in decision strategies. This is in agreement with the MES methodology.

Several researchers have reported similar definitions of “strategies”, how they are employed, and what the underlying structure is. Non-researchers, however, tend to use the term loosely. In the story “Peter Pan”, Darling explained to the Lost Boy that a strategy is a plan of attack. In the eyes of strategies research, this is not an appropriate definition, since the plan of attack is the outcome of strategizing the attack. A strategy is the process of coming up with a solution which includes considerations of the external factors that influence the plan and sometimes the effects of conducting the plan.

1.2.1 Repertoire of decision strategies

In decision-making, there is a strategy selection stage where the decision-maker chooses an appropriate process to come up with a plan (Reder, 1987). Before one goes into strategy selection, there must be a decision problem that the decision-maker is trying to solve. The problem is often a situation which does not conform to the decision-maker’s desires.

A literature search identified 12 basic strategies employed in choosing between alternatives. The example below explains and examines the 12 strategies for the components in the MES. The strategies are arranged in order of one’s experience with the problem.

According to Rasmussen (1986), novices performed knowledge-based problem solving in which they examined the problem and generated a solution that was novel to them. When they solved it a second time, they recalled the previous solution and started to develop heuristics for the problem. This is termed rule-based decision making. If they continue facing

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the same problem and solving it multiple times, they will become very accomplished and can leap very quickly from the problem to the solution. Rasmussen termed this “skill-based” decision-making. The 12 decision strategies are organized along the knowledge-rule-skill spectrum.

There are three available options in the decision in a scenario where a decision-maker selects a route to go to work:

	Toll	Travel time	Road Condition
Route A	\$1.50 (1)	60min (3)	Smooth (1)
Route B	\$1.80 (2)	40min (2)	Average (2)
Route C	\$2.00 (3)	20min (1)	Bumpy (3)

* The numbers in brackets are the rank of the three choices for each attribute: 1 being the most favorable and 3 being most unfavorable.

Multiattribute Utility Decomposition (MAUD) (Keeney, 1977) – The MAUD strategy is the most computationally-intensive and comprehensive strategy in classical decision making. This strategy yields an optimal solution and MAUD is typically the normative benchmark in decision-making. Alternatives (means) are compared by computing an index that takes into account the value (effect) of each attribute (goal), as well as weights assigned to the attributes. The MAUD index combines the utility functions of two or more attributes.

Weighted additive (WADD) – The WADD strategy is the simplest case of the MAUD strategy where the function used in computing the MAUD is additive. In deciding between the three routes, one can assign weights to each of the attributes (toll, time, and road condition) and compute an index for each route to decide which alternative to go to. The weight depends on the priorities of the decision-maker. If travel time is the most important, a higher weightage is given to this attribute. As an example, if the weightages for toll, time, and road condition are one, three and one respectively, the revised score for the time attribute would be 11 for Route A, 10 for Route B, and 9 for Route C. Route C will thus selected.

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Equal weight (EQW) - The EQW strategy is one simple version of the WADD strategy where every attribute is given equal weightage. Similar to MAUD and WADD, an index that takes into account the value (*effect*) of each attribute (*goal*) for each alternative (*means*) is computed. Given that the weightage is the same for all three attributes, the index for Route A, B, and C would be 5, 6, 7 respectively, and Route A will be chosen.

Maximax (Wright, 1975) - When using the Maximax strategy, decision-makers look at the best attributes (*effects*) of each alternative (*means*) and choose the alternative that maximizes their utility (*goal*). In this strategy, the decision-maker would consider the low toll and smooth road condition of Route A and the shorter traveling time to Route C. In this case, Route A which scores highest on most of the attributes will be selected.

Minimax (Wright, 1975) - Contrary to the Maximax strategy, decision-makers look at the worst attributes (*effects*) of each alternative (*means*) and choose the alternative that minimizes the loss (*goal*). The decision-maker would then consider the high toll and bumpy road condition of Route C and the longer traveling time to Route A. Route B will be selected since it does not score badly on any of the attributes.

Lexicographic (LEX) - Decision-makers who use the LEX strategy identify the attribute (*goal*) that is most important and choose the alternative (*means*) based on the utility of this attribute (*effect*). If time is the most important attribute, the decision-maker simply chooses Route C which offers a 20 minutes shorter time. If this 20 minutes difference is insignificant, the next important attribute is evaluated.

Elimination-by-aspects (EBA) (Tversky, 1972) - Similar to the LEX strategy, the EBA evaluates the most important attribute (*goal*). In addition, a cutoff value for the attribute (*effect*) is set. All alternatives (*means*) with a value higher than the cut-off are retained. The process is repeated for the next important attribute. Here, the decision-maker does not compare alternatives. Instead, a cutoff is set for the most important attribute – in this

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case time. If 50 minutes is the cutoff, Route A will not be selected. If the next important attribute is toll, Route B will be selected.

Satisficing (SAT) (Simon, 1996) and Recognition-Primed Decision (Klein, 1989) - In SAT, alternatives (*means*) are considered one at a time and the first solution that meets the minimum criteria (*effect*) is taken. This is similar to Klein's recognition-primed decision model where decision-makers mentally simulate solutions and go ahead with the first solution that works. This strategy is very efficient but it may not give the optimal solution (*goal*). If the decision-maker is getting late for her appointment, she simulates driving along one of the routes and takes the first route that does not result in an undesirable situation (e.g. feeling uncomfortable from a bumpy drive).

Conjunctive (Wright, 1975) - In the Conjunctive strategy, decisions are made based on a below-cutoff (*effect*) for each attribute (*goal*). Any alternative (*means*) that does not meet the below-cutoff for any of the attribute is rejected. The remaining alternatives are pooled together and analyzed using another strategy. If a decision-maker sets a cutoff for travel time of no more than 45 minutes, a cut-off fee of no more than \$1.90, and a cut-off road condition factor of no worse than average, Routes A and C will be rejected, leaving Route B as the only acceptable route.

	Toll	Travel time	Road Quality
Route A	\$1.50 GOOD	60min BAD	Smooth GOOD
Route B	\$1.80 GOOD	40min GOOD	Average GOOD
Route C	\$2.00 BAD	20min GOOD	Bumpy BAD

Disjunctive (Wright, 1975) - The disjunctive strategy, on the other hand, sets an above-cutoff (*effect*) for each attribute (*goal*). Alternatives (*means*) that meet the above-cutoff are pooled together and analyzed using another strategy. Similar to the conjunctive strategy, the decision-maker sets a cutoff for travel time to be no more than 45 minutes, a cut-off fee of no more than \$1.90 and a cut-off road condition factor of no worse than average. Route A and Route B satisfy the toll and road condition attributes while Route C

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satisfies the travel time attribute. Unlike the conjunctive strategy, all three alternatives are acceptable as they each possess attributes that meet the above-cutoff.

Majority of confirming dimensions (MCD) (Russo & Doshier, 1983) - In the MCD strategy, pairs of alternatives (*means*) are compared based on the values (*effects*) of all attributes (*goals*). The alternative with the better index is retained and compared with the next alternative. A decision-maker would compare Route A which has a lower score than Route B. Therefore, she drops Route B. Then, she compares Route A and Route C. Route A scores higher and is therefore selected.

Direct retrieval (Reder, 1987), Affect referral (Wright, 1975), & Pattern recognition (Klein, 1989) - The decision-maker had previously evaluated the problem (cause) and tested the solution (*effect*). He recognizes the task (*goal*) and uses a past solution (*means*). If he has evaluated the problem before and found that Route B was the best, he would continue to select Route B.

Other than suggesting that goal, means, cause, and effects are components in a decision strategy, a point to note is that different strategies result in different outcomes. The choice of strategy is largely dependent on the expertise of the operators and the amount of resources available for making the decision. While identifying the factors affecting strategy selection is important, it is equally important to examine the commonalities across all the strategies to aid the communication of decision strategies. This is especially true when it is difficult to prescribe the strategy being used.

1.2.2 MES for representing decision strategies

The 12 different strategies and how they are used have four fundamental elements which are repeatedly observed: (1) the situation that activates the strategies (cause); (2) the goals that were not fulfilled in the situation (why);

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(3) the action that rectifies the situation (how); and (4) the effect of implementing the action (effect) (Gordon, 2003). Coincidentally, the motivation dimension comprises of the why-how and the expectation dimension the cause-effect.

Why - As mentioned, a strategy is invoked when there is a problem where the situation is not what the decision-maker desires (Beach & Mitchell, 1977). An individual decision-maker has a set of values that guides his actions (Payne, et al., 1993). In an organization, the management sets long-term goals and agrees upon objectives, and their employees work towards these goals (Grant, 2007). In a system, there are specific functional goals and every actor in the system works towards sustaining these goals (Rasmussen, et al., 1990).

How – In every strategy, there is typically more than one possible solution and the decision-maker needs to make a choice (Payne, et al., 1993). Each solution has its strength and weaknesses. The “How”, in a strategy, presents all possible solutions. A solution can be a single action or a set of actions that run either in parallel or series (Gordon, 2003). The process of deriving the means is referred to as “strategizing”. For the driver’s selection of route (Section 1.2.1), different strategies will yield different solutions. The final solution depends on the availability of the strategy, as well as factors that influence the strategizing.

Cause –When strategizing, decision-makers sometimes look back to the past to find the reasons that lead to the current state (Einhorn & Hogarth, 1987). They frame the causes (either real or hypothetical) into an explanation (Klein & Hoffman, 2009). Generally, it is accepted that a cause is an explanation. However, this feedback mechanism explains only partially how causal relations are applied in decision strategies.

A good strategist takes a feed-forward perspective and assesses the effects of a problematic situation and the effects of implementing potential solutions. “Cause”, in this context, is an undesirable or problematic state

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that evolves into a subsequent effect state under either existing conditions or hypothetical solutions to solve the problem. If the situation did not happen, its effects will not be examined. This is reflected in the route-selection problem. The problem itself is the “cause”. Although “cause” is labeled only in the last strategy “Direct Retrieval”, it is actually featured in all 12 strategies, since the problematic situation (i.e. the need to select a route to work) is the common cause leading to an examination of the effects in all solutions.

Thus, “cause” can be said to have two definitions. Depending on its usage, it is either an explanation or a situation that does not conform to the desires of the decision-maker. This distinction is necessary for designing systems that project into the future. Before any solution is selected and subsequently implemented, the cause has to be a problematic situation (not an explanation) and the effects are based on the system’s image of how the situation would unfold. After the event, the causal relations would explain why certain decisions were made. This can be useful for troubleshooting the logics in automation.

Effect – Decision-makers propose different solutions and mentally run them to examine the consequences of the solution on the current situation. Effect, is the envisioned outcome of a strategy (Gordon, 2003). In the MES, the effect is the anticipated outcome when the MES is used for planning. Anticipation was observed in most but not all the 372 strategies studied by Gordon. It is not surprising that not all decision-makers can predict the future. According to Gagliardi (2006), a strategy simplifies a complex situation by introducing a methodology. Good strategists plan for the future. They examine events and contingencies that relate actions to outcomes, as well as the probabilities and expected values of those events (Payne, et al., 1993). They set up value features to objectively appraise their resources (Grant, 2002; Rasmussen, et al., 1990).

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The integration of the why, how, cause and effect in the two MES dimensions can illustrate a mental projection while considering the current goals, see Figure 1-1. This can be illustrated using the business Macaroni defense, one of the strategies studied by Gordon (2003). The following paragraph was how Gordon abstracted the defense for programming an artificial intelligence:

“The planner has a Leadership role in an Organization, and Envisions a threat to goals of the Organization that a different agent A1 will execute a plan that includes Trade of an Amount of resources of the agent A1 for Portions of ownership that are a Majority portion. The planner executes a plan to Make an offer to a different agent A2 where the Offer requirement is that the agent A2 Transfers resources to the Organization of an Amount of resources, and the Offered action is that the planner will Schedule the Transfer of resources to the agent A2 of an Amount of resources that is greater than in the Offer requirement, with the Offer condition that If it is the case that if an Arbitrary agent executes the plan, that is the plan in the Threat, the Organization will Enable the agent A2 in the offer to cause the Organization to Reschedule the Offer action with an Amount of resources that is greater. The planner then Schedules a plan to Inform the agent A1 in the Threat of this offer after the Successful execution of the plan.”

To put it simply, Agent A1 is planning to takeover Organization O and this causes Planner P to be under the threat of losing its leadership in O. The Macaroni defense is a strategy to prevent an O from being taken over by A1 via issuing bonds to a second Agent A2, with a condition that will deter A1 from the exercising the take-over. The condition is that if any arbitrary agent, in this case A1, is to take over O, the bonds will be redeemed at a much higher price. This strategy can be represented in the MES in Figure 1-2. The MES structure can be analyzed from any position as long as the user understands that the implications of moving in the four directions:

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1. upward is the goal,
2. downward is the action that satisfies the goal,
3. to the left is the preceding situation or the hypothesized cause, and
4. to the right is the effect or anticipated effect.

Figure 1-2 Macaroni Defense Strategy represented using the Motivation-Expectation Space

Here, the goal of the planner (topmost box) is to maintain leadership in his organization. He has a problem; A1 is planning to take over his leadership by trading resources for the majority portion (leftmost boxes). He needs to prevent a take-over that A1 is planning. His only alternative is to issue bonds to A2, which is reflected in the box below the “prevent take-over” box. The effect of issuing the bond is that A1 will need to take-over with more resources and is represented in the boxes to the right.

The Macaroni Defense demonstrates how the MES can represent strategies in a structured and comprehensive manner. The why-how, and cause-effect relation have strong theoretical basis in how decision-makers strategize their moves. This suggests that MES can be a useful representation for aiding a broad range of expertise.

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While there was strong evidence to suggest that the MES contained fundamental pieces of information in decision strategies, it was uncertain if the orthogonal structure was easy to follow. While the MES was seemingly simple and unrestrictive, some people may be mentally challenged with the structure.

Research has shown that there are individual differences in people's ability to create, hold, and manipulate spatial representations (Chi, Feltovich, & Glaser, 1981; Simon & Simon, 1978). This could mean that some people might face difficulty in interpreting the MES.

While some people believed that visualizers learn better with visual representations and verbalizers learn better with verbal representations, Massa & Mayer (2006) did not find any differences that supported this notion. They noted that it was unnecessary to develop different instructional material for the two groups of learners; users can adapt well to any given representation.

With these contradicting reports, it was difficult to determine if there would be a difference in performance between the MES and a non-MES representation (e.g. displaying the same information using only text). It should be noted that the MES is not a pure graphical representation. Each box in the MES can house a paragraph of text, see Figure 1-2. As such, there is a need for an experiment to validate the effectiveness of the MES representation, see Chapter 3.

1.2.3 Human and automation decision strategies

Decision automation is capable of making complex computations at a fraction of the speed needed by humans. The decision strategies that are programmed into the automation typically optimize the solution space. The human, on the other hand, has developed heuristics for various circumstances, which can simplify the decision-making considerably.

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Both human and decision automation have a limited repertoire of familiar strategies. Human decision-makers learn strategies prior to their application. They seldom come up with novel mechanism, but they are capable of combining strategies, and these combinations can be novel (Mintzberg, 1987; Payne, et al., 1993). Decision automation is similarly limited by the strategies that have been programmed. Examples include neural networks and rule-based algorithms. A neural network algorithm is similar to the Weighted Additive strategy, while the rule-based algorithm is similar to a Maximax-Minimax strategy.

In both human and automation decision strategies, there is the goal of optimizing specific attributes. However, humans have limited capacity for computation and have developed two implicit goals, which are applied in making decisions in a naturalistic environment (Payne, et al., 1993). They are (1) accuracy, when we examine a complete solution space using a comprehensive strategy such as the Weighted Additive strategy and (2) effort, when we choose simpler strategies such as the Direct Retrieval strategy. A human decision-maker chooses a strategy that leads to the most accurate solutions while exerting an affordable amount of effort (Beach & Mitchell, 1977; Payne, et al., 1993).

Unlike a human decision-maker, it is rare to find a decision automation that computes using two or more strategies. Decision automation is designed to solve very specific problems with a fixed strategy. In a neural network, where the algorithm is similar to the weight additive strategy, the decision automation can learn to modify the weightage in the equation thus adapting to the environment. However, when the solution space becomes more complex, it does not change to a simplifying rule-based algorithm. The computation is still limited to a single strategy, and decision automation does not have the adaptability to switch between strategies.

Understanding the limitations of both the human decision-makers and decision automation has implications for Cognitive Systems Engineering.

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Lengthy computations can be assigned to decision automation. Information presentation and decision support can be designed to make tedious strategies less effortful to use and thus influence the choice of strategy (Chu & Spires, 2000; Payne, et al., 1993; Todd, 1994; Todd & Benbasat, 2000).

The Ecological Interface Design, which is influenced by Cognitive Work Analysis, is one such design methodology where information and the relationships between pieces of information are systematically designed with due considerations for information integration (Burns, 2000; Burns & Hajdukiewicz, 2004). The MES has the same potential of being an informative representation of data.

1.3 Decision automation

Automation refers to systems that perform functions which were previously handled by human operators or are impossible for human to perform (Parasuraman, Sheridan, & Wickens, 2000). The functions range from sensing (perception) to actuating (action). In this thesis, the focus is on decision automation which computes solutions based on state assessment, pre-defined logics, and assumptions. This is particularly useful for an environment where uncertainty and complexity hinder a comprehensive evaluation of options.

Contrary to popular beliefs that automation can replace human, automation has not removed the human from the loop. Rather, human operators are tasked to perform the difficult functions that cannot be automated, and it is inevitable for human to stay in the automation equation. As much as we try to automate, at least one human operator would still be needed to troubleshoot the system when things go awry.

In a joint cognitive system, human operators work with automation to achieve their goal more efficiently. However, there are times when automation fails and the human is required to intervene. The human has to

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recognize the problem and decide on the best course of action. If the human cannot interpret what might have gone wrong and/or if the automation fails repeatedly, the human operator would lose confidence on the automation and stop using the automation. A review of research on automation trust and dependence was conducted to identify information display design factors that affect and calibrate operator's use of automation and the MES was evaluated against these factors.

1.3.1 Automation trust and dependence

Automation can sometimes be compared to a co-worker. In controlling an aircraft, pilots need to entrust their co-pilots with functions that they cannot handle alone (Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009; Sulistyawati & Chui, 2009). Senior pilots are aware of the knowledge that their junior pilots possess. Their confidence and trust in their co-pilots determines the tasks they assign to the co-pilot. Even when they cannot be sure that they can trust the co-pilots, they will take calculated risks and depend on the co-pilots to complete some tasks.

Similarly, human operators can entrust automation with certain tasks. This reduces the workload of the human operator, who can allocate his attention to other concurrent tasks, while monitoring and ensuring that the automation is running safely (Parasuraman, Molloy, & Singh, 1993). The use of automation, analogous to having a co-pilot, also anchors on operator's trust and dependence on the system (Lee & Moray, 1994; Lee & See, 2004). The more operators trust the automation, the less attention they spend on monitoring and the more they depend on the automation (Muir, 1989). If the operator's workload is high, the operator will have to tap on features in the automation which are sufficiently reliable, even if he does not entirely trust the system (Dzindolet, Peterson, Pomranky, Pierce, & Beck, 2003).

In allocating attention resource to automation, there are two sampling bias issues which can be placed at the two extremes of a disuse-overuse

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spectrum. At the disuse end, operators have little faith and are skeptical about automation. They do not use the system and perform the automated function manually by processing the raw data using other tools. Their self-confidence in their manual control ability misleads them into performing tasks which the automation can perform more efficiently (Lee & Moray, 1994; Moray, Inagaki, & Itoh, 2000). They missed the larger picture that they can direct their effort to other tasks. In this case, the operators *distrust* the system and the automation is *disused* by the operator (Parasuraman, 1997).

At the other end of the spectrum, operators may be complacent and rely too much on the automation. They over-trust the system when they do not check the output of the system periodically and fail to arrest errors in the automation. When the sampling is too low insofar as an error in the system is not identified and rectified by the operator, there is *overtrust* and *overuse*. Parasuraman (1997) used the term “misuse” rather than “overuse” to describe such situations. Muir (1989), however, used the term mistrust to describe miscalibrated trust which is a combination of distrust and overtrust. In this thesis, Muir’s (1989) convention was adapted for describing dependence. Like mistrust, misuse refers to the combination of disuse and over-use in automation.

An appropriate use of automation is when the operator is able to perform concurrent tasks while relying on automation for the function that the automation can handle. When automation fails, the human operator is able to react in a timely manner. Operators tend to *overuse* automation which are prone to misses and *disuse* automation with high false alerts (Wickens, Dixon, Goh, & Hammer, 2005). Lee and See (2004) recommended designing for appropriate trust rather than greater trust. Moray (2003) used the term “eutactic” to describe an operator who demonstrates an appropriate use or calibration of automation. He, however, also pointed that it is difficult to determine the optimum sampling frequency.

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1.3.2 Measuring automation trust and dependence

Automation trust is a relatively new construct and is believed to be a moderator of operator's dependence on automation (Muir, 1989; Parasuraman, Sheridan, & Wickens, 2008). One has to develop trust on the automation before relying on the automation. High level of trust and dependence, however, do not guarantee good performance since there can be undetected automation errors.

Automation trust is a multidimensional construct (Muir, 1989). Several dimensions had been used in the development of trust questionnaire (e.g. Goillau, Kelly, Boardman, & Jeannot, 2003; Jian, Bisantz, & Drury, 2000; Lee & Moray, 1992; Madsen & Gregor, 2000). One early versions of trust questionnaire was developed based in part on research in social trust (Muir, 1989). Jian et al. (2000) extended the research and did an empirical study comprising word elicitation and cluster analysis. They confirmed that trust and distrust indeed fall along a continuum and are not different concepts. Their cluster analysis identified 12 factors which were used in designing a human-to-automation trust questionnaire. The questionnaire has been used in several studies (e.g. Bisantz & Seong, 2001; Lees & Lee, 2007). Their questionnaire addresses seven positive factors (confident, security, integrity, dependable, reliable, trust, and familiar) and five negative factors (deceptive, underhanded, suspicious, wary, and harmful). These factors were adapted and used in this thesis.

Other than subjective measures, a more objective measure would be a self-report where operators answer if they have used the automation. During the data collection, operators can choose one of the following options: (1) fully relied on the automation, (2) cross check the output of the automation with other information, and (3) did not use the automation at all. This data, by itself, can be used to determine whether they trust (when they fully rely) or distrust (did not use or cross check). However, it does not specify if there is an overtrust - comply with an erred automated suggestion.

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For a Joint Cognitive System where operators has the final say in making binary-choice decisions, three conditions are needed to define automation trust and dependence: operator's use of the automation, automation's decision, and operator's decision, see Table 1-1. When the operators report that they do not use the automation, it is an indication of distrust and disuse. Operators who perform a counter-check can be said to have distrust in the automation especially if they countercheck every action taken by the automation. However, these operators are actually using the automation. They could be counter-checking with the purpose of understanding the automation and calibrating their trust on the automation. In doing so, they may commit an overuse.

Table 1-1 Matrix for classifying participants' trust and dependence on the navigation aid

Trust		Operator's decision					
		fully relied		cross-check		did not use	
		correct	wrong	correct	wrong	correct	wrong
Automation suggestion	correct	trust	illogical	distrust	distrust	distrust	distrust
	wrong	illogical	overtrust	distrust	distrust	distrust	distrust

Dependence		Operator's decision					
		fully relied		cross-check		did not use	
		correct	wrong	correct	wrong	correct	wrong
Automation suggestion	correct	use	illogical	use	use	disuse	disuse
	wrong	illogical	overuse	use	overuse	disuse	disuse

Operators who reported that they fully rely on the automation commit overtrust and overuse only when they comply with an automation error. Both the automation and operator must then commit the same error. The agreement in operator's and automation's performance is an indication of

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operator's use of the automation, and disagreement is an indication of disuse. If an operator reports using the automation but there is disagreement, the data is illogical. This could mean that the operator do not understand the question or the task. When there are too many illogical data, an analyst should revisit the data collection set-up. These trust-dependence matrix, decision agreement and Jian et al. (2000) trust questionnaire were used in the experiment in Chapter 3.

1.3.3 Factors influencing automation trust and dependence

The factors that influence automation trust and dependence can generally be classified under purpose, performance, and process (Lee & Moray, 1992). Parasuraman and Miller (2004) recently added the effect of etiquette on trust. Similar to how trust develops between people, trust on automation is also moderated by the tone that the automation delivers the message. This could describe how courteous or how authoritative the automation is.

Purpose refers to designer's intention when creating a system (Lee & Moray, 1992). Automation should be designed and implemented with due considerations for how the human operator would use and command the automation (Parasuraman, 1997). This factor conforms to the basic tenet of Cognitive Systems Engineering that the human and machine should work towards a common goal. The utility of the automation, as envisioned by the designer, has to be clearly conveyed to the operators so that they can use or override the automation appropriately.

Perry et al. (2005) reported a case study of a life-threatening automation failure. The automation, which dispensed medication, had a new safety interlock feature that would prevent overdosing. The patient had been recently admitted and resuscitated. At the second admission, the nurses were aware of the medication needed by the patient and tried to extract the drug from a seemingly working automated dispensing unit. Due to an upgrade to include the new feature, the record of the earlier admission was

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not captured in the system. The system went into an interlock mode and gave an uninformative message which the nurses could not understand. They had to work around the malfunction to get the medication, and the patient eventually had to be intubated for four hours.

The “safety interlock” was designed without consideration for how it would be used in emergencies where patients need non-cardiac arrest drugs. The nurses could not comprehend the interlock message and recover timely from the error. This failure would not have happened if the purpose of the new feature had been communicated clearly to the nurses.

The second factor, performance, is achieved when the automation consistently exhibits desirable behavior (Muir, 1989). Robust automation leads to good performance and renders an increase in the use of the automation. However, decisions are computed based on at least one pre-determined limit value that toggles a decision change. The value can be optimized but can never be perfect (Wickens & Dixon, 2007). Lowering the limit has the implication that failures go undetected (misses) while increasing the limit leads to an increase in false alarms.

It was found that the cry wolf effect in false alarms reduces trust in automation and system performance more so than when the automation that misses events (Dixon, Wickens, & McCarley, 2007; Johnson, 2004). When the automation reports too many false alarms (cry wolf), operators lose trust in the system and do not comply with the system’s suggestion. This, in turn, leads to disuse of the system and degrades the overall performance of the cognitive system.

The performance of decision automation is widely quantified using statistical measures of reliability and robustness. However, operator’s dependence on automation performance has a dynamic character which is related to the change in the performance. In an experiment where participants controlled a pasteurization plant, Lee et al. (1992) found that operator’s trust of the automation depends not only on the current but also on recent system

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performance. Subsequent studies reported that operator's self-confidence and their trust jointly determine their dependence on the automation (Lee & Moray, 1994; Wang, Jamieson, & Hollands, 2009). To help operators decide if they would use the automation, Lee et al. (1994) suggested displaying information of the recent past performance of the automation.

More recently, it was found that providing information on the performance of automated decision aid, in particular reliability, improves both operators trust and task performance (Oduor & Wiebe, 2008; Seong & Bisantz, 2008; Wang, et al., 2009). Seong et al. (2008) provided participants with meta-information in an aircraft identification task. From the 11th trial onwards, participants were shown the relative weights of the cues and the reliability of the aid. Participants who were shown meta-information of the past performance of the automation were more likely to trust the system.

Bagheri and Jamieson (2004), instead of showing operators past performance, provided operators with information on the upcoming activities and their associated reliability. Operators were told that the automation would undergo maintenance and the reliability would decrease. The information improved operator's scanning pattern in detecting failure. These studies suggest that designers should identify the different context in which the automation will be used, and the reliability for each context. Such information should then be conveyed to the operators before the activity (e.g. maintenance) takes place.

The last factor, process, refers to the understandability of the rules that governs the automation and the errors that may be produced (Lee & Moray, 1992). For decision automation where many logics beneath the decisions are masked, knowledge of how the recommendations are computed and how the automation can fail are keys to the appropriate use of the automation. Providing details of how the decision automation derives its solution and how it fails can help operators appreciate the automation capabilities and limitations, and thereby aid them in understanding the

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system (Bisantz & Seong, 2001; Dzindolet, et al., 2003; Oduor & Wiebe, 2008). Operators who have a good overview of the system can control the system effectively as they can discern bad decisions from good decisions made by the automation.

It has been proven that operators are more likely to trust and depend on the automation when they know the cause of the error in the automation (Bisantz & Seong, 2001; Dzindolet, et al., 2003). In an anti-air warfare identification task, participants who were told that the failure was caused by an enemy's sabotage were less likely to use the automated information than participants who were told that the cause was a component failure (Bisantz & Seong, 2001). After a failure was injected, the use of the system decreased for a short period of time, but they did not permanently abandon the system. This study highlights the importance of feedback. When operators are aware of the cause of the failure, they adjust their level of trust and dependence accordingly.

Dzindolet et al. (2003) similarly found that providing an explanation for an automation error increases trust and dependence on the automation. When there was no explanation available to participants, even trustworthy automation (with high reliability) was not trusted. Operators, however, trusted unreliable systems when an explanation of the error was given. This implies a potential misuse of feedback. Dzindolet et al. (2003) suggested displaying how the decision automation derived the solution in addition to an explanation for the automation error.

Oduor and Wiebe (2008) presented the algorithm for a decision aid that guided participants with decisions for managing a simulated city. They found that having knowledge about the algorithm improved the operator's trust and usage of the system. Participants also understood the system and performed better. In their study, the algorithm was represented in two formats: textual and graphical. They hypothesized that the graphical representation is cognitively more usable than presenting the information in

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plain text. However, they did not find any significant difference between the two formats. It is possible that the diagrammatic algorithm was not designed to be used by the general population. Perhaps, only software engineers who are trained to use these diagrams can interpret the diagrammatic algorithm readily. A Cognitive Task Analysis approach, where information is designed around the operator's mental process, can be used to develop an effective and more usable design (Guerlain, Jamieson, Bullemer, & Blair, 2002; Kaber, Segall, Green, Entzian, & Junginger, 2006).

To conclude, in terms of information design, operator's trust and dependence on automation can be calibrated by:

1. Explicitly displaying the goal/function of the decision automation (purpose of the automation)
2. Diagnosing and informing the operator the cause of these failure (details of failure in the automation)
3. Providing the operator with information on how the automation made the decision (details of the automated process)
4. Providing operator with the past performance data of the automation (performance of the automation)
5. Presenting the information in a tone that is reflective of the message contents (etiquette)

The MES is able to support the first three information requirements (purpose, cause, and means). It presents the goals and function of the decision automation at its vertical means-ends link and cause of the failure at its horizontal cause-effect link. The MES possess multiple requirements which were each found to improve trust and dependence. However, the MES does not provide the past and future performance data, which were found to aid operators in calibrating their trust and dependence on the automation. It also does not address issues related to automation etiquette. Though the MES does not address all the requirements, supporting three of

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the requirements might be sufficient for mitigating automation trust and dependency issues.

1.4 Summary of proposed research

Decision automation which helps human operators evaluate options is a form of cognitive system. It reduces operator's workload and is particularly helpful in complex environment. However, it is also inherent in decision automation to commit false alarms and misses. Like other forms of automation, decision automation can experience technical failures. These failures affect operator's trust and dependence on the automation.

In this thesis, the Motivation-Expectation Space (MES) is proposed as a representation for communicating the rationale behind the solutions recommended by decision automation. The MES was developed when the author used Cognitive Task Analysis and Cognitive Work Analysis to study operator's thought processes in troubleshooting faults in petrochemical plants (Tan, et al., 2007). It was observed that the operators persistently traversed both the means-ends and causal spaces as they explained their solutions. A horizontal causal dimension was therefore added to Rasmussen's means-ends vertical links, see Figure 1-1. Since the MES was conceptualized from questioning operators on their problem-solving, it would to some extent match the schemas of how human naturally strategize.

Literature on human decision strategies was reviewed and the MES was critiqued for its potentials and limitations in bridging the communication of strategies between human and automation, see Section 0. In behavioral studies and engineering disciplines, decision strategies have consistently been reported to be the process of how decisions are made (Gagliardi, 2006; Gordon, 2003; Grant, 2007; Payne, et al., 1993; Rasmussen, et al., 1994). It turns out that means-ends and cause-effect relationships depicted in the MES are common characteristics in the strategizing process. Gordon (2003), while abstracting 372 strategizing behavior for developing artificial

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intelligence, reported the following four relations as the underlying structure in strategies:

1. the situation that activates the strategies (cause),
2. the goals that were not fulfilled in the situation (why),
3. the action that rectifies the situation (how), and
4. the effect of implementing the action (effect)

In addition to being fundamentals of how human typically strategize, the four relations in the MES were also found to address three of the five known information requirement for calibrating automation trust and dependency. The MES displayed the goal of the automation, details of failure, and details of the automation process. What it lacked was the communication of the performance of the automation. It was also unclear how the user would view the etiquette of the concise messages that are used along the two dimensions.

The merits of the MES were partially addressed in a study where participants controlled a simulated city (Oduor, 2006). Instead of the MES, the explanation provided was the automation algorithm, presented in either diagrammatic or text format. The diagrammatic format was hypothesized to lead to better performance than the text format, since relationships in the algorithm were depicted directly via the visual properties of the representation. It was found that having knowledge of how the solutions were generated, improved operator's trust on the automation. Results, however, showed no difference in performance between the two representations.

This finding is similar to Massa and Mayer's (2006) study that recommended that it was not necessary to develop different instructional material for visualizers and verbalizers. It appeared that people can adapt well to any given representation, suggesting that there may be no difference in results between the MES or text representations.

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The statement that “graphical representation is better than text representation” was debatable for the MES since the information in the MES is a combination of text and graphics. On one hand, previous research suggested that there could be minimal or no advantage in representing the information along the orthogonal structure in the MES. On the other hand, the simple traversing rules could have the advantage of supporting a quick scanning and interpretation of the fundamental information in the automation strategies. This could translate to lesser time and effort needed to process the information.

Given the varying arguments supporting and disputing the effectiveness of the MES, an experiment was conducted to test the effect of providing automation strategies on participant’s trust, dependence, performance, and time to interpret the MES. Specifically, the following hypotheses were tested:

1. Better decisions are made with decision automation that explains its decision strategies than with decision automation that offers no explanation.
2. Operators place *appropriate automation trust and dependence on decision automation that explains its decision strategies than on decision automation that offers no explanation.
3. Better decisions are made with decision automation that explains its decision strategies in the MES format than explanation in plain text.
4. Operators place *appropriate automation trust and dependence on decision automation that explains its decision strategies in the MES format than explanation in plain text.
5. Operators take less time to interpret when the decision strategies are presented in the MES format than in plain text.

*Appropriate is when (1) operators are using the decision automation; and (2) while using, they are able to correctly reject the wrong suggestions and accept the correct suggestions while.

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To test these hypotheses, strategies modules in two different formats: graphical MES and textual, were designed for an in-car navigation decision automation. The textual format presented the automation strategies in plain text while the graphical MES presents in the orthogonal graphical format.

Before conducting the experiment, a case study using Cognitive Task Analysis was conducted to investigate how drivers make decisions concerning navigation and choice of routes, see Chapter 2. Other than developing the material for the experiment, there were two other objectives for the case study.

First, the case study presents a new context of how the MES can be developed from findings in CTA and CWA. The earlier development in the petrochemical industry was less familiar to the general population and the results can be difficult to understand unless the reader is familiar with process control. In-car navigation aiding was chosen because there is a large community who drives and uses of electronic aids that taps on the information from the global positioning system (GPS) and wireless network.

It was also recognized that the petrochemical context has many more physical constraints than intentional constraints. There had been many arguments regarding the value of the CWA in systems with intentional constraints. The second objective of the case study was to present a case of how intentional constraints can be mapped onto the Abstraction Hierarchy and MES.

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2 Case study: Conceptualizing an in-car navigation aid

This case study examines the technologies in navigation support and identifies the cognitive challenges involved in making navigation decisions on the road. The findings were intended to be used to conceptualize a decision automation within which the Motivation-Expectation Space (MES) could be tested for its effectiveness in communicating the automation strategies in Chapter 3.

The key objective was to demonstrate how the MES could be applied together with established methodologies in Cognitive Systems Engineering, namely the Critical Decision Method and Cognitive Work Analysis in a context that was familiar to a larger population. Other than being easily understood by many people, the navigation support context possessed intentional constraints which was lacking in the earlier MES development in process control. A second objective of the case study was to further develop the MES framework for context with intentional constraints.

The joint cognitive system in this case study consisted of a driver and an in-car navigation aid. Together, their goal was to select the best route for driving to the destination. The navigation aid would be the decision automation and the MES module would explain the reasoning behind the decision of the navigation aid.

2.1 Data collection

The objective of the data collection was to generate a set of goals and decision automation failures for in-car navigation. The focus was on understanding how drivers select their route and exploit this understanding to determine how current technologies in a route selection task can evolve in the near future. Knowledge about the navigation task and its associative technologies were acquired via interviews, observations, and document reviews.

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2.1.1 Interview

Three participants were interviewed using the Critical Decision Method. They were asked about challenging incidents that they had faced while using the existing in-car navigation aid, also commonly known as a Global Positioning System. The participants were probed for details of how they had handled the situation, as well as how they would handle the situation if they were to face it again. The objective of the interview was to identify the technical challenges and explore how the MES could be used to explain the technical failures to the operators.

Table 2-1 Challenging incidents faced by the participants while using the GPS

Challenging situations	Means to recover
[Weak satellite signal] The terrain was hilly. The GPS could not detect satellite signal to triangulate the driver's location.	The navigator uses his paper map instead of relying on the GPS.
[Weak satellite signal] There were too many tall buildings in the city and the GPS could not detect satellite signal.	The navigator compares street names with the map in the GPS system.
[Poor map resolution] The map resolution was insufficient to pinpoint the exact location. Navigation aid did not direct user to the carpark closest to the building. Instead, it identified the destination as the road just outside the designated building. The user was not sure if the destination is on the left or right side of the road.	The navigator stops the car and looks around. The navigator suggests driving not more than 100m away from the destination identified.
[Obsolete map] There was a new exit at the expressway which is faster than the route the GPS advises. Driver learned about the new exit and wanted to give it a try.	The navigator tried the new exit, knowing that the GPS would re-compute a new route when the car deviates from the planned path.

The incidents are summarized in Table 2-1. Most of these incidents, except Situation 4, had caused inconvenience to the participants. The problems drivers faced were generally related to (1) weak satellite signal, (2) poor map resolution, and (3) obsolete map.

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2.1.2 Document review

The purpose of the document review was to gather an overview of the in-car navigation functions that were considered by developers in the navigation aid industry. The review also included an update of the technological concepts which would be deployed in the near future for predicting and redirecting traffic flow. The material selected for the review was guided by the findings from the interview.

Table 2-2 List of websites and software as of May 2011.

Web tools

1. Google Maps (<http://maps.google.com/>)
2. Yahoo Maps (<http://maps.yahoo.com/>)
3. MapQuest (<http://maps.yahoo.com/>)
4. Wikimapia (<http://wikimapia.org/>)
5. Bing (<http://www.bing.com/maps/>)
6. Gothere (<http://www.gothere.sg>)
7. StreetMap @ Singapore (<http://www.map.gov.sg/StreetMap/>)
8. Quantum Inventions (<http://www.livetraffic.sg>)

Software

9. Garmin (<https://buy.garmin.com/shop/shop.do?cID=134>)
10. Magellan (<http://www.magellangps.com/Products/All-Vehicle-Navigators>)
11. TomTom (http://www.tomtom.com/en_gb/products/car-navigation/)
12. Mapping 2007 (Mapping International Limited, 2008)

Table 2-2 shows the list of web tools and software that were reviewed. The web tools are free online tools, and users typically printed the results of suggested route before their travel. The software packages are installed in a portable machine which has a Global Positioning System that tracks the location of the users. Users pay a fee for the use of these maps. The features in Garmin, Magellan and Tomtom were extracted from the information available in their websites. The online manuals of their latest

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and most expensive make of their GPS were downloaded and reviewed. A copy of Mapping 2007 was purchased, reviewed, and used for developing the experimental material in Chapter 3. Mapping was chosen for the development as it had the best map for Singapore and it could be installed onto a laptop for recording.

Technologies related to traffic prediction were also reviewed to aid the conceptualization of the navigation aid. In 1995, the United States Department of Transportation initiated a project to develop a real-time Traffic Estimation and Predictable System (U.S. Department of Transport, 2005). Using a computer simulation based on historical data and human behavior, one may predict the travel time between two locations. Drivers can call the 511 phone line or visit http://traffic.511.org/his_traffic_text.asp to plan their travel.

In Singapore, the Land Transport Authority and IBM developed a Traffic Prediction Tool that computes based on adaptive statistical techniques (Mega & Walbridge, 2007). The predictions are currently broadcasted along the road in the form of estimated time to reach major towns. This helps to re-route commuters to less congested roads. Other than empowering the drivers with such information, a variable toll is also implemented. A higher toll is imposed on commuters who drive through roads which are more congested (Chin, 2002). This adds a layer of feed-forward behavioral dynamics, which is different from the system adopted in the United States. Its effects were briefly captured in the decisions observed in Section 0

2.1.3 Observation

The objective of the observation was to identify driver's considerations in a naturalistic environment. These were translated into the functional goals of the joint cognitive system in Section 2.2.1. The route taken by the participant was also modified to create the scenario for the later experimentation.

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The participant, aged 64, was shadowed for 10 sessions as he performed a routine drive. The retired participant was had to pick up his children during the evening peak period from three different locations. Time and traffic condition were important considerations, as he had to enter the city during the peak hour where toll charges were higher. He learnt that he was unable to avoid the toll charges but he could pay less with a better decision.

During his journey, there was one decision which changed dynamically depending on the situation. As he travelled into the city, he could choose between three different routes with three different gantries. Over the 10 sessions, he learnt that the toll to enter the city varied at different gantries and at different times of the day. Generally, the later he passed the gantry, the higher the toll charges.

He did not use one of these gantries as he thought that the route would result in a higher toll, see Route 1 in figure. He was correct as the distance to that gantry was further from his starting position and he might have incurred a higher cost if he had entered from that gantry. This particular route was also the shortest and he might have saved cost on fuel by taking this route at other times of the day.

Figure 2-1 Schematic of the 3 routes the participant's decision

In the first few sessions, the participant tried the other 2 routes and noted the toll charges he incurred. At the latter sessions, it was observed that the

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participant would not decide until he arrived at the junction dividing the two routes.

He would first assess the traffic condition leading to the junction. A heavy traffic meant that he had missed the timeframe for the cheaper toll. It would be another 20min before the toll charges increased at both gantries. If he was still within the timeframe before the toll charges changed, he would likely choose Route 2 which has a toll gantry closer to the road juncture. This decision also depended on the traffic on Route 2.

The participant had learnt, in the earlier trials, that the traffic on Route 2 was usually heavy when he was stuck in a traffic jam. Before the participant reached the junction dividing the two routes, he would tune in to the local radio station for traffic updates. Along his way to the junction, he would also look at the messages displayed on the Expressway Monitoring Advisory System which reports the traffic conditions and their related causes.

This set of observations, unlike the interview findings, found that the goal of an in-car navigation system is not purely to reach the destination quickly. There were other goals such as minimizing toll charges.

The findings also highlight the dynamic nature of route selection decisions. Based on their knowledge of the changes in the traffic condition, drivers have to make quick decisions as they choose their route. They have to integrate information from various sources such as the news channel and their knowledge of traffic patterns.

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2.2 Data analysis

The knowledge elicitation process helped in understanding the state-of-the-art in the use of navigation aid. The navigation aids performed route selection based on distance, toll charges and/or use of freeway. Although there were various traffic prediction tools, none of the aids had the capability to receive such information and re-route drivers to a better route as the traffic condition changes. Drivers had to make such re-routing decisions.

The re-routing can potentially be computed by decision automation at two different levels. At the micro level, the navigation aid optimizes the solution only for the driver. The navigation aid receives traffic updates and computes the optimal route for the functions that the driver desires. The second is at the macro level, where the navigation aid optimizes the traffic condition for the region. A traffic hub collects the destination data of every vehicle on the road (via the driver's input in the navigation aid), optimizes the route, and transmits the information back to the driver. Though both levels are equally plausible, the analysis would focus on the micro level as the data collected from the observations and interviews is insufficient for an analysis at the macro level.

The goals in route selection, problematic situations, actions taken to rectify the situations and the effects of taking these actions were extracted from the data. In the following sub-sections, the goals and its associative technologies were modeled as means-ends relationships in the Abstraction Hierarchy. The situations that can arise in the route selection tasks are discussed as cause-effect relationships. These relationships were then modeled in the MES.

2.2.1 Means-Ends

The data collected was categorized into 14 functions which were optimized by drivers and used for route selection, see Table 2-3. The most frequently cited functions were time and distance.

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Table 2-3 List of functions. Numbers in brackets indicate frequency of occurrence in the web tools and software reviewed in Section 2.1.2.

1. Shortest time (10)	8. Avoid traffic jams (5)
2. Shortest distance (11)	9. Avoid accident zone (1)
3. Lowest fuel consumption (2)	10. Comply with traffic rules (6)
4. Fair weather (2)	11. Preferred expressway (7)
5. Minimal toll (7)	12. Avoid slope (1)
6. Pass by gas station to pump petrol (3)	13. Lowest parking fees (2)
7. Pass by restaurant to dine (3)	14. Preferred parking (parallel vs. conventional) (1)

Some of these functions are implied from other functions. As an example, avoiding slopes and preferring expressways are means to consume less fuel and these functions are means of lowering cost. Therefore, these functions can be generalized to a single function of reducing cost. Using similar arguments, the 14 functions were represented as six values or priorities that drivers exhibited in selecting their route: walking distance (distance between parked location and destination), travel distance, cost, time to destination, safety, and enjoyment. These are represented in the Abstraction-Decomposition Hierarchy, see Figure 2-2.

To achieve the sub-goals that the drivers have as they select a route, the tools that enables the computation of the optimal route were also identified. The most basic tool is the Geographical Information System which provides an infrastructure database for computing possible routes. To facilitate the computation of safety, the navigation aid could keep a record of past accidents. Other than keeping databases, there has to be an updating function that receives real-time data of weather and traffic conditions. This information is used to analyze the comfort and safety of the drive.

The means-ends analysis concludes that the goal of the system is to arrive at the destination by optimizing one or more of the following parameters:.

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Figure 2-2 Abstraction Hierarchy for route selection in a navigation task

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walking distance, travel distance, cost, time to destination, safety, and enjoyment. To optimize the goal, traffic updates are used to predict the outcome of each alternative route, and the best outcome is selected. The difficulty in the route selection task includes the screening of information for the decision and the cognitive challenge in optimizing the solution space within a limited time. Like other decisions, the difficulty increases with the number of options and the time frame for making the decision.

The navigation aid, for the experiment in Chapter 3, was designed around the assumption that it was possible to collate and analyze real-time traffic information to compute the best route for the users based on the goal specified by the user

2.2.2 Cause-Effect

The study of causal relations in this set of data, coupled with the review of literature in strategies and decision automation, led to the conclusion that there are typically three types of cause-effects relationships. They are (1) goals-dependent, (2) environment-impacted, and (3) technology-challenged causal relations.

The goals-dependent causal relations were reported in the study of decision strategies, see Section 0. In this kind of relation, the options that are available to the decision-maker are the causes, and the outcomes of choosing each option are the effects. The dimension of cause-effect, which is to be evaluated, depends on the goal. The goals-dependent causal relations represent the results of the computation performed by the decision aid in optimizing the goal.

This was observed when the driver (see Section 0) was evaluating the different routes that were available. He had three different options. On days when there were traffic jams along Route 2, he would choose Route 3 as he would reach the toll gantry earlier, thereby minimizing his expenditure. Such

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computation can be more effectively handled by a navigation aid that can retrieve the latest traffic condition. This goal-dependent causal relation reflects the positive work done by the navigation for the system and are represented in Figure 2-3.

In technology-challenged causal relations, the causes are technical failures. The technology-challenged causal relations are in contrast to the goal-dependent causal relations. Instead of reporting the work done, the automation reports its inability to perform.

Such report of failure causes have been tested in earlier studies. It was found that participants who were told that the cause of the error was a technical failure trust and rely on the automated information more than participants who were not informed about the cause (Bisantz & Seong, 2001; Dzindolet, et al., 2003). Participants continued to trust and rely on the automation, which provided the causal reasoning, even as the automation performance decreased to an unacceptable level (Dzindolet, et al., 2003). The researchers recommended providing information on how the automation derives the solution, such as the goal-dependent causal relations, in addition to information on the technical failures.

Figure 2-3 The goal-dependent causal relations for a route-selection task that optimizes cost. Each alternative route has a different toll which is represented as the effect of choosing the route. In this case, The Central Tunnel Expressway leads to the cheapest toll which the system should select.

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Figure 2-4 The technology-challenged causal relations for the Global Positioning System which is a form of navigation decision automation that performs route selection.

Three such technical failures were elicited from the interview: (1) weak satellite signal; (2) poor map resolution; and (3) obsolete map. The effect is an explanation of what the navigation aid is doing or not doing, see Figure 2-4. For weak satellite signal and poor map resolution, the navigation aid is unable to locate and direct the driver. For the case of having an obsolete map, the navigation aid represented the location but it was unable to compute the route because of the unfamiliar track.

Ideally, the effects represented, are the steps taken by the designers to mitigate the situation. The effect relation could also be used to explain the technical failure to the user. In the case of receiving weak satellite signal, users who are less technology-savvy may not be able to comprehend the implications. By providing a series of effects, the user can better appreciate the technical failure. However, the addition information would clutter the display.

The environment-impacted causal relations are when the environmental factors that have an impact on the system are represented as the cause. The environment-impacted causal relations in route selection lead to one common effect: slow traffic. In the worst case, the traffic comes to a halt. The causes that lead to slow or halt traffic are infinite though some of the causes occur frequently. The frequently occurring road conditions in

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Singapore were road works, tree pruning, plant watering, road sweeping, road closure, vehicle breakdown, and accidents (Land Transport Authority, 2009). Some of these causal relations are depicted in Figure 2-5.

Figure 2-5 The environment-impacted causal relations for a route-selection task lead to a single common effect: slow traffic.

It is important to note that the single-effect feature in the environment-impacted causal relation is unique to the route selection task. In an earlier study which investigated petrochemical plant operations (Tan, et al., 2007), a single-cause feature was observed instead of the single-effect feature, see Figure 2-6. The loss of supply was the single most common environment-impacted cause though there is a variety of supply, such as the supply of petroleum or hydrogen, which could have been lost. Each supply that is cut off typically has a unique effect. For example, a shortage of hydrogen would imply that carbon cannot form a chemical bond with hydrogen and the carbon would not be able to leave the reactor. This would result in the formation of a layer of coke in the reactor, known as coking. This effect of coking caused by a loss of hydrogen supply is different from the effect of the loss of petroleum supply.

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Figure 2-6 The environmental-impacted causal relations for a petrochemical operation have a single common cause: loss of supply

Causal reasoning, like decision strategy, has been widely studied and it continues to be subjected to multiple interpretations (Klein & Hoffman, 2009). It is possible that the solution space of the cause and effects for environment-impacted causal relations are related to the complexity of the system goals. However, this is a deep philosophical issue. At this stage, it remains unclear how the single-effect and single-cause phenomenon come about.

2.2.3 Motivation-Expectation Space

The means-ends and cause-effect relations analysis were combined in Figure 2-7. The definitions of the four relations were elaborated.

The why-what-how vertical link has not changed much, although the definition of “how” is more specific. Previously, it was unclear if the “how” relation refers to the means that the automation, human operator, or both have. After performing the data analysis, it became clear that the “how” relation should refer to all options in the system and highlight the best option. The best option is what the decision automation computes and recommends to the human operator. From the top of the why-what-how link, the operator can quickly trace the function which is optimized.

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Figure 2-7 Motivation-Expectation Space definitions

The horizontal dimension was expanded to incorporate the three types of cause-effect relations: goal-dependent, technology-challenged, and environment-impacted causal relations. The goal-dependent causal relation focuses on the outcome of the decision-making computation performed by the automation. The technology-challenged causal relation, on the other hand, presents technical failure(s) which hinders the computations. The environment-impacted causal relation refers to external factors that can impact the solution space. The data collected is expanded from the means-ends and cause-effect representations to demonstrate the power of using the MES.

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2.2.4 Design of MES for navigation aid

With a deeper understanding of MES for the in-car navigation aid, the MES for communication the automation strategies was designed. Figure 2-8 shows the MES for the goal-dependent causal relation for a decision point at Route A which splits into three roads. The example is an abstraction of the decision made by a participating driver, see Section 0. It is possible for a navigation aid to automate his decision by collecting and analyzing the traffic situation from multiple sources. In Figure 2-8, Route X is the best option as it minimizes the amount of toll that the driver needs to pay. However, if the toll charges are the same for all three roads, the optimal path would be the shorter Route Y. If the driver would like to know why the navigation aid chooses Route X and not Route Y, he could refer to the MES in Figure 2-8. He would be able to see the function which is being optimized, the alternatives he has, and the effects of selecting each option.

Figure 2-8 Motivation-Expectation Space that presents why Route X was chosen: The goal was to minimize the toll charges and the effect of taking Route X was the cheapest among the three alternative routes.

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The same representation can be expanded to include the environment-impacted causal relation. Figure 2-9 shows the MES for the case where there are road works along Route Y. As a result, the time to reach the destination, by taking Route Y, is unpredictable. As such, the decision automation chooses Route X based on optimizing time.

Figure 2-9 Motivation-Expectation Space that presents environment-impacted causal relation: The road work at Route Y leads to slow traffic and the time to reach the destination by taking Route Y cannot be computed. The automation recommends that the driver takes the alternative Route X which would mean that the driver can get to the destination in eight minutes.

For technology-challenged causal relation, the goal would be the functional purpose, which is the highest level goal identified in the Work Domain Analysis, see Figure 2-2. This is unlike the other two causal relations where the goals represented on the MES are second level goals in the Abstraction Hierarchy: values and priority measures. When there is a technical error, the decision automation is unable to compute, and therefore any attempts to recover would be to achieve the system's functional purpose.

As shown in Figure 2-10, the goal of the system is to arrive at the destination. The navigation aid experiences a weak signal. The effect of the technology challenge is that the navigation aid is unable to identify the

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system's current position. When this happens, one solution is to drive to the next road intersection and input the intersection into the navigation aid. With the start point and destination, the navigation aid can simulate the route and advise on the turning points. The driver will need to lookout for these points and not rely on the navigation aid alerts. This is narrated via the downward link, which represents the actions that the driver should take.

Figure 2-10 Motivation-Expectation Space that explains the hibernation of the GPS and mitigation steps that the user should take

In the validation experiment reported in Chapter 3, the road conditions were adjusted to create the scenarios in the simulation. The system's goal was fixed at minimizing cost. The set-up meant that that goal-dependent causal relation was fixed while the environmental-impacted causes varied to achieve the varying traffic speed. The technology-challenge causal relation was not tested as its introduction would complicate the design the experiment targeted at proving the effectiveness of the MES.

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2.3 Conclusion

Based on the findings in the case study, a first-of-its-kind in-car navigation aid was conceptualized, and the MES graphical representation for communicating its automation strategies was designed for the validation experiment in Chapter 3.

This case study demonstrated the possibilities of (1) integrating the MES with existing Cognitive Systems Engineering methodologies for conceptualizing functions in a decision automation, and (2) applying the MES in a context with intentional constraints. The means-ends analysis aids the conceptualization of the navigation aid (Bisantz, et al., 2003). It maps the driver's goals and tasks. With the mapping, it was possible to identify areas which can be automated. The proposed navigation aid was a step ahead of the technology that was available; it assumed that the navigation aid was able to receive real-time information on the local traffic and weather conditions. Using information which was available to drivers via radio or electronic signboards, the navigation aid could help drivers make sense of the situation and compute an optimal route.

The case study also raised the need for an elaborated definition of causal relations and refurbished the MES with a stronger definition. It revealed three types of causal relations in the Joint Cognitive System (JCS): (1) goal-dependent, (2) environment-impacted, and (3) technology-challenged. A strategy, as defined in the literature, is invoked when there is a situation which does not conform to the goals of the system. The goal-dependent causal relation is the situation when there is more than one possible solution, and some solutions are better than others for different attributes (which is a measure of the goal). The environment-impacted causal relation is when an event, external to the JCS, alters the dynamics of the decision. The technology-challenged causal relation is when the decision automation fails. In this case, the decision automation tries to recover. If possible, the decision automation should try to satisfy the functional goal of the JCS which is to direct the driver to the destination.

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3 Effectiveness of MES on automation trust and dependence

In this thesis, the MES is proposed as a representation for communicating strategies between man and machine in a joint cognitive system. The literature review found that the pieces of information presented in the MES are fundamental in decision strategies and in calibrating automation trust and dependence. Several studies have found better performance when an explanation was provided (e.g. Bisantz & Seong, 2001; Dzindolet, et al., 2003; Oduor & Wiebe, 2008). Providing automation strategies may assist operators in identifying erred solutions made by the decision automation, thereby achieving better performance. While the MES addressed many of the information requirements recommended in the literature, it did not address all the requirements. The additional information may also result in automation mistrust and misuse.

Another research question was whether the orthogonal structure would speed up the interpretation process. On one hand, the simple traversing rules could mean that a shorter time is required to make a better-informed decision. However, earlier studies have found no difference in performance between textual and graphical representations. An experiment was thus designed to test the following hypotheses:

1. Better decisions are made with decision automation that explains its decision strategies than with decision automation that offers no explanation.
2. Operators place *appropriate automation trust and dependence on decision automation that explains its decision strategies than on decision automation that offers no explanation.
3. Better decisions are made with decision automation that explains its decision strategies in the MES format than explanation in plain text.

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4. Operators place *appropriate automation trust and dependence on decision automation that explains its decision strategies in the MES format than explanation in plain text.
5. Operators take less time to interpret when the decision strategies are presented in the MES format than in plain text.

*Appropriate is when operators use the automation but are able to correctly reject the wrong suggestions and accept the correct suggestions.

3.1 Method

The experiment was conducted in a pre-recorded simulation in which the participants made binary decisions with the support of the in-car navigation aid which was the decision automation conceptualized in Chapter 3. The in-car navigation aid and each participant formed the joint cognitive system and their common goal was to reach the destination using the cheapest route. Participants had to pick up visual and auditory cues in the simulation and, with the assistance of the navigation aid, decide on the cheapest route for the travel described in the experiment.

This was cognitively challenging as the computation involved was difficult for a typical unaided human mind. The cost was a function of both static and dynamic parameters. The only parameter that would not change over the duration of the drive was distance. The longer the distance, the more fuel was needed to get to the destination and therefore, the more expensive the route. This was easy and participants would not have problems computing the cost if they only had to consider static parameters.

The difficulty was with the many dynamic parameters in the same problem space. These included the varying road situations, traffic speed, tolls, and fuel efficiency. The same route would bear a different cost when there was a traffic accident leading to slow traffic. This in turn lowered the fuel efficiency and increased the cost. With the change in traffic speed, the toll charges incurred would change and the change was dependent on the time of the

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drive. If the drive was approaching peak hour where the toll charges were increasing, a delay meant higher cost.

With these high cognitive demands, participants who experienced difficulty had to depend on the navigation aid for directions. Participants were told that the navigation aid received real-time traffic conditions and integrated the updates with data of the car's fuel efficiency to compute the cost of each route. They were also aware that they might receive suggestions which were sub-optimal and the error rate was between 20% to 30%. The errors altered participants' trust and dependence on the navigation aid. Participants would have to decide if they would rely on or ignore the navigation aid. They could, however, detect errors in the navigation aid by comparing the suggested directions with the visual and auditory cues from the electronic signboards and radio station in the simulation.

3.1.1 Participants

Ninety-six undergraduates at the Nanyang Technological University participated in this experiment. Data from two participants were excluded as there was a possibility they did not understand the experiment or that they were not serious in performing the experimental task. The median age of the 94 participants was 22. Half the group had at least one year of driving experience. Most of the participants had little experience in driving the simulated route (80%) and in using the GPS (64%). The GPS is the equivalent of the in-car navigation aid. Within the group who had used a GPS before the experiment, 65% did not mind the use of GPS, 17% were reluctant to use it again, and 18% enjoyed having the aid.

None of the participants had problems with the reliability of the traffic news and EMAS messages. This was important as these technologies provided the auditory and visual cues in each scenario. Participants could choose to use these raw data for computing the cheapest route instead of relying on the in-car navigation aid. Less than a third of the participants (27%)

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indicated that they had no experience using the information in traffic reports over the radio channel. Of those who had experience, 71% felt that traffic news had been reliable thus far while the remaining 29% felt that traffic news was only sometimes reliable. A higher proportion of participants (37%) had no experience with the EMAS. Of those who had seen and used the EMAS, 81% felt that it was reliable, and 19% felt that it was only sometimes reliable.

To ensure that participants took the navigation task seriously, their remuneration was computed based on the quality of their decisions. They each started the experiment with \$35 which they would spend on mileage and toll in the simulated drive. They were told that the unused balance would be their remuneration. Depending on their performance, they received between \$15 to \$25 for the approximately 90 minutes experiment.

3.1.2 Material

Participants received a set of documents which comprised of the indemnity form, material to help them with the decisions, and questionnaires, see Appendices. They read the instructions from the workstation which they interacted with via a mouse, headset with microphone, 15" monitor, and a 3M™ MicroTouch™ M170 15" touch-screen monitor.

The 15" monitor displayed a pre-recorded egocentric dashboard view of the drive, see Figure 3-1. The videos were captured using Sony HD Camcorder and edited using Sony Vegas Movie Studio Platinum 9.0 into the .wmv format with a frame size of 1024X768X25s. The purpose of the editing was to create the cues and feedbacks in the simulation. There were two main types of cues: visual cues from the Expressway Monitoring and Advisory System (EMAS); and auditory cues from a pre-recorded radio station. The cues were masked in a noisy background comprising of road signs, music, and traffic updates that were unrelated to the decisions. The videos were segmented at each decision point and were called up according to the

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participants' selection. Following their decision, the quality of the decision (either correct or wrong) would be shown across the center of the screen as a visual feedback of their performance.

Figure 3-1 Screenshot of the Motivation-Expectation Space strategies module (top left), navigation aid (bottom left), and simulated drive (right).

The 15" touch-screen monitor displayed the navigation aid and it was placed adjacent and to the left of the monitor that showed the dashboard view. The images and instructions in the navigation aid were created from MapKing2007 and stitched into a video in the same format as the simulated drive. However, the video was shrunk proportionally onto a 624X468 frame when it was played.

The experiment tested the effect of explaining automation strategies to the users and compared two variations of presentations. The strategies modules, each at an image size of 880x300, were displayed above the navigation aid. The space was left empty under the control conditions.

The videos and images were activated concurrently using a program that was written specifically for this experiment. The program was designed to call up the video of the dashboard view, video of the GPS display and image of the strategies module accordingly to the participants' selection. The

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program also supported (1) the display of the instructions in the .xps format, (2) the logging of participants' input and selection, and (3) a clock that displayed the elapsed time.

Morae 3.0, a COTS software for usability studies, was used together with a Logitech QuickCam Sphere webcam to capture participants' eye movement. This was used to measure the amount of time participants looked at the strategies module. All the software, videos and images were run from a HP XW4600 workstation with an Intel Core™ 2 Quad processor.

3.1.3 Experimental task

In each trial, the participants were tasked to make a series of four binary decisions with the objective of minimizing cost. Throughout the simulation, they received real-time traffic information from two sources: an auditory radio channel and a visual channel of road signs and messages from the Expressway Monitoring and Advisory System (EMAS). EMAS was an electronic display of traffic updates found near and along the expressways in Singapore. The updates were always correct but participants had to sieve the information from a noisy background such as music, advertisements, and traffic information related to the task. Each update was only broadcasted once in either of the two sources.

At each decision point, options were presented to choose between two routes. Participants pressed the left, right, or up keys to make their selection. They then answered a short questionnaire regarding the decision they had made. This includes a question on their use of the navigation aid, see Appendices. After they completed the questionnaire, the simulator played the route that they had selected and gave participants feedback on the correctness of their decision. A wrong decision was the one that resulted in a higher overall expense. This was repeated for the remaining three decisions.

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To reduce their workload, they could choose to rely on the navigation aid that helped them compute the cheapest route. When they reached the destination, they would fill up a trust questionnaire in which they rated their level of trust on the navigation aid. At the start of the experiment, they were told that the navigation aid took in real-time traffic information (including road closure, toll charges, and traffic speed) and computed the distance, toll charges, and the time needed for all routes that lead to the destination. As the traffic condition changed in their drive, the navigation aid dynamically re-computed the cheapest route.

Participants were informed that the navigation aid had an error rate between 20% - 30%. If they did not agree with the route or decision, they could ignore the suggestion. They might hold such a belief when:

1. the recommendation contradicted the cue in the pre-recorded simulation. The report is the raw data which is always correct but it has not been filtered and processed for the decision. In this case, the participant had developed appropriate trust and dependency on the navigation aid.
2. the navigation aid was wrong in the previous drive. This led to the reduced trust and dependency in the following decision/s.
3. the recommendation contradicts some prior knowledge about the route. The participants might have driven along the simulated route and matched their knowledge about the route to their experience. If it happened that the scenario differed from the participants' experience, they might choose to ignore both the navigation aid and the cues, which were always correct in the simulation. This would confound the experiment. To reduce this effect, only participants who rarely or had never drove the simulated route were selected.

If they did not trust the navigation aid, they could use the maps and information sheets on their desk to work out the cheapest route, see

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Appendices. The information consisted of the fuel economy of the vehicle, distance of each segment of the route, location of expressway exits, location of toll gantries, and the toll charges over the day. They were provided with heuristics for estimating the fuel consumption, and adequate stationeries to help them work out the cheapest route.

The navigation aid was set at 75% reliability, where one of the four suggestions in each scenario was wrong/sub-optimal. An example of a wrong suggestion would be that the navigation aid suggests a route with road works. If the participants over-relied on the system, by not listening to the traffic report, the participants would follow the suggestion and make a wrong decision. The participants would subsequently receive a feedback that the decision was wrong, and they would see the road works in the video simulation after they turned into the road. The vehicle would automatically maneuver out from the situation but the participants would have to bear the additional time and cost. The feedback in the simulation was critical because such feedback provided the only basis for forming some degree of trust in the navigation aid.

Each participant first went through a practice trial. Instead of practicing all four decisions, participants practiced the protocol for two of the decisions and watched the computer select the other two decisions. The first experimental trial collects the baseline measure for checking that the participants were randomly assigned to the experimental conditions. All the participants underwent the same protocol described in this section. In the second experimental trial, a control group received an experimental condition that was similar to the conditions in Trial 1, and two experimental groups were provided with an additional module that presented the strategy used by the navigation aid. This additional strategies module function was presented in two formats: graphical MES and textual. Participants in the experimental groups received either one of the two formats. Prior to their Trial 2 with the additional function, they went through a short introduction on the information available in the additional module.

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3.1.4 Design

The experiment controlled for two factors: strategies module and order of scenario. Participants were randomly assigned to one of the 3 (strategies module) X 2 (order of scenario) between-subjects conditions. There were three conditions for strategies module: control, textual, and graphical MES. One experimental group received the strategies module in the textual format while the other received the module in the graphical MES format. Figure 3 2 shows samples of the two formats of strategies module.

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Figure 3-2 Samples of the strategies module. The two samples show the same information in two different formats. The one at the top is in the graphical Motivation-Expectation Space format and the one at the bottom is in the textual format.

The fonts and choice of highlights were kept consistent to control for any variability that could result from legibility. Both formats of strategies modules presented the information related to the selected route in black and those related to the alternative route in grey. They both contained the following pieces of information:

1. the suggested route
2. active goal in the suggestion and other goals were concurrently optimized
3. effect of the suggested route based on the active goal
4. effect of the alternative route based on the active goal
5. the cause that led to the effects in 3 and 4

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6. events following the decision if the suggestion is adopted, as well as the events leading to the decision

The effect of the strategies module was tested in Trial 2 while Trial 1 checked that participants were randomly assigned to each of the three conditions. In Trial 2, participants in the control group received the same assistance provided by the same navigation aid they received in Trial 1. The two experimental groups performed Trial 2 with the navigation aid and an additional module that presented the strategies used by the navigation aid.

A comparison of the mean scores between the control group and the experimental groups indicated the effect of providing the elements in the strategies behind the suggestion, see Table 3-1. A comparison of the text group and the MES group indicated the effectiveness of the graphical MES format over the textual format.

Table 3-1 Table of comparison for the experiment

	Measure*	Comparison			Purpose of comparison
		Control	Text	MES	
Trial 1 (no strategies module)	Performance, Trust, Dependence	X	X	X	To test if the three samples are from the same population. There should be no significant difference between their mean score.
Trial 2 (with strategies module)	Performance, Trust, Dependence	X	X	X	To illustrate the effect of providing automation strategy
	Performance, Trust, Dependence, Time to interpret		X	X	To illustrate the effect of MES over plain text

X refers to the mean scores for the stated measures.

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Finally, the order of the two scenarios used in Trial 1 and Trial 2 was controlled for in the balanced design. Three scenarios were created for the experiment. Scenario 1 was used in the practice trial; Scenario 2 and Scenario 3 for the two experimental trials. The 75% reliability in the navigation aid was manipulated by introducing an automation error at the second decision point for Scenario 2, and at the third decision point in Scenario 3. This was designed to introduce uncertainty. However, there were concerns that there may be differences in difficulty between the two scenarios. Hence, half the participants underwent Scenario 2 followed by Scenario 3 and the other half underwent the two scenarios in the reversed order. All participants received the same Scenario 1, with no error committed by the navigation aid, in the practice trial.

3.1.5 Measures

Six measurements were collected in the study: (1) performance, (2) time to interpret, (3) trust and dependence, (4) trust ratings, (5) confidence and difficulty, and (6) decision agreement. Except for the trust ratings, all measurements were taken at four decision points. The average score of the four measurements was computed to obtain an overall score for each trial.

The decisions were also studied separately based on the occurrence of a “Failure decision”. Out of the four decisions, the decision automation commits an error in either the second or third decision. Decisions made before the “Failure decision” were labeled as “Pre-failure decisions”. Where there were two decisions, the average score would be computed for the analysis. Similarly, decisions made after the “Failure decision” were labeled as “Post-failure decisions” and the average scoring was applied.

Performance. Participants made four binary decisions in each experimental trials and each decision was graded as either correct or wrong. The mean of the four decisions was computed to obtain an overall performance score for each trial. Participant scored between 0 (all decisions were wrong) and 1 (all

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decisions were correct) with an interval of 0.25 for each trial. Other than comparing the overall performance scores, the pre-, post-, and during failure performance were analyzed.

Time to interpret. The time taken to interpret the strategies module was measured at every decision point in the Trial 2 for the two groups of participants who received the additional strategies explanation. This measurement was used to study the effectiveness of representing the decision strategies in the graphical format over the text format. It also served to monitor the learning effect of the strategies module over time.

The time was logged by the experimenter using Morae when the participants turn their head towards the navigation system and look at the strategies module at the upper half of the screen. Participants typically look at the strategies module more than once for each decision. The total time for all the glances for each decision was added. Glances that were less than 2 seconds were not included as participants reported that they were checking for changes in the information rather than trying to interpret. Participants also exhibited eye shifts away from the screen when they were thinking about the meaning of the strategies module. An example would be when they were comparing the information in the strategies module with the paper material. The time for their eye glances away from the screen, in this case, was included. The data was analyzed at both trial and decision levels.

Trust and Dependence. After every decision, participants answered a question on whether they had used the navigation aid in their decision. They chose one of the three options: (1) fully relied, (2) cross-check, and (3) did not use. If participants did not use the navigation aid, it meant that they distrusted and disused the navigation aid. Participants might have focused his attention on the traffic report and tried to work out the best route themselves. They might also have relied on their experience and made their selection intuitively.

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If the participants fully depended on the navigation aid, the outcome of their decision was matched against the outcome of the navigation, see Table 3-2. If both decisions were correct, the participants had trusted and used the navigation aid appropriately. If both were wrong, they had overtrusted and overused the navigation aid. A difference in the outcome meant that the participants were inconsistent in answering the questionnaire. This could mean that the participants did not understand the task.

Table 3-2 Matrix for classifying participants' trust and dependence on the navigation aid

Trust		Participant					
		fully relied on GPS		cross-check with GPS		did not use GPS	
		correct	wrong	correct	wrong	correct	wrong
GPS	correct (75%)	trust	illogical	distrust	distrust	distrust	distrust
	wrong (25%)	illogical	overtrust	distrust	distrust	distrust	distrust

Dependence		Participant					
		fully relied on GPS		cross-check with GPS		did not use GPS	
		correct	wrong	correct	wrong	correct	wrong
GPS	correct (75%)	use	illogical	use	use	disuse	disuse
	wrong (25%)	illogical	overuse	use	misuse	disuse	disuse

If the participants indicated that the suggestion provided by the navigation aid was cross-checked, it meant that the participants distrusted the navigation aid. The navigation aid was overused when the participants wrongly accept a wrong suggestion. Otherwise, the participants would have

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used the navigation aid regardless of the outcome of their decisions. The frequency of their distrust, trust, overtrust, disuse, use, and overuse were collated and analyzed at the trial level.

Trust rating. At the end of each experiment, participants rated a seven-point trust questionnaire which was modified from the trust questionnaire developed by Jian, Bisantz, and Drury (2000), see questions in Table 3-3. In the experiment, the navigation aid was introduced to the participants as smartGPS. There were seven positive and five negative questions in this questionnaire. Each question was analyzed independently from the other questions.

Table 3-3 Trust questionnaire (Jian, et al., 2000)

1. The directions provided by the smartGPS are deceptive.
2. The smartGPS behaves in an underhanded/sneaky manner.
3. I am suspicious of the smartGPS's intent, action or outputs.
4. I am wary of the smartGPS's ability to compute the cheapest route.
5. The directions provided by the smartGPS could have a harmful outcome. (i.e. the suggestion could lead me to the more expensive route.)
6. I am confident of the directions provided by the smartGPS.
7. The smartGPS provides security towards fulfilling my objective.
8. The directions provided by the smartGPS have integrity.
9. The smartGPS is dependable for computing the cheapest route.
10. The smartGPS is reliable for computing the cheapest route.
11. I can trust the smartGPS to compute the cheapest route.
12. I am familiar with the smartGPS.

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Confidence and difficulty. Participants rated their difficulty in making each decision and their confidence in each decision they made. The difficulty would be high and participants' confidence would be low when they hear confounding evidences that indicated that the navigation aid was wrong. An example would be that he heard a traffic report of an accident, and the navigation aid asked him to turn into the accident zone. These measurements were used to explain irregularities in the findings.

Decision agreement. In examining the relation between participant's trust and performance, their decision agreement with the navigation aid was examined. Each decision scored a 1 when the participant's selection is the same as the navigation aid's recommended route. The score is 0 otherwise. The analysis was performed at both trial and decision levels.

3.1.6 Analysis

There were two main inference test used in analyzing the data: Kruskal Wallis test and Wilcoxon Mann-Whitney test. Both tests involve ranking the scores and comparing the difference between the mean ranks of each sample. The Kruskal-Wallis Test was performed to study the differences between the three strategies module conditions and the Wilcoxon Mann-Whitney test was used as the post-hoc test. The Wilcoxon Mann-Whitney test was also used to study the differences between the two experimental conditions and the order of the two scenarios.

The objective of Trial 1 was to check that the participants were randomly assigned to each of the three experimental conditions for the strategies module received. This was a test for no difference and the critical p-value was .100. The critical p-value for the other tests was .050.

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3.2 Results

Table 3-4 shows a summary of the mean and standard deviation of each measurement in Trial 2. Other than the familiarity dimension in the trust rating, the analyses showed no differences in the other measurements in Trial 1, indicating that there was random assignment of the participants into the three experimental conditions. To overcome the difference in the trust rating, the hypothesis testing was modified to analyze participant's change in trust rating from Trial 1 to Trial 2. The null hypothesis was that there is no change in trust rating and the analysis was applied to the average score for each dimension in the trust questionnaire filled by each of the three groups of participants.

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Table 3-4 Mean and standard deviation

Mean (Standard Deviation)	Control (n=31)	Text (n=32)	MES (n=31)	p
<i>Analysis performed at decision level (pre-failure, failure, post-failure)</i>				
Performance				
(Overall)	.53 (.21)	.72 (.15)	.68 (.16)	.001
Pre-failure	.45 (.44)	.95 (.15)	.84 (.33)	< .001
Failure	.45 (.51)	.13 (.34)	.06 (.25)	< .001
Post-failure	.71 (.42)	.92 (.18)	.97 (.13)	.006
Decision Agreement				
(Overall)	.56 (.26)	.91 (.12)	.90 (.17)	< .001
Pre-failure	.45 (.44)	.95 (.15)	.84 (.33)	< .001
Failure	.55 (.51)	.88 (.34)	.94 (.25)	< .001
Post-failure	.71 (.42)	.92 (.18)	.97 (.13)	.006
Difficulty				
(Overall)	3.71 (1.26)	2.73 (1.07)	3.05 (1.20)	.004
Pre-failure	3.52 (1.66)	2.70 (1.31)	2.97 (1.36)	ns
Failure	4.06 (1.34)	2.75 (1.67)	2.97 (1.28)	.001
Post-failure	3.58 (1.37)	2.69 (1.34)	3.10 (1.54)	.025
Confidence				
(Overall)	4.90 (1.17)	5.05 (0.96)	4.57 (1.24)	ns
Pre-failure	4.66 (1.30)	5.03 (1.14)	4.76 (1.43)	ns
Failure	4.29 (1.40)	5.16 (1.37)	5.00 (1.39)	.030
Post-failure	4.91 (1.43)	5.11 (1.30)	4.94 (1.49)	ns
Time to interpret				
(Overall)	N.A.	46.31 (14.92)	37.93 (13.34)	.012
Pre-failure	N.A.	52.15 (22.84)	49.66 (25.47)	ns
Failure	N.A.	47.05 (25.11)	37.47 (23.54)	ns
Post-failure	N.A.	32.02 (15.74)	21.20 (10.58)	.003
<i>Analysis performed at trial level</i>				
Trust				
Overall (all four decisions)				
Fully rely on	.18 (.26)	.29 (.34)	.20 (.25)	ns
Cross check	.52 (.32)	.66 (.32)	.69 (.29)	.047
Did not use	.31 (.26)	.05 (.10)	.11 (.22)	< .001
When GPS was correct (three decisions)				
Fully rely on	.16 (.28)	.29 (.35)	.18 (.27)	ns
Cross Check	.54 (.32)	.68 (.34)	.69 (.31)	ns
Did not use	.30 (.28)	.03 (.10)	.13 (.25)	< .001
When GPS was wrong (one decision)				
Fully rely on	.23 (.43)	.28 (.46)	.26 (.45)	ns
Cross Check	.45 (.51)	.63 (.49)	.71 (.46)	ns
Did not use	.32 (.48)	.09 (.30)	.03 (.18)	.003

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Mean (Standard Deviation)	Control (n=31)	Text (n=32)	MES (n=31)	p
Trust and dependence (Interpreted from matrix in Table 3-2)				
Overtrust	0.19 (0.40)	0.25 (0.44)	0.26 (0.45)	ns
Trust	0.42 (0.72)	0.84 (1.05)	0.52 (0.77)	ns
Distrust	3.30 (1.04)	2.84 (1.35)	3.19 (1.01)	ns
Overuse	0.48 (0.51)	0.88 (0.34)	0.90 (0.30)	< .001
Use	2.19 (0.95)	2.88 (0.34)	2.65 (0.76)	.001
Disuse	1.23 (1.02)	0.19 (0.40)	0.42 (0.89)	< .001
Change in trust rating				
Deceptive	0.13 (1.55)	-0.39 (1.75)	0.16 (1.37)	N.A.
Underhanded/sneaky	0.30 (1.04)	-0.06 (1.16)	-0.10 (0.98)	N.A.
Suspicious	*0.37 (1.18)	-0.06 (1.29)	0.05 (1.21)	N.A.
Wary	0.36 (1.11)	-0.19 (1.64)	-0.31 (1.27)	N.A.
Harmful outcome	*0.48 (1.27)	-0.29 (1.36)	0.23 (1.80)	N.A.
Confident	-0.09 (1.32)	*0.80 (1.50)	0.12 (1.05)	N.A.
Security	-0.13 (1.39)	*0.80 (1.18)	-0.05 (1.05)	N.A.
Integrity.	-0.02 (1.12)	*0.37 (0.95)	-0.02 (0.92)	N.A.
Dependable	-0.29 (1.08)	*0.53 (1.22)	0.27 (1.43)	N.A.
Reliable	-0.40 (1.18)	*0.56 (1.27)	0.28 (1.31)	N.A.
Trust	-0.37 (1.32)	*0.65 (1.23)	0.15 (1.18)	N.A.
Familiar	0.05 (0.70)	*0.71 (1.08)	*0.58 (0.89)	N.A.

*significantly different from the zero null hypothesis.

3.2.1 Performance

Participants in both experimental groups performed significantly better than participants in the control group (χ^2 (2, N = 94) = 14.61, $p = .001$). After controlling for Type I error across the post-hoc tests by using the Bonferroni approach, the study concluded that the control group performed significantly poorer than the text group ($z = -3.53$, $p < .001$) and the MES group ($z = -2.96$, $p = .003$). However, there was no difference in performance between the two experimental groups. This was coherent with the control group reporting higher task difficulty than the text group ($z = -3.080$, $p = .002$) and MES group ($z = -2.399$, $p = .016$) with no significant difference between the two experimental groups (χ^2 (2, N = 94) = 10.86, $p = .004$).

When the decisions in Trial 2 were broken down into pre-failure, failure, and post-failure decisions, there was significant strategies module effects for the

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pre-failure decisions ($\chi^2 (2, N = 94) = 28.69, p < .001$), failure decision ($\chi^2 (2, N = 94) = 15.93, p < .001$), and post-failure decisions ($\chi^2 (2, N = 94) = 10.21, p = .006$). The results of all three post-hoc analysis similarly concluded that the differences lie between the control group and the two experimental groups with no difference between the two experimental groups.

Plotting the performance revealed that participants who had received a strategies aid (either text or MES) performed better than the control group only when the decision aid was correct, see graph in Figure 3-3. When the decision aid was wrong, the converse was true. The drastic dip in the performance of the two experimental groups when the decision aid made an error was not expected.

Further investigation into the differences suggested that participants in the experimental groups exhibited higher compliance with the navigation aid, thereby committing erred decisions when the navigation aid failed. This was indeed true as shown in the second graph in Figure 3-3. The mean of the MES and text groups fluctuated above the 80% compliance line while the control group only picked up but did not cross the 80% line even at the conclusion of the experiment. Before the participants were showed the strategies aid (graphs in Trial 1), the three groups of participants exhibited similar trends in similar ranges at all three stages of their decision-making. In Trial 2, there were significant strategies module effects on decision agreement (pre-failure: $\chi^2 (2, N = 94) = 28.69, p < .001$; failure: $\chi^2 (2, N = 94) = 15.93, p < .001$; and post-failure: $\chi^2 (2, N = 94) = 10.21, p = .006$) and the post-hoc analysis again showed that the only non-significant comparison was between the two experimental groups.

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Figure 3-3 Graphs of performance, decision agreement, and difficulty

The deep V-shape performance curve was also backed by participant's report of the task difficulty. Participants in both experimental groups consistently reported lower task difficulty ratings and higher confidence ratings (not shown in the graphs) than participants in the control group in Trial 2. When the navigation aid gave a flawed suggestion, the experimental groups did not felt the increase in task difficulty reported by the control group, see the inverted-V peak in the control graph ($\chi^2 (2, N = 94) = 14.31, p$

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= .001). Their differences remained significant at the post-failure decisions ($\chi^2(2, N = 94) = 7.38, p = .025$).

3.2.2 Time to Interpret

The Wilcoxon Mann-Whitney test revealed that there was a significant 12.2s difference between the two experimental groups in the time they used to interpret the two forms of strategies modules, $z = -2.52, p = .012$. The participants receiving the graphical MES format consistently took a shorter time than the participants receiving the textual format in their pre-, post- and during failure decisions. However, the difference was not significant in the pre-failure and failure decisions. It was only at the post-failure decision that there was a significant 11.12s difference, $z = -2.99, p = .003$.

3.2.3 Trust and dependence

Participants answered a question on whether they fully relied on the navigation aid, cross-checked their decision with the navigation aid, or did not use the navigation aid after they make each decision. Figure 3-4 shows the relative frequency across the three groups for their decisions when the navigation aid was correct (75% of trials), wrong (25% of trials), and as an overall score.

In examining the frequency for “fully-relied on”, the Kruskal Wallis Test showed no significant difference between the three groups in relying on the navigation aid for all three scores. For cross-checking, only the overall score showed a difference ($\chi^2(2, N = 94) = 6.09, p = .047$). The post-hoc Mann-Whitney test revealed that participants given the MES aid performed more cross-checking than the participants in the control group ($z = -2.32, p = .020$). Cross-checking is an indication that participants were using the navigation aid but they do not fully trust the automated aid.

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Figure 3-4 Graphs showing percentage of participants who fully relied, cross-checked, and did not use the in-car navigation aid under each experimental conditions

For the “did not use” frequency, significant differences were found for all three scores (overall: $\chi^2(2, N = 94) = 24.28, p < .001$; wrong: $\chi^2(2, N = 94) = 11.35, p = .003$; correct: $\chi^2(2, N = 94) = 22.64, p < .001$). In all three scores, participants in the control group significantly did not use the navigation aid more than participants in the two experimental groups. This suggests greater distrust and disuse in the control group. There were no differences between the two groups.

Participant’s trust and dependence were also analyzed using the matrix in Table 3-2. The analysis found no differences in the measure of trust between the three groups. However, there were significant differences in their disuse ($\chi^2(2, N = 94) = 24.28, p < .001$) and overuse ($\chi^2(4, N = 94) = 22.09, p < .001$) of the navigation aid. Similar to the earlier analyses, participants in the MES group (11%) and text group (5%) were less likely to disuse the navigation aid than the control group (31%). In addition, participants who received the strategies module in the graphical MES format (95%) and textual format (93%) were more likely to overuse the navigation aid than participants in the control group (62%). This conformed to the

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decision agreement analyses that the experimental groups had a higher tendency to accept faulty suggestions provided by the navigation aid. There were no significant differences between the two experimental groups.

3.2.4 Change in trust rating

The Kruskal Wallis test for comparing the three groups that received different strategies module conditions revealed that the random assignment did not work ideally. A significant difference in the trust rating for the question on familiarity was observed ($\chi^2(2, N = 94) = 7.97, p = .019$). The post-hoc test revealed that, prior to participants' exposure to the strategies module; participants in the text group rated their familiarity with the navigation aid lower than the rating by participants in the control group.

To account for the differences in their trust rating on familiarity before the participants' exposure to the strategies module, the change in trust rating from Trial 1 to Trial 2 was computed to study if their rating dropped or increased after their exposure. The change was compared with $H_0 = 0$ in the Wilcoxon Mann-Whitney test. This replaced the original planned comparison between the three groups,

Participants in the control group reported a positive change in their trust rating for two of the five negative dimensions, see Table 3-5. Participants who received the strategies module in the textual format, on the contrary, reported a positive change in all seven positive dimensions. Participants in the MES group only reported being more familiar with the navigation aid.

All analyses that test for differences between the two scenarios showed no significant differences between the two scenarios. When the scenarios difference was examined jointly with the order in which they were presented, only the analysis for overuse showed a significant difference for the order in which they were presented ($\chi^2(2, N = 94) = 17.81, p < .001$). The analysis

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showed that the odd of misusing the navigation aid was 3.86 times more likely in Trial 2 than in Trial 1.

Table 3-5 Change in trust rating that are significant for each group of participants

	M	z	p
Control group			
I am <i>suspicious</i> of the smartGPS's intent, action or outputs.	0.37	-2.03	.042
The directions provided by the smartGPS could have a <i>harmful outcome</i> . (i.e. the suggestion could lead me to the more expensive route.)	0.48	-1.97	.049
Textual format group			
I am <i>confident</i> of the directions provided by the smartGPS.	0.80	-2.70	.007
The smartGPS provides <i>security</i> towards fulfilling my objective.	0.80	-3.28	.001
The directions provided by the smartGPS have <i>integrity</i> .	0.37	-2.09	.036
The smartGPS is <i>dependable</i> for computing the cheapest route.	0.53	-2.29	.022
The smartGPS is <i>reliable</i> for computing the cheapest route.	0.56	-2.30	.021
I can <i>trust</i> the smartGPS to compute the cheapest route.	0.65	-2.77	.006
I am <i>familiar</i> with the smartGPS.	0.71	-3.18	.001
MES format group			
I am <i>familiar</i> with the smartGPS.	0.58	-3.08	.002

3.3 Discussion

The experiment revealed that presenting automation strategies, in either the textual or MES format, to the participants led to greater automation trust. This greater trust was translated to better overall performance in the experiment. However, the better performance was also a reflection of the high 75% automation accuracy rather than the automation strategies itself. When the navigation aid commits an error, the performances of the experimental groups dipped badly and were lower than that of the control group. Contrary to hypothesis 2, the greater trust in the experimental groups did not result in an appropriate use of the navigation aid. The experimental groups with higher trust committed overuse of the automation – accepting

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flawed suggestions. They, however, committed less disuse of the navigation aid than the control group.

Between the two experimental groups (graphical MES vs. textual format), only two differences were found. First, participants who received the automation strategies in the textual format placed automation trust in more dimensions than participants receiving the graphical MES format. These dimensions, however, did not seem to have an impact on their performance and dependence. Both experimental groups showed similar trends in automation dependence and performance despite their tendency to be more comfortable with the textual representation.

Second, the orthogonal structure in the MES aided in reducing the time needed for interpreting the information. This was as hypothesized and demonstrated that the orthogonal structure was indeed easy to follow. However, the MES still possesses the earlier issues of overtrust and overdependence which are related to the information presented and are independent from its orthogonal structure.

3.3.1 Effects of providing automation strategies on performance

The experiment revealed that the strategies modules resulted in better performance. The better performance was attributed to the higher decision agreement with the highly reliable navigation aid. The hypothesis that participants who received the additional strategies aid would perform better than participants who were given only the decision aid was expected to be valid in all pre-, post-, and during failure decisions. Even if the hypothesis was not true for all three cases, providing an explanation was expected to aid participant's understanding of an automation failure which would result in lower automation overuse. Instead, the experiment revealed that participants in the experimental groups overtrusted the navigation aid in accepting the wrong suggestions. They exhibited lower disuse but not lower overuse.

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The higher decision agreement in the pre-, post-, and during failure decisions by the two experimental groups was consistent with an earlier study which correlates participant's judgment and the decision aid's estimate (Seong & Bisantz, 2008). Comparing participants who received an explanation to those who did not, they found that the correlation was higher for decision aid with high reliability, and lower for decision aid with low reliability. The correlation is also an indication of decision agreement. This thesis examined only the high reliability condition and similarly found high decision agreement with the suggestion provided by the automation. The high decision agreement explained the dip in participant's performance when the automation failed.

The dip was also observed in an earlier study where participants were overly complacent (Parasuraman, et al., 1993; Singh, Molloy, & Parasuraman, 1997). Participants who were given decision automation that had constant reliability developed dependence on the automation over 10 trials. At their 11th trial, a total automation failure was injected and their performance dipped drastically. Another group of participants who were given decision automation with variable reliability, on the other hand, grew skeptical about the automation and their dip in performance was moderated. Unlike the interaction observed in this experiment (see Figure 3-3), the skeptical participants performed consistently better than the complacent participants. This suggests that the complacency induced by providing the automation strategies is not necessary evil when the automation has high reliability. The lower disuse exhibited by the experimental groups was one justification.

Another argument would be the better performance exhibited by the experimental groups in their pre-failure decisions in Trial 2. All participants had similar performance in Trial 1 and they chose to agree with the correct solution provided by the decision aid in the post-failure decision. It could be that they were told that the navigation aid had 70-80% reliability and felt that the probability of receiving another wrong decision in Trial 1 was low. In

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Trial 2, the game was reset and the probability that the erred solution was in the first decision would be high. If participants held this belief, there should be moderate decision agreement. The results showed that only the control group exhibited this belief (45%) while the two experimental groups had much higher decision agreement (>80%). By virtue of the high reliable, the navigation aid actually made correct decisions and benefitted the participants in the experimental groups who were quicker in trusting the reliable automation.

The overtrust and overuse of the navigation aid was similar to the findings in Dzindolet et al. (2003) and Odour (2006). Dzindolet et al. (2003) provided participants with explanations for errors committed by decision aids while Odour (2006), similar to this experiment, provided information on how the automation derived the solution. Both studies, as well as this experiment, found that participant exhibited higher trust on decision aids when explanations were provided. This was insofar as participants who were provided with explanations for errors committed by decision aids with low reliability exhibited higher automation trust than participants who received high reliability decision aids that do not have an explanation (Dzindolet, et al., 2003).

Dzindolet et al. (2003) suggested that a combination of both kinds of explanations might calibrate operator's trust and dependence. Though it was not tested in this experiment, it seemed unlikely that providing both sets of explanation would calibrate participant's trust to Moray's "eutactic" point – a point where participants uses the correct suggestion and reject the wrong suggestions (Moray, 2003). Each kind of explanation was separately found to cause a bias in participant's trust. If put together, the outcome would likely be (1) a greater overtrust or (2) the level of trust would remain at the same level where only one kind of explanation is provided. If such a study is to be conducted, the comparison should be to find the difference in trust and dependence between the two kinds of explanation.

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The findings in this experiment suggest that an explanation would be useful for reliable decision automation which has high disuse. However, measures should be taken to mitigate automation overuse. Perhaps, operators could be taught to look for disconfirming evidences in the explanation. For decision automation that has low reliability, Seong and Bisantz's study suggested that operators would moderate their trust on automation with explanation for automation with different reliability (Seong & Bisantz, 2008). Unfortunately, this experiment did not examine decision automation with low reliability and there were no literature that reports a micro-analysis of performance in pre-, post-, and during failure decision. Future study could examine the low reliability condition in greater depth to understand how offering an explanation would vary when there is low decision agreement.

3.3.2 Effect of the orthogonal structure in the MES

The experiment found no difference in performance between participant who received the strategies module with an orthogonal structure (MES group) and without the structure (text group). This is similar to findings in Massa and Mayer (2006).

There were, however, significant differences between the MES and text groups for (1) time for interpreting the information, and (2) trust on the navigation aid. Participants who received the graphical MES format took a shorter time to interpret the information in the strategies module than participants receiving the textual format. This is important because operators using decision automation should not be burdened with the additional task of deciphering the decision automation. In the context of this experiment, the effect size was 12.2s. This may seem short for most tasks but would mean a lot to time-critical tasks where decisions have to be made within minutes.

Similar to Odour's (2006) and Dzindolet et al. (2003) study, the experiment found that providing participants with the automation strategies increased

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their subjective trust and dependence on the navigation aid insofar as an automation overuse. While participants in the control group became suspicious and worried about a harmful outcome, participants in the experimental groups felt that they had become more familiar with the navigation aid. The text group, in addition, gave significantly higher rating in the remaining 6 positive dimensions in Jian, et al., (2000) trust rating scale.

With the higher reported trust, the text group was expected to exhibit higher decision agreement than the MES group. Instead, these participants exhibited slightly lower automation overuse than the MES group. In this study, the orthogonal structure seemed to have calibrated the participants' trust but not their dependence on the navigation aid, suggesting that lower trust need not lead to lower dependence. Participants who received the MES format only showed an increase in their trust rating for familiarity. This was a reasonable increase since participants had more information about the decision aid and more exposure in the second trial compared to the first trial. Unfortunately, their moderated trust did not translate to better dependency and performance.

This experiment found that the orthogonal structure in the MES was effective for communicating automation decisions in two aspects. First, participants took less time to interpret the representation and this could be useful for time-critical decisions. Second, the MES format calibrated participant's trust on the navigation aid. However, the issues of automation overtrust and overuse with the additional explanation remains.

3.3.3 On issues of trust measurements

Though issues of trust measurements were not the main focus of this thesis, the experience in searching and applying a suitable metric became instrumental and the lessons learnt were valuable. In the experiment, the questionnaire for measuring trust by Jian et al. (2000) was implemented on the Asian community and there were a couple of issues. The questionnaire

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did not seem to work very well with the Asian community. During the pilot study, many participants could not understand the questionnaire. The context was later added for each question in the twelve dimensions before the participants had a better appreciation of the questions.

Participants also had difficulty recalling their rating for the twelve dimensions when the questionnaire was first implemented in an electronic form. The recall was pertinent for heightening the sensitivity of the trust measurement. When implemented in the electronic form, the results did not make sense. Ratings for twelve dimensions were too many for participants to remember. When implemented in the electronic format, participants were unable to refer to their previous assessment. Without the baseline, the trust questionnaire did not elicit meaningful changes. The electronic version was thus replaced with paper copies of the questionnaire and the sensitivity of the questionnaire improved.

With the changes in the implementation, the results suggest that the trust questionnaire is capable of eliciting human trust on automation. Compared to the objective measure of trust (analyzed using the matrix in Table 1), the subjective rating led to the elicitation of the nuances in trust. The study found that participants in the control group, who had no idea about the strategies taken by the navigation aid, grew more *suspicious* and thought that the navigation aid would lead them to a more expensive route (*harmful outcome*). Participants who were given the strategies in plain text, however, became more *confident*, *secured towards*, *depended on*, and *trusted* the navigation aid. Their rating for the navigation aid's *integrity*, *reliability*, and *familiarity* also increased. Participants, given the strategies in the MEs format only felt more *familiar* with the navigation aid. If there was only the objective measure, it would seem like participants in all three groups placed the same level of trust on the navigation aid.

4 Conclusions and future studies

Decision automation is designed to support cognitive functions which were previously performed by human operators. Human operators can thereby direct their attention to other tasks since they have the option to depend on automation. However, decision automation can fail and operators need to monitor the automation. The decision algorithm may also be too complex insofar that the operator cannot understand what the automation is doing. Operators would use the decision automation only if they trust the automation. Supporting operators with information on how the automation makes decisions might calibrate their trust and dependency on the automation.

This thesis proposes the Motivation-Expectation Space (MES) as a representation for communicating information pertaining to automated decision strategies. The MES was conceptualized from a cognitive task analysis which examined how operators derived solutions. (Tan, et al., 2007). In strategizing their solutions, the operators were mindful of the automation strategies. Both human and automation strategies were integrated in a space that was goal-oriented (motivation) and effects-based (expectation). It was thus believed that the MES, when designed appropriately, can aid in communicating automation strategies.

This argument is strengthened, through this thesis, by examining commonalities in strategies used in military, business, behavioral, and systems engineering domain. The review revealed that the MES coheres to the human reasoning space found in various research fields in decision strategies, particularly for business and military decisions. The MES was also found to support three of the five factors (i.e. goal of the automation, details of failure, and details of the automation process) that influence automation trust and dependency, see Section 1.3.3. The literature provided a theoretical foundation for proposing MES as the representation for decision strategies (Tan, Helander, & Soh, 2010). In addition to the review, a case study and an experiment were conducted.

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4.1 Case study

There were three objectives for conducting the case study. First, the case study provides a platform for demonstrating how the MES can be developed from data collected in a CTA and CWA. Unlike the previous application of the MES in petrochemical context, an in-car navigation aid context is familiar to most people. The context itself is accessible and would facilitate comprehension of its application.

Second, the case study demonstrated how the MES could be applied in a context that is limited not only by physical constraints. Petrochemical processing is largely constrained by thermodynamics properties. There are minimal intentional constraints imposed by the operators or the organization. Choosing navigation as a context provided an opportunity to examine how intentional constraints could be factored into the MES.

Finally, a set of MES representations was needed for the experiment. Cognitive Task and Work Analysis were performed to develop the representations for the experiment, as well as to demonstrate the link between the MES and current tools and methodologies in Cognitive Systems Engineering.

An unexpected but interesting issue was identified while performing the analysis. The data led to the classification of three variants of causal relations: (1) goals-dependent, (2) environment-impacted, and (3) technology-challenged. The original MES did not incorporate these distinctions. It was through the design of the representation for the SmartGPS that we noted that the MES was too abstract. This was interesting because the technology-challenged causal relation resulted in different information being represented on the MES. It was unclear if the three types of causal relations would be observed in other contexts. However, these issues can be a potential research area for elaborating decision strategies.

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4.2 Experiment

Using the representations developed in the case study, the experimental results showed that participants in both experimental groups performed significantly better than participants in the control group. This was in part due to the high reliability of the decision automation in the experiment. Similar to other studies that provided explanation, participants in the experimental groups exhibited higher trust and dependence and accepted more suggestions provided by the decision automation. In accepting the automation's recommendation, participants also tended to overuse the system – by accepting wrong suggestions provided by the navigation aid

There were, however, no differences between the MES and textual formats in improving automation dependence, and performance. The main advantage of the orthogonal structure over plain text was a 12.2s difference in time to interpret. Participants who received the MES took a shorter time to interpret the automation strategies than participants who received the automation strategies in the textual format. Other than time, participants in the text group exhibited higher trust in more dimensions than the MES group. The orthogonal representation seemed to have moderated participant's trust but not dependence on the decision automation.

The literature and experiment suggest that an explanation could be provided to gain operator's trust on reliable automation which has high disuse. This is particularly useful for automation with high reliability, since operators who received an explanation performed better than participants in the control group when there was no automation failure. However, when the automation failed, participants continued to trust and commit an error with the automation. Measures thus should be taken to mitigate the overuse. Future studies could look into training operators to look for disconfirming and/or contradicting evidences in the explanation.

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4.3 Contributions and limitations of the MES in decision making

Although the experiment identified only a minor advantage in representing decision strategies along the orthogonal in the MES, the four relations (mean, ends, cause, and effects) in the MES were valuable in establishing trust on automation. Below are some applications and limitation of the MES in aiding decision-making.

Human decision-makers use different strategies for solving tasks of varying complexity. Complexity increases with the number of attributes and alternatives. When the number of alternatives and attributes that satisfies the objectives in the decision is small, the decision-maker will use compensatory choice processes such as MAUD, WADD, EQW, MCD & FRQ that gives a detailed and accurate decision (Wright, 1975). Otherwise, they use non-compensatory processes which do not consider all the information systematically. The MES may be a useful tool for evaluating the task complexity. The goals and alternatives can be systematically represented in the MES. One can then count and compare the complexity for different tasks.

In time-stressed situations where decision-makers do not have ample time to optimize decisions, they make decisions using strategies which are based on effort-accuracy trade-off (Payne, et al., 1993). The task complexity, stability and ambiguity affect the choice of strategy. The MES may potentially be used to identify information that is needed for these decisions (Tan, Helander, & Soh, 2010). The information needed may be computed by the decision automation using a more accurate strategy. Decision-makers may use the processed MES information and make their choice at a faster rate.

When the task changes during and after a decision, the task is temporarily unstable. The use of strategies is contingent; although the strategy may be pre-planned, it can be modified to fit the situation (Grant, 2005; Mintzberg, 1987; Payne, 1976; Waller, 1984). To be robust as a representation, the

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MES tool needs to be meticulously planned. This requires the designer of the decision automation to anticipate the various situations. To capture these changes is tedious and it takes great skills to develop.

Figure 4-1 shows how the MES is envisioned to be applied in practice. At the start of the undertaking, the MES will have to be created manually. A CTA will first be conducted, and elements in the work would be abstracted. The parameters would be tested and refined in a lab setting. When the analyst has sufficient knowledge on the data needed for the communication between automation and human, the analyst will work out what the automation needs to sense and feedback to the operator. Sensors would be planted into the system to collect the data needed to populate the MES.

Figure 4-1 Automating the Motivation-Expectation Space in a system

One limitation of applying the MES is with ambiguous tasks. A task is ambiguous when information is incomplete, and the decision-maker has to make assumptions and hypotheses about the problem. The MES can only support operators in analyzing the existence of the means, ends, cause and effects. In presenting information, the MES neither informs operators on the probability nor the severity of these events. Other tools, such as Failure Mode and Effect Analysis, are needed to complement the MES.

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Though the MES does not provide information on the stability and ambiguity of decision tasks, it may still be a useful problem-solving tool. Operators can be trained to evaluate their decision tasks along the two dimensions of the MES. By using the MES, operators may be better equipped to solve problems. When they meet a novel situation which they have not encountered before, MES-trained operators may be able to generate a solution that is more focused (goal-oriented) and proactive in that they consider the effect of the solutions. For unstable and ambiguous tasks, operators can also apply the MES dimensions even though they may need to couple it with other tools. This is assuming that operators are highly adaptable and can take on the responsibility for finishing the design (Vicente, 1999, pp. 109-136).

In summary, the MES can be used to elicit knowledge for designing artifacts that facilitate decision strategies. It can also be used to classify the complexity of a problem space. However, the MES cannot support decision tasks which are unstable and/or ambiguous. It is only effective to the point where the operators are trained to reason and clarify a decision along the two dimensions which are used in strategizing: Why-What-How and Cause-Effect. The generation of solutions for unstable and ambiguous tasks ultimately depends on the creativity and adaptability of the operators.

4.4 Contribution to Cognitive Systems Engineering

This thesis has demonstrated two contributions of the MES to the field of Cognitive Systems Engineering. First, the MES, as a representation, can be used to bridge the communication gap between man and machine. Second, the MES can be the representation for performing Strategies Analysis in the context of Cognitive Work Analysis.

A third contribution, which requires a substantial effort is to link the MES to research in Situation Awareness (SA), an important research area in Cognitive Systems Engineering. SA has gradually gaining recognition as a

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useful intermediate construct for assessing human behavior (Parasuraman, et al., 2008; Wickens, 2008). The most widely accepted and clear definition of SA was given as (Endsley, 1988, p. 97):

1. the perception [noticing] of the elements in the environment within a volume of time and space, and
2. the comprehension of their meaning, and
3. the projection of their status in the near future

There are two common concepts in SA and MES: goal orientation and projection. This suggests that the MES may be a useful representation for aiding SA. The Situation Awareness Global Assessment Tool (SAGAT) uses Goal-Directed Task Analysis (GDTA) for representing the task before the questions to be used in SAGAT are formulated (Endsley, 1995). In a GDTA the analyst organizes the task activities in a hierarchy. This approach is similar to how tasks are organized using WDA, and MES. The motivation dimension captures the goals of the joint cognitive system and the means to achieve these goals. Analyzing means-ends relationship aids one's comprehension of information (Level 2 SA).

Projection is another common concept in SA and MES. The expectation dimension depicts the causal relation between knowledge states. This requires that the understanding and assessment be made forward and backward in time and space. Although Level 3 SA is concerned only with the forward projection, MES also includes backward projection for supporting strategizing.

The similarities between SA and MES provide an interesting commonality link between the research efforts in Situation Awareness (SA) and Cognitive Systems Engineering. The Cognitive Systems Engineering and Cognitive Task Analysis scene traditionally focuses on empirical studies in Naturalistic Decision Making, and a formative approach in Cognitive Work Analysis. Situation Awareness, on the other hand, has a different set of approach to

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personnel selection, training, and design. Further research should be conducted to investigate the dynamism between the four approaches: Cognitive task Analysis, Cognitive Work Analysis, Strategies Analysis, and Situation Awareness.

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Appendices

Appendix A.	Indemnity form
Appendix B.	Experiment instructions (electronic)
Appendix C.	Paper maps
Appendix D.	Expressway exits information sheet
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Appendix F.	Fuel economy information sheet
Appendix G.	Decision tree
Appendix H.	Trust questionnaire

Appendix A. Indemnity form

Centre for Human Factors and Ergonomics
School of Mechanical & Aerospace
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Div of Systems & Engineering Management
50, Nanyang Avenue Block N3.1-B1a-02
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SUBJECT INFORMATION SHEET FOR NAVIGATION DECISION-MAKING

6 September 2010

Dear Volunteer,

You are invited to participate in a research study conducted by the **Centre of Human Factors and Ergonomics, Nanyang Technological University**. The purpose of this study is to study how people make decisions with the help of a smartGPS. The smartGPS computes the best route for a car using real-time traffic information which includes considerations for road closure, toll charges, and traffic speed.

YOUR ROLE IN THE STUDY

As part of the study, you will participate in 3 experimental sessions with us. In each session, you will make 4 decisions. You will also complete some questionnaires during, between, and after each session.

RISKS

There is minimal risk and hazard since the study is conducted in a lab-based simulation. You may experience some confusion between the facts in the simulation and in the real world since the set-up was based on the traffic conditions in year 2009. E.g. the ERP charge rate is different from the current charge rate stipulated by the LTA. It is your responsibility to re-adjust to the real-world traffic situation after the study. You may request for the experimenter to direct you to the relevant websites for this purpose after the completion of the experiment.

BENEFITS

By taking part in this study, you will contribute to our understanding on how people make decisions with the help of technology aids such as the GPS. This will advance our research in man-machine interaction.

As a form of appreciation for your help in the research, you will receive a token sum between \$15 to \$25. The amount depends on the quality of the decisions you make during the experiment.

Appendix A. Indemnity form

WITHDRAWAL

Your participation in the study is completely voluntary. You may choose to withdraw your participation at any point in time during the study. If so, monetary compensation will be pro-rated based on the extent of your participation.

COSTS

You do not have to pay or incur any expenditure for participating in this study.

CONFIDENTIALITY

Any information which we obtain about you in the course of the study, including your identity constitutes confidential information. This information will be used solely for the purposes of this study. No information will be revealed which will enable your performance to be identified. The results will not be released or shared with any third party not involved in research, unless you request that we do so. When results of this study are published, your name will not be used.

INFORMED CONSENT

Participation in this study is on a voluntary basis. There will be no prejudice or consequences for not volunteering. Agreeing to participate in this trial would indicate your consent to keeping the information confidential.

As part of the research process, photography, videography, and voice recording of the trial process and procedures will be carried out for documentation purposes. All photos, videos and voice recordings will be kept by CHFE and viewed by relevant personnel only. Participation in this study will indicate your consent to be photographed and videotaped.

Lastly, we seek your careful consideration in participation. This is in the interest of improving our understanding in how man and machine works together. If you have any questions, you can contact me at 81289411 or email me at bubblegenie@pmail.ntu.edu.sg

Thank you!
Angela Tan

Appendix A. Indemnity form

A.1 Informed Consent Form for Volunteers

1. I acknowledge that (please tick)

- ☐ I have read the Information Sheet and have had an opportunity to ask questions and discuss the study to my satisfaction;
- ☐ I understand that the purpose of the project is for research;
- ☐ I have been informed of the possible risks of the test or procedures;
- ☐ I have been informed that I am free to withdraw from the project at any time without prejudice;
- ☐ I have been informed that any information I provide will be safeguarded and remain confidential;
- ☐ I understand that because the project is related to the military, I will not disclose or reveal any information about the project to anyone or any third party without your prior written consent; and
- ☐ I have been informed and agree to be photographed and/or videotaped during the trial for research documentation purposes.

2. I **consent/ do not consent*** to participate in the above research project, the particulars of which have been explained to me, and the details of which are attached in the Information Sheet.

Signature: _____

Date: _____

Name: _____

NRIC: _____

3. For volunteers under 21 years of age:

I, _____ (Name of parent/ legal guardian*), NRIC _____, being the parent/ legal guardian* of the above named personnel, have read your letter and understand the contents and request for my informed consent to allow my son/ ward* to participate in the study on a voluntary basis.

I **consent/ do not consent*** to my son's/ ward's* participation in the study.

Signature: _____
(parent / legal guardian)

Date: _____

Relationship to volunteer: _____

* Please delete accordingly

INSTRUCTIONS FOR SESSION 1

1

This experiment investigates how people trust and rely on decision support systems (e.g. GPS).

There would be 3 experimental sessions. In each session, you will make a series of binary decisions with the assistance of a smartGPS that suggests to you the cheapest route. You can choose to follow or ignore the suggestion.

At the end of the study, you will be compensated for your time. The token sum is dependent on the quality of your decisions. The better your decisions , the more you would be compensated. At the start of the experiment, you have \$35. You will be spending the money on fuel and toll in the 3 experimental sessions. The remaining sum would be your compensation. This would range between \$15 - \$25. Your mission is to maximize your compensation by minimizing the cost of travel.

2

Maps and information on route

On your desk, you can find an overview of the locations of all the decisions points.

3

Decision 1 is at the intersection of West Coast Rd and Jurong Town Hall Rd. You can choose to enter the Ayer Rajah Expressway (AYE) via Jurong Town Hall Rd or continue along West Coast Highway to enter via Clementi Rd. Trace the Green and Blue routes and note their differences.

Decision 2 is along the expressway. You can choose to exit at Alexandra or continue on AYE.

If you have chosen to exit at Alexandra Rd in Decision 2, you will make Decision 3 at Jln Bukit Merah (D3b). Otherwise, you will make Decision 3 along AYE (D3a). In Decision 3, you take either AYE or the Central Tunnel Expressway (CTE).

If you have chosen AYE in Decision 3, you will choose between exiting at Keppel Rd or continue onto the East Coast Parkway (ECP) to exit at Marina South.

If you have chosen CTE in Decision 3, you will choose between North Canal Rd or New Bridge Rd in Decision 4.

You also have a copy of the expressway exits along AYE, CTE, and ECP.

The green boxes highlight the area which you will travel in the 3 experimental sessions. Please note the order of the exits.

Take some time to study where the decision points are relative to the exits. You can use the post-its to help you.

ECP/AYE			Expressway Exits Datasheet		
Exit No.	Exit Name	Exit Type	Exit No.	Exit Name	Exit Type
1	Exit 1	Exit Type	1	Exit 1	Exit Type
2	Exit 2	Exit Type	2	Exit 2	Exit Type
3	Exit 3	Exit Type	3	Exit 3	Exit Type
4	Exit 4	Exit Type	4	Exit 4	Exit Type
5	Exit 5	Exit Type	5	Exit 5	Exit Type
6	Exit 6	Exit Type	6	Exit 6	Exit Type
7	Exit 7	Exit Type	7	Exit 7	Exit Type
8	Exit 8	Exit Type	8	Exit 8	Exit Type
9	Exit 9	Exit Type	9	Exit 9	Exit Type
10	Exit 10	Exit Type	10	Exit 10	Exit Type
11	Exit 11	Exit Type	11	Exit 11	Exit Type
12	Exit 12	Exit Type	12	Exit 12	Exit Type
13	Exit 13	Exit Type	13	Exit 13	Exit Type
14	Exit 14	Exit Type	14	Exit 14	Exit Type
15	Exit 15	Exit Type	15	Exit 15	Exit Type
16	Exit 16	Exit Type	16	Exit 16	Exit Type
17	Exit 17	Exit Type	17	Exit 17	Exit Type
18	Exit 18	Exit Type	18	Exit 18	Exit Type
19	Exit 19	Exit Type	19	Exit 19	Exit Type
20	Exit 20	Exit Type	20	Exit 20	Exit Type
21	Exit 21	Exit Type	21	Exit 21	Exit Type
22	Exit 22	Exit Type	22	Exit 22	Exit Type
23	Exit 23	Exit Type	23	Exit 23	Exit Type
24	Exit 24	Exit Type	24	Exit 24	Exit Type
25	Exit 25	Exit Type	25	Exit 25	Exit Type
26	Exit 26	Exit Type	26	Exit 26	Exit Type
27	Exit 27	Exit Type	27	Exit 27	Exit Type
28	Exit 28	Exit Type	28	Exit 28	Exit Type
29	Exit 29	Exit Type	29	Exit 29	Exit Type
30	Exit 30	Exit Type	30	Exit 30	Exit Type
31	Exit 31	Exit Type	31	Exit 31	Exit Type
32	Exit 32	Exit Type	32	Exit 32	Exit Type
33	Exit 33	Exit Type	33	Exit 33	Exit Type
34	Exit 34	Exit Type	34	Exit 34	Exit Type
35	Exit 35	Exit Type	35	Exit 35	Exit Type
36	Exit 36	Exit Type	36	Exit 36	Exit Type
37	Exit 37	Exit Type	37	Exit 37	Exit Type
38	Exit 38	Exit Type	38	Exit 38	Exit Type
39	Exit 39	Exit Type	39	Exit 39	Exit Type
40	Exit 40	Exit Type	40	Exit 40	Exit Type
41	Exit 41	Exit Type	41	Exit 41	Exit Type
42	Exit 42	Exit Type	42	Exit 42	Exit Type
43	Exit 43	Exit Type	43	Exit 43	Exit Type
44	Exit 44	Exit Type	44	Exit 44	Exit Type
45	Exit 45	Exit Type	45	Exit 45	Exit Type
46	Exit 46	Exit Type	46	Exit 46	Exit Type
47	Exit 47	Exit Type	47	Exit 47	Exit Type
48	Exit 48	Exit Type	48	Exit 48	Exit Type
49	Exit 49	Exit Type	49	Exit 49	Exit Type
50	Exit 50	Exit Type	50	Exit 50	Exit Type
51	Exit 51	Exit Type	51	Exit 51	Exit Type
52	Exit 52	Exit Type	52	Exit 52	Exit Type
53	Exit 53	Exit Type	53	Exit 53	Exit Type
54	Exit 54	Exit Type	54	Exit 54	Exit Type
55	Exit 55	Exit Type	55	Exit 55	Exit Type
56	Exit 56	Exit Type	56	Exit 56	Exit Type
57	Exit 57	Exit Type	57	Exit 57	Exit Type
58	Exit 58	Exit Type	58	Exit 58	Exit Type
59	Exit 59	Exit Type	59	Exit 59	Exit Type
60	Exit 60	Exit Type	60	Exit 60	Exit Type
61	Exit 61	Exit Type	61	Exit 61	Exit Type
62	Exit 62	Exit Type	62	Exit 62	Exit Type
63	Exit 63	Exit Type	63	Exit 63	Exit Type
64	Exit 64	Exit Type	64	Exit 64	Exit Type
65	Exit 65	Exit Type	65	Exit 65	Exit Type
66	Exit 66	Exit Type	66	Exit 66	Exit Type
67	Exit 67	Exit Type	67	Exit 67	Exit Type
68	Exit 68	Exit Type	68	Exit 68	Exit Type
69	Exit 69	Exit Type	69	Exit 69	Exit Type
70	Exit 70	Exit Type	70	Exit 70	Exit Type
71	Exit 71	Exit Type	71	Exit 71	Exit Type
72	Exit 72	Exit Type	72	Exit 72	Exit Type
73	Exit 73	Exit Type	73	Exit 73	Exit Type
74	Exit 74	Exit Type	74	Exit 74	Exit Type
75	Exit 75	Exit Type	75	Exit 75	Exit Type
76	Exit 76	Exit Type	76	Exit 76	Exit Type
77	Exit 77	Exit Type	77	Exit 77	Exit Type
78	Exit 78	Exit Type	78	Exit 78	Exit Type
79	Exit 79	Exit Type	79	Exit 79	Exit Type
80	Exit 80	Exit Type	80	Exit 80	Exit Type
81	Exit 81	Exit Type	81	Exit 81	Exit Type
82	Exit 82	Exit Type	82	Exit 82	Exit Type
83	Exit 83	Exit Type	83	Exit 83	Exit Type
84	Exit 84	Exit Type	84	Exit 84	Exit Type
85	Exit 85	Exit Type	85	Exit 85	Exit Type
86	Exit 86	Exit Type	86	Exit 86	Exit Type
87	Exit 87	Exit Type	87	Exit 87	Exit Type
88	Exit 88	Exit Type	88	Exit 88	Exit Type
89	Exit 89	Exit Type	89	Exit 89	Exit Type
90	Exit 90	Exit Type	90	Exit 90	Exit Type
91	Exit 91	Exit Type	91	Exit 91	Exit Type
92	Exit 92	Exit Type	92	Exit 92	Exit Type
93	Exit 93	Exit Type	93	Exit 93	Exit Type
94	Exit 94	Exit Type	94	Exit 94	Exit Type
95	Exit 95	Exit Type	95	Exit 95	Exit Type
96	Exit 96	Exit Type	96	Exit 96	Exit Type
97	Exit 97	Exit Type	97	Exit 97	Exit Type
98	Exit 98	Exit Type	98	Exit 98	Exit Type
99	Exit 99	Exit Type	99	Exit 99	Exit Type
100	Exit 100	Exit Type	100	Exit 100	Exit Type

Toll Charges Datasheet

As you are entering the city, you will pass the ERP gantries. For all (2⁴ = 16) routes, you will pass through one ERP gantry, see map detailing ERP gantries. The ERP rate for the gantries are the same. However, depending on the route you choose, the time of passing the gantry can differ and hence a difference in the toll charge incurred.

In addition to the paper tools, which you can refer to during the drive, you will also have a smartGPS to assist you in your task.

About the smartGPS

The smartGPS take in real-time traffic information (including road closure, toll charges, and traffic speed) and computes the distance, toll charges, and the time needed for all routes that lead to the destination. As the traffic condition changes in your drive, the smartGPS dynamically re-computes and suggest the best route to you. It will also suggest a new route if you miss a turn or exit.

However, there are sometimes errors with the updates and signals may be lost intermittently. Hence, you may experience suggestions which are either sub-optimal or wrong. **It is known that the error rate is between 20-30%.**

Throughout this experiment, the smartGPS has been set to **minimize cost.**

16

You are about to start the first experiment session. Before we begin, you need to pay attention to the following notes on the simulator.

About the Simulator

The simulator has three main components:

1. Visual: The screen on the right displays what you would see along the drive. You would be alerted to some of the road signs and the Expressway Monitoring and Advisory System (EMAS) messages.
2. Audio: A radio channel would be played during your drive. You should listen for radio updates pertaining to your route.
3. As you approach a decision point, a set of left, right or arrows would pop up. You select your route by clicking the arrows.

Experimental Session 1

18

Session 1

Your friend just collected his new car at Teban Gardens Crescent. After the collection, he needs to go to town to process his insurance. He wants to park his vehicle at the Market Street Carpark.

Your goal is to help him **select the cheapest route** as he drives. You will be leaving the collection centre on a **Thursday at 8:10am**. You have the following items to help you in your route selection task:

1. Maps
2. Fuel Economy Datasheet
3. Toll Charges Datasheet
4. Rough paper
5. Post-its
6. SmartGPS

19

INSTRUCTIONS FOR SESSION 2

20

You have completed Session 1. Session 1 is a practice session to gear you for the next 2 sessions. It is shorter than the actual experimental sessions; you made 2 decisions instead of 4. You should also notice that you have 3 main tasks:

- 1) Route selection. You select the **cheapest** route based on your understanding of the traffic conditions.
- 2) Questionnaire. You answer a series of questions pertaining to the decision you made.
- 3) Trust rating. You rate how much you trust the smartGPS. The smartGPS is the GPS unit and consist of the map and the auditory turn-by-turn instructions.

If there is anything that you do not understand about the task or questions, you should ask the experimenter now.

21

You are about to begin Session 2.

During the experiment, if you would like to use the smartGPS but do not understand the smartGPS's recommendation, you should seek the experimenter's assistance before you make your decision selection.

If you have fully understood the task, press next to continue.

22

Experimental Session 2

23

Session 2

Your friend just collected his new car at Teban Gardens Crescent. After the collection, he needs to go to town to process his insurance. He wants to park his vehicle at the Market Street Carpark.

Your goal is to help him **select the cheapest route** as he drives.

You will be leaving the collection centre on a **Thursday at 9:08am**.

You have the following items to help you in your route selection task:

- 1. Maps
- 2. Fuel Economy Datasheet
- 3. Toll Charges Datasheet
- 4. Rough paper
- 5. Post-its
- 6. SmartGPS

24

**INSTRUCTIONS FOR SESSION 3
(CONTROL)**

25

You have completed Session 2.

You are about to begin Session 3. Press next to continue.

26

Experimental Session 3

27

Session 3

Your friend just collected his new car at Teban Gardens Crescent. After the collection, he needs to go to town to process his insurance. He wants to park his vehicle at the Market Street Carpark.

Your goal is to help him **select the cheapest route** as he drives. You will be leaving the collection centre on a **Thursday at 7:45am**. You have the following items to help you in your route selection task:

- 1. Maps
- 2. Fuel Economy Datasheet
- 3. Toll Charges Datasheet
- 4. Rough paper
- 5. Post-its
- 6. SmartGPS

INSTRUCTIONS FOR SESSION 3
(MES)

You have completed Session 2. In the next session, an additional function is added to the smartGPS. This add-on explains the decisions made by the smartGPS. You activate this function by clicking the “Explain” button.

The roads that you have passed and would pass through is presented on the main spine of the graphical explanation.

This representation hinges largely on the concept of the Motivation-Expectation Space (MES). The MES comprises of four elements that are fundamental in decision strategies: why, how, cause, and effect. Why-how is presented on the vertical axis. It describes the motivation or goal for a decision and the means of achieving the goal. Cause-effect is presented on the horizontal axis and describes what one expects to happen or to have happened.

32

You interpret the representation by knowing that moving along the links:

- 1) Upward leads to the goal that is being optimized
- 2) Downward leads to the means of achieving the goal
- 3) Left refers to what has happened (expected cause)
- 4) Right refers to what is going to happen (expected effect)

33

In the earlier example using Decision 1 at West Coast Road.

- 1) Moving up, we see that there are 3 goals that can be optimized for this decision.
- 2) Moving down, we see that there are 2 means for getting to the final destination .
- 3) Moving left, we see that there is a traffic jam if the system chooses the Jurong Town Hall Rd exit.
- 4) Moving right, we see the effect (in terms of cost) for taking each of the options. The cost includes the ERP charges and fuel cost based on the updated traffic condition.

34

Shading and font colors are used to highlight user's selection and conditions that are satisfied.

In the simulation, the goal has been pre-selected to minimize total cost. The selected cost function is shaded in yellow. The smartGPS, based on the cost function, suggests taking the Clementi Ave 2 exit. Taking the Clementi Ave 2 exit also happens to be a faster route than taking the Jurong Town Hall Rd exit. The two functions which are satisfied (cost and time) are presented using black fonts. The distance function, which is not satisfied, is displayed using gray fonts. Similarly, the cheaper option (Clementi Ave 2) is displayed using black font and the more expensive option (Jurong Town Hall Rd) is displayed in gray.

To put it simply, the conditions which are satisfied are in black fonts. The rest are in gray. The user selection has yellow shading.

35

You are about to begin Session 3.

You are required to click on the “Explain” button to call up the explanation. If you experience any difficulties, please alert the experimenter.

Please press next to begin.

36

Experimental Session 3

37

Session 3

Your friend just collected his new car at Teban Gardens Crescent. After the collection, he needs to go to town to process his insurance. He wants to park his vehicle at the Market Street Carpark.

Your goal is to help him **select the cheapest route** as he drives.

You will be leaving the collection centre on a **Thursday at 7:45am**.

You have the following items to help you in your route selection task:

1. Maps
2. Fuel Economy Datasheet
3. Toll Charges Datasheet
4. Rough paper
5. Post-its
6. SmartGPS

38

INSTRUCTIONS FOR SESSION 3 (TEXT)

39

You have completed Session 2. In the next session, an additional function is added to the smartGPS. This add-on explains the decisions made by the smartGPS. You activate this function by clicking the “Explain” button.

40

If you enter AYE via Clementi Ave 2, you will incur a lower cost of \$3.00.

If you enter AYE via Jurong Town Hall Road, you will encounter traffic jam and incur \$5.00.

It is suggested that you take the Clementi Ave 2 exit as you will save on cost, as well as time but not distance.

You have passed Teban Gardens Cres and Penjuru Rd and you are on West Coast Road. To take Clementi Ave 2, please continue onto West Coast Highway, followed by Pandan Circus and Jalan Buroh.

- In the earlier example using Decision 1 at West Coast Road,
- 1) the first line presents the recommended option
 - 2) the second line presents the alternative.
 - 3) the third line presents the functions that are optimized if you take the smartGPS’s recommendation
 - 4) the last line presents where you have been and the road you will take if you follow the recommended path.

41

If you enter AYE via Clementi Ave 2, you will incur a lower cost of \$3.00.

If you enter AYE via Jurong Town Hall Road, you will encounter traffic jam and incur \$5.00.

It is suggested that you take the Clementi Ave 2 exit as you will save on cost, as well as time but not distance.

You have passed Teban Gardens Cres and Penjuru Rd and you are on West Coast Road. To take Clementi Ave 2, please continue onto West Coast Highway, followed by Pandan Circus and Jalan Buroh.

Font colors are used to highlight conditions that are satisfied.

In the simulation, the goal has been pre-selected to minimize total cost. The smartGPS, based on the cost function, suggests taking the Clementi Ave 2 exit. Taking the Clementi Ave 2 exit also happens to be a faster route than taking the Jurong Town Hall Rd exit. The two functions which are satisfied (cost and time) are presented using black fonts. The distance function, which is not satisfied, is displayed using gray fonts. Similarly, the cheaper option (Clementi Ave 2) is displayed using black font and the more expensive option (Jurong Town Hall Rd) is displayed in gray.

To put it simply, the conditions which are satisfied are in black fonts. The rest are in gray.

42

You are about to begin Session 3.

You are required to click on the “Explain” button to call up the explanation. If you experience any difficulties, please alert the experimenter.

Please press next to begin.

43

Experimental Session 3

44

Session 3

Your friend just collected his new car at Teban Gardens Crescent. After the collection, he needs to go to town to process his insurance. He wants to park his vehicle at the Market Street Carpark.

Your goal is to help him **select the cheapest route** as he drives.

You will be leaving the collection centre on a **Thursday at 9:08am**.

You have the following items to help you in your route selection task:

1. Maps
2. Fuel Economy Datasheet
3. Toll Charges Datasheet
4. Rough paper
5. Post-its
6. SmartGPS

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FINAL INSTRUCTIONS

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You have completed all 3 experimental sessions.

Please fill in a final questionnaire while the experimenter process your compensation.

Click the exit button and wait for the experimenter to push the questionnaires to this computer. Alert the experimenter if you do not receive the questionnaire.

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Appendix C1. Map (Overview)

MAPS

Magnified map of destination with information on ERP gantries.

Map with location of (1) start position; (2) destination; (3) Decision points

Appendix C2. Map (Detail of Decision 1)

Appendix C3. Map (Detail of Decision 2)

Appendix C4. Map (Detail of Decision 3)

Appendix C5. Map (Detail of Decision 4a)

Appendix C6. Map (Detail of Decision 4b)

Appendix D. Expressway exits

ECP/AYE				
To Changi Airport	Exit No.	Flyover/ Map & Grid	Exit No.	From Changi Airport
PIE (Jurong) TPE (SLE)	1	Changi Flyover - 95 2B	1	PIE (Jurong) TPE (SLE)
Changi Coast Rd Tanah Merah Coast Rd Tanah Merah Ferry Terminal Changi Village	2A	Tanah Merah Flyover 95 1D	2A	Changi Coast Rd Tanah Merah Coast Rd Tanah Merah Ferry Terminal Changi Village
Xilin Ave Singapore Expo	2B	- 116 1B	5	Carpark F3 East Coast Park
Bayshore Rd	6	115 2B	-	
East Coast Park	7A	Laguna Flyover - 115 1B	7A	East Coast Park
Bedok South	7B		7B	Bedok South
Siglap Rd	8A	114 2C	-	
Marine Vista	8B			
East Coast Park ECP (City)	10A	Marine Parade Flyover 114 1C	-	
Still Rd Marine Parade	10B		10B	East Coast Park Still Rd Marine Parade
Tanjong Katong Rd	11	Tanjong Katong Flyover 113 1D	-	
East Coast Park Fort Rd Mountbatten Rd	13	Tanjong Rihu Flyover - 112 2D	13	East Coast Park Fort Rd Mountbatten Rd
KPE	14	112 1D	14	KPE ERP - 30
Rochor Rd	15	Benjamin Sheares Bridge 133 2A	15	Rochor Rd
ERP - 59	-	133 1C	17A	Marina South
	-	Telok Ayer Flyover - 133 1C	17	Prince Edward Rd
	-	Keppel Viaduct - 132 1D	18	Keppel Rd
ECP is above this row AYE is below this row				
Keppel Rd	2B	Keppel Viaduct - 132 1D	2A	Keppel Rd
CTE	2C	Radin Mas Flyover - 131 2C	-	
Lower Delta Rd	3	Lower Delta Flyover - 131 2C	3	Lower Delta Rd
Alexandra Rd	6	Gillman Flyover - 130 1B	-	
ERP - 36	-	130 1B	7A	Normanton Park
Portdown Rd	7B	129 2A	-	
North Buona Vista Rd South Buona Vista Rd NUH Science Park	8	Buona Vista Flyover - 107 2D	8	North Buona Vista Rd South Buona Vista Rd NUH Science Park
Clementi Rd NUS Singapore Polytechnic	9	University Flyover - 106 2C	9	Clementi Rd NUS Singapore Polytechnic
Clementi Ave 2	10B	Clementi Flyover - 106 1B	10A	West Coast Rd Clementi Ave 2
Clementi Ave 6	11	Pandan Flyover - 106 1A	11	Clementi Ave 6 West Coast Way
Jurong Town Hall Rd	13	Teban Flyover - 83 1D	13	Jurong Town Hall Rd
	-	83 1C	14	Penjurong Rd
Yuan Ching Rd	15B	82 1D	-	
	-	Corporation Flyover - 82 1D	15A	Corporation Rd Jurong Port Rd
Boon Lay Jurong Pier Rd Jurong Island Jurong Bird Park Corporation Rd Jurong Port Rd	17	Jurong Hill Flyover - 81 1D	17	Boon Lay Jurong Pier Rd Jurong Island Jurong Bird Park
Pioneer Rd North Pioneer Rd First Lok Yang Rd	18	Pioneer Flyover - 80 2D	18	Pioneer Rd North Pioneer Rd
Benoi Rd Gul Circle Joo Koon Circle Singapore Discovery Centre	20	Benoi Flyover - 79 2D	20	Benoi Rd Gul Circle Joo Koon Circle Singapore Discovery Centre
Tuas Rd PIE	22	Tuas Flyover - 79 1D	22	Tuas Rd PIE Tuas Avenue 2
Tuas West Rd Raffles Country Club	24	Tuas West Underpass - 78 1A	24	Tuas Avenue 8 Tuas West Rd Raffles Country Club
	-	Tuas Checkpoint Viaduct 77 2A	26A	Tuas West Drive Raffles Marina
From Tuas Checkpoint	Exit No.	Flyover/ Map & Grid	Exit No.	To Tuas Checkpoint

SLE/CTE				
To BKE (Woodlands)	Exit No.	Flyover/ Map & Grid	Exit No.	From BKE (Woodlands)
BKE (PIE) Mandai Rd Turi Club Ave Kranji Rd	11	Woodlands South Flyover 23 2A	-	
Woodlands Ave 2 Admiralty Rd	10	Marsiling Flyover - 11 2D	10	Woodlands Ave 2 Admiralty Rd
Woodlands Ave 12	9	Ulu Sembawang Flyover 25 1A	9	Woodlands Ave 12
Mandai Rd Zoo Night Safari	8A	Sembawang Flyover - 25 2B	8B	Mandai Ave
Upper Thomson Rd	5	Upper Thomson Flyover 45 1A	5	Upper Thomson Rd
Lentor Ave	3	Lentor Flyover - 46 1A	3	Yishun
	-	Seletar Flyover - 47 1A	1B	TPE / Seletar West Link
TPE	1	47 1A	1A	Yio Chu Kang Rd
SLE is above this row CTE is below this row				
Yio Chu Kang Rd	15	Yio Chu Kang Flyover 47 1B	-	
	-	Ang Mo Kio North - 47 1D	14	Ang Mo Kio Ave 5 Ang Mo Kio Ave 3
Ang Mo Kio Ave 5	12B	Ang Mo Kio Central - 68 2A	-	
Ang Mo Kio Ave 3	12A			
Ang Mo Kio Ave 1		Ang Mo Kio South - 68 1C	11	Ang Mo Kio Ave 1 ERP - 35
Braddell Rd	10	Braddell Flyover - 89 2A	10	Braddell Rd ERP - 31
Upper Serangoon Rd PIE (Changi Airport)	8B	Whampoa Flyover - 89 2C	8B	Upper Serangoon Rd PIE (Changi Airport)
ERP - 51	-		8A	PIE (Jurong)
Jalan Bahagia	7B	Moulmein Flyover - 111 1A	7D	Balestier Rd (Kallang)
Moulmein Rd	7A		7C	Balestier Rd (Thomson) Moulmein Rd
	-	110 2B	6	Bukit Timah Rd Cavenagh Rd
	-	Kg Java Tunnel - 110 2B	5	Cairnhill Circle
	-	110 2C	4	Orchard Rd
Merchant Rd Clemenceau Ave	2	Chin Swee Tunnel - 132 2A	2	Havelock Rd ERP - 20
Tiong Bahru Outram Rd	1B	Outram Flyover - 132 1B	1B	Outram Rd
	-	Bukit Merah Flyover 131 2C	1A	Jalan Bukit Merah
From AYE (Delta)	Exit No.	Flyover/ Map & Grid	Exit No.	To AYE (Delta)

Appendix E. ERP charge rate

Time	Toll
▲ 08:00 - 08:05	\$1.00
▲ 08:05 - 08:30	\$2.00
▲ 08:30 - 09:00	\$2.50
▼ 09:00 - 09:25	\$2.00
▼ 09:25 - 09:30	\$1.50
▼ 09:30 - 09:55	\$1.00
▼ 09:55 - 10:00	\$0.50
▼ 10:00 - 12:00	\$0.00
▲ 12:00 - 12:05	\$0.50
▲ 12:05 - 14:00	\$1.00
▲ 14:00 - 14:05	\$1.50
▲ 14:05 - 14:55	\$2.00
▼ 14:55 - 15:00	\$1.50
▼ 15:00 - 17:30	\$1.00
▲ 17:30 - 18:00	\$1.50
▲ 18:00 - 18:05	\$2.30
▲ 18:05 - 18:25	\$3.00
▼ 18:25 - 18:30	\$2.50
▼ 18:30 - 18:55	\$2.00
▼ 18:55 - 19:00	\$1.50
▼ 19:00 - 19:55	\$1.00
▼ 19:55 - 20:00	\$0.50
▼ 20:00 - 22:30	\$0.00

Appendix F. Fuel economy

Traffic Condition	km/l
Highway 30kph	11
Highway 40kph	12
Highway 50kph	13
Highway 60kph	13
Highway 70kph	13
Highway 80kph	13
Highway 90kph	13
Highway Jam*	6
Road	9.8
Road Jam**	2

* >5 startup/km

** >10 startup/km

Appendix G. Decision tree

Appendix H. Trust questionnaire

Trust Questionnaire

Subject ID: _____

Session: 1 / 2 / 3 (please circle)

Below is a list of statement for evaluating trust between people and automation. There are several scales for you to rate intensity of your feeling of trust, or your impression of the smartGPS while using the smartGPS to minimize your cost of travel. Please mark an "x" on each line at the point which best describes your feeling or your impression.

1. The directions provided by the smartGPS are deceptive.

1 2 3 4 5 6 7
Not at all Extremely

2. The smartGPS behaves in an underhanded/sneaky manner.

1 2 3 4 5 6 7
Not at all Extremely

3. I am suspicious of the smartGPS's intent, action or outputs.

1 2 3 4 5 6 7
Not at all Extremely

4. I am wary of the smartGPS's ability to compute the cheapest route.

1 2 3 4 5 6 7
Not at all Extremely

5. The directions provided by the smartGPS could have a harmful outcome.
-
- (i.e. the suggestion could lead me to the more expensive route.)

1 2 3 4 5 6 7
Not at all Extremely

6. I am confident of the directions provided by the smartGPS.

1 2 3 4 5 6 7
Not at all Extremely

7. The smartGPS provides security towards fulfilling my objective.

1 2 3 4 5 6 7
Not at all Extremely

8. The directions provided by the smartGPS have integrity.

1 2 3 4 5 6 7
Not at all Extremely

9. The smartGPS is dependable for computing the cheapest route.

1 2 3 4 5 6 7
Not at all Extremely

10. The smartGPS is reliable for computing the cheapest route.

1 2 3 4 5 6 7
Not at all Extremely

11. I can trust the smartGPS to compute the cheapest route.

1 2 3 4 5 6 7
Not at all Extremely

12. I am familiar with the smartGPS.

1 2 3 4 5 6 7
Not at all Extremely