Chapter 2: Background and Literature Review

Scheduling allocates *resources* (material, machines, capacity, processing time) to *jobs* (tasks) in order to meet specified *goals* (number of items produced, minimize total lateness, maximize profit [turnaround, timeliness and throughput]). Scheduling theory was first formalized in the mid 1950s to maximize the effectiveness and efficiency of the manufacturing processes that were becoming rapidly prevalent. The government demand for additional work in the area of scheduling prompted a wave of books and articles in the 1970s and 80s. Researchers continued refining scheduling theory, and defining the many scenarios and heuristics that optimized performance of a system in a given setting. Today, scheduling theory is a robust and well-studied field that is applied to many industrial settings daily.

Scheduling theory has also been considered in relation to aiding human schedulers and evaluating human scheduling behavior. In order to most clearly see the linkage between scheduling in a manufacturing setting and scheduling related to human behavior, both aspects will be introduced in conjunction with the explanation of scheduling elements.

Scheduling theory's main goals are allocation and sequencing. The allocation of the limited resources to best achieve the specified goal is the primary result of scheduling algorithms. The sequence in which jobs or tasks should be accomplished to make the best use of the available time, resources, and constraints is another key result. Some basic definitions must be understood before further discussion of the theory can occur. In traditional scheduling theory, resources are material or machines that are consumed in the production of the end product. Resources have characteristics with associated values affecting the way resources are used. Those resource characteristics are capacity, processing time, degradation rates, repair rates, and many others that define how a particular resource may be consumed in the execution of the job.

When applied to human behavior, the resources are the humans themselves with each human as an individual having characteristics of capacity, processing time to complete a specific task, degradation of attention rates, recuperation/ revitalization rates. These human characteristics are directly relatable to machine characteristics as applied in scheduling theory.

When considering the human as an acting element in job execution, the human will be defined as a single resource and no distinction will be made about the various attentional resources a person has. This will avoid the need to account for individual differences and will also prevent the need to define and assess individual attentional resources, since that is difficult to measure and varies widely from person to person. Because of the wide individual variation of attentional resource capabilities and many external factors that affect those resources, no attempt will be made to differentiate resources within the individual person. This will not affect the results of the theory and should make the theory more robust in that it can be applied across a broader spectrum without the need to assess and record individual capabilities which would certainly impact the resultant recommendations of the theory.

In scheduling theory, jobs are the entities that travel through the system, get worked on, and become the end product after completing their path. Jobs have characteristics that define resources needed, processing time, ready times, due dates, priority, and precedence. Each of these factors is relevant in a task that a human would have to perform. The only difference is that the *human* would perform the *task* instead of a *machine* performing a *job*. But, whether the job is performed by a person or a machine, the job / task characteristics remain consistent. A task performed by a human will have characteristics that define resources needed, processing time, ready times, due dates, priority, and precedence, exactly as a manufacturing job does. Therefore, it is logical to apply scheduling theory to consider humans performing sets of tasks instead of machines performing sets of jobs. In fact, it is possible to consider groups of people performing specific sub-tasks in order to accomplish a main task the same way groups of machines are considered in scheduling theory.

The goals of scheduling theory can also be easily translated to apply to a group of people executing a task. For example, the goal of minimizing overall lateness of all tasks is one that can be clearly likened to human task execution system. To minimize the overall lateness of work done by humans can be treated in the same way as minimizing the overall lateness of jobs in a manufacturing setting. Many other optimization goals used in traditional scheduling problems can be applied to work done by humans in an organization. An Emergency Operations Center (EOC) is a good example of an organization of humans with a series of sub-tasks that must be performed in order to achieve the main goal of managing a crisis. The exact definition of "managing a crisis" will be dependent on the needs of the organization as defined in the problem statement and will provide clarification of the goal to which the EOC system should be optimized.

Scheduling theory is a robust quantitative means of analysis that could present robust recommendations for human organizations. However, once a problem has more than two resources working on jobs (or people working on tasks) the scheduling problem becomes too large to be solved in an acceptable computational time; it is considered NP-Hard. NP-Hard is "Non deterministic Polynomial-time Hard" (Wikipedia, 2004), and the problem cannot be solved optimally within a reasonable computational time. Thus, for NP-Hard problems, a heuristic is used which provides a result that is within the acceptable space close to the optimum. The heuristic is a simplified process that cuts computational time down so that the problem can be solved within an acceptable time frame. Problems that are most difficult to solve are dynamic systems. A dynamic system is one in which the job arrival times, or resource ready times, occur after the initiation of the system. A static system is one in which all jobs and resources are ready upon initiation of the system. Therefore, there is no waiting time required to begin operations and jobs can be processed as demanded by the system. The dynamic system is much more computationally complex and are generally NP-Hard. In order to find the heuristic that best solves a particular problem set of a dynamic system, a static system is analyzed and a heuristic is created that can be applied to a dynamic system that will produce results within an acceptable solution space. A graphic representation of the acceptable solution space from which results are found for dynamic systems compared to the optimal solution that is found by completing all calculations can be found below:

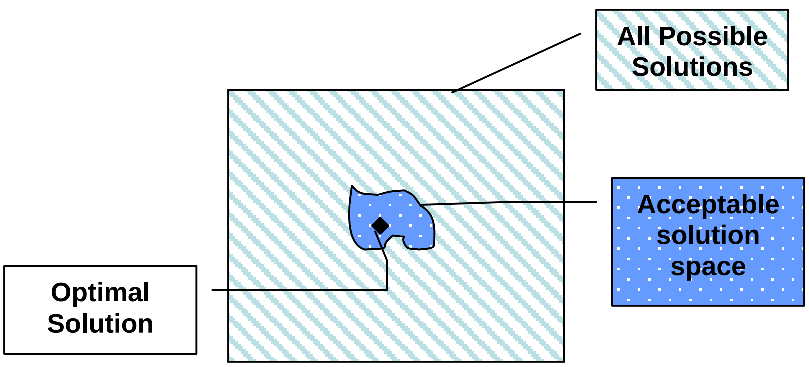

Figure XXX. Adapted from classes and reading…

When considering an EOC, it must be treated as a dynamic system since many of the sub-tasks and tasks will not be known until after the event and EOC operations have begun. Thus, the tasks are available after the system has begun operation and it must be considered dynamic. To solve this dynamic problem, a static problem will be solved first and then a heuristic will be developed that will facilitate finding the correct number of people for each EOC section. But, what is the theoretical and academic background for this proposal?

The process of human scheduling and human schedulers has long been a subject of academic research. In 1980, Tulga and Sheridan performed a seminal experiment concerned with developing a model that represents the way humans make decisions about task ordering and execution (i.e. scheduling). They used several network-type models for analysis of the task behavior. The task was relatively simple, but the robust model addressed many of the issues effecting the human decision making process. In their model, key human and task related elements were characterized by variables that were previously modeled in network problems; similarly the elements of decision making in EOCs can be modeled as a scheduling problem. Tulga and Sheridan's model described the human as having "supervisory control as the decision maker (DM) monitoring and controlling a system of independent tasks…" (Tulga and Sheridan, 1980, p. 217). The independent tasks were represented by a display of four rows of blocks presented on a computer screen. The blocks had varying widths and depths representing the duration and value density of each task. As the subject clicked on a block with the cursor, the task was "worked on" and the width of the block decreased. Each block moved at an independent rate across the screen and the goal for the user was to decrement each block completely before it reached the far side of the screen or "due date." Through this experiment, Tulga and Sheridan were able to validate their paradigm, illustrating that dynamic decision making can be represented by a combinatorial graph-theoretical model.

Tulga and Sheridan's work opened the door for further research into the application of existing mathematical models, typically applied to non-human systems, to be applied to human activity and decision making. Scheduling theory, specifically, was becoming prevalent in industrial settings as a programming methodology and appeared to be applicable to human decisions about activity scheduling. The human factors community realized this and critically focused on how scheduling theory and humans interact. In 1989, Sanderson published a review of the work that had been done over the previous 25 years to address this issue.

One of the most beneficial realizations of the research community was that the human scheduler's performance could be compared against the benchmark resultant from a quantitative scheduling analysis of the same situation. Although each experiment could compare the human versus the schedule algorithm they all reached different conclusions about whether the human or the algorithm produced the best results. Each experiment tested different conditions with different skill level schedulers in different scenarios. The only clear, consistent result from all of the experiments is that there is no consistent best solution. Sometimes, the human scheduler was able to perform better in the time allotted than predicted; sometimes the human was worse than predicted. Ultimately, it was determined that the human scheduler is much more flexible in considering tasks which enter the system late or as a high priority because he or she can change heuristics at any point in the schedule. But, scheduling theory offers a more optimal use of resources. As the base of knowledge grew, it became evident that the subjective measures used to evaluate the human cognitive process of scheduling were insufficient to draw conclusions. "Simply showing that the scores a subject achieves are similar to those achieved by a certain rules is not sufficient to draw conclusions about human cognitive processes." (Sanderson, 1989, p. 652). We need to know when the human changes strategies and what triggers the change. Beyond that, there was a need for a standard comparison tool to truly evaluate the human scheduling performance versus a standard.

Dessouky "optimal"

Sanderson (1989) also noted that the justification in using scheduling theory to compare the human performance versus single or combined scheduling rules or heuristics was not rigorously analyzed. This is especially important, since one of the major consistent results of previous experiments was that humans commonly use more than one heuristic to solve a scheduling problem and often change their heuristic mid-flow. Sanderson noted that in order to create a scheduling theory-based system that can compare to this unique human ability, a close look must be taken to ensure the scheduling rules applied are justified completely. It was not until Dessouky et al. in 1995 that this was fully addressed. As described earlier, in Appendix XXX, they defined the one-for-one mapping of characteristics of human decision making with the characteristics of machine operations in scheduling theory. The application of scheduling theory to human behavior was solidly outlined by Dessouky, Moray and Kijowski in 1995. In their research, Dessouky, et al. clearly matched one-for-one the scheduling theory parameters with their equivalent measure in human behavior. After illustrating that components of scheduling theory can be applied to human strategic behavior, Dessouky et al. described several situations in which scheduling theory would benefit human activity scheduling. Their main example was that of a human pilot executing a series of checklists necessary for the overall task of flying. In order to allow the reader to clearly see the relationship of human behavior and task execution elements to traditional scheduling elements, they created the one-for-one mapping. The complete mapping of scheduling elements to behavioral elements can be found in Appendix TBD. It is this guide that will provide a basis for analysis of EOCs in this research.

Another limitation of the previous research, as described by Sanderson (1989), was that there was no existing theory on what aspects of system configuration affect human scheduling abilities. It was not known how stress, environmental clutter, noise, lighting, and distorted or jumbled information flow affect the human DM. Moray et al. (1991) addresses part of this issue by considering the affect of time stress, rule knowledge, and subjective workload on a human's efficiency of performance when scheduling tasks. They found that time stress was the most significant factor to affect the performance efficiency when a human performs a scheduling task. "Subjective workload increases as a function of time pressure." (Moray el al., 1991, p. 621). In a scheduling context, as tested by Moray, the implications are that the more tasks a person is able to complete, the lower the overall subjective workload. As the person has more time to complete the tasks (i.e. more slack time) he or she is less stressed by the time limitations for completion. The less slack time there is available to complete tasks, the fewer tasks were completed and the higher the subjective workload was rated.

In the first laboratory task, the Tulga task, as described above, was used to demonstrate how scheduling theory could be applied. [Four colored blocks would move across a computer screen from left to right each along its own track. The subject selected a block with a mouse-driven cursor in order to decrease the size of the block. The goal for the subject is to reduce the colored blocks to zero before the block reached a vertical line (the due date) at the right side of the screen. The block would move at constant speeds or various speeds (processing time) depending on the test criteria.] Subjects would be evaluated as to how effective their strategy was for eliminating the blocks given the number of blocks, speed of block movement, processing time and transportation time (moving cursor to blocks). In this relatively simple experiment, the strategies subjects employed could be compared against the scheduling methods of Longest Processing Time (LPT), Shortest Processing Time (SPT), Earliest Due Date (EDD) and others. In some cases, the subjects determined their own method of approaching the task and in others subjects were provided the optimal heuristic and were required to apply it to managing the task.

Through this experiment, Moray et al. (1991) discovered that although a user may know the optimal heuristic to apply to a given situation to optimize performance, the knowledge of the heuristic did not improve performance and, in many cases, actually decreased performance. This was especially true for situations where the heuristic was complicated to implement. In that case, the attempts to implement the heuristic collapsed the subjects' ability to accomplish any of the tasks. Therefore, it must be acknowledged that the heuristic must not be too computationally complex. This is a challenge because as problems become more complicated, it is more likely that a scheduling theory solution would be useful to the human scheduler. If the problem is simple enough for a human to apply a simple heuristic, it is less likely that scheduling theory would be able to provide a better solution than the one determined by an experienced human. However, if the heuristic is too complex, the computation quickly overwhelms the human and performance is better without the application of an optimal scheduling heuristic.

This illustrates that although humans may use a heuristic of their own development in solving problems, the best use of scheduling theory may not be to have the human scheduler directly apply the heuristic. Perhaps another application for the scheduling theory would be more useful to humans in decision making situations. Moray et al. point out that "a great virtue of the application of scheduling theory as a tool for psychological research into workload and strategic behavior is that it makes it absolutely necessary to make the task criteria clear. This alone seems to warrant the use of scheduling theory as an important addition to the methodology of behavioral research." (Moray et al., 1991, p. 620).

This finding echoes Sanderson's (1989) realization

Dessouky et al. (1995) use scheduling theory to provide an "optimal" standard to compare human strategic behavior, particularly task ordering / scheduling. Before this, one of the main challenges of evaluating human scheduling performance was that there was no "optimal" upon which comparisons could be made. Much of the research evaluated human schedulers on the basis of percentage correct, root mean square (rms) error or other reflexive measures. However, these measures did not provide the most accurate reflection of true performance. By adapting scheduling theory to apply to human performance, there could then be a benchmark upon which comparisons could justifiably be made. This approach provides a solid standard measure that can be used to objectively evaluate the effectiveness and efficiency of human scheduling against an "optimal" solution. They referred to human scheduling in a broader context and defined, instead, human strategic behavior.

"Strategic behavior is characterized by the need to decide among several courses of action, each of which may lead to a desired goal, subject to time constraints." Strategic behavior consists of a series of inputs that can be translated / mapped into to terms of scheduling theory. Those are: a specific number of tasks, specific order in which tasks must be accomplished, limited resources to allocate to the accomplishment of those tasks, resources are consumed in the execution of the tasks, tasks can be preempted or delayed, and the resultant execution of some task orders is in a shorter time than another "less optimal" order of those same tasks.

Figure 2 (from Moray et al., 1995) illustrates how strategic decision making factors can be mapped with relative closeness to the intent of the scheduling parameters. Figure 2 presents the processes, inputs, outputs, and noise describing a situation where helicopter pilots are conducting a search and rescue mission. It is important to note that each human being is a processor itself and this concept is defined for multi-unit processors (i.e. many people in a team performing a task).

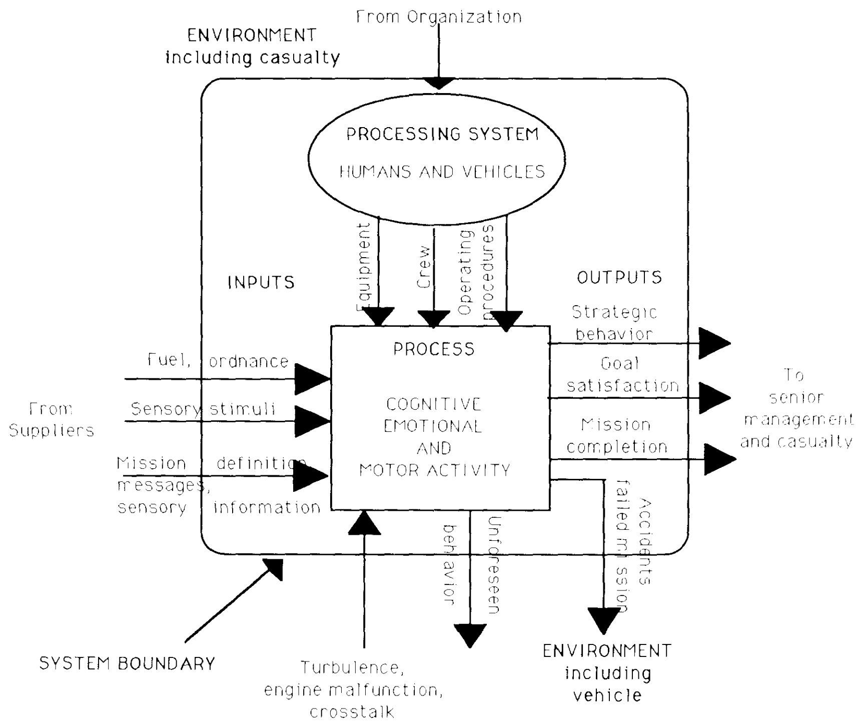

Figure 2. *Characteristics of a search-and-rescue process in which a helicopter flies in an environment to find a casualty on the orders of senior management.*

Scheduling theory mapped to strategic decision making can be used to evaluate the performance of a task by providing a validation or "optimal" solution which can be used to compare against actual performance. "Without a formal definition of optimum, or at least a formal definition of acceptable strategy, however, behavior cannot be evaluated. It is simply not adequate to choose arbitrarily measures such as response time and commission errors without formally specifying their frame of reference." The benefit of using scheduling theory is that the "figure of merit" may have a best known solution. Therefore, the performance of the human can be evaluated against that best known solution.

To illustrate the slight change in mind set, from having the human scheduler use scheduling heuristics to using the scheduling optimums to compare actual human performance, Moray et al. reviewed a laboratory task and created one realistic application scenario. They reviewed their

Tulga task experiment from 1991. After re-looking the analysis of the experiment, Moray et al concluded that although none of the operators were able to execute the most complex heuristic, “many spontaneously discovered a strategy that can be shown to be a heuristic that is close to the Moore-Hodgson optimum” (the most computationally complex heuristic used in the experiment)(Moray, 1991, p 461). In this way, the human capabilities were clearly evaluated compared to the optimal possible schedule and despite the fact that the humans did not employ the specific “best” solution, the performance was close. This reinforces the concept that scheduling theory can be a strong evaluation tool, but too difficult for the human operator to execute while trying to perform specific tasks in a real scenario.

Moray et al. further speculated on how scheduling theory might be applied to a real world example. They describe a situation of emergency management where an operator is aware of an impending tsunami. There are several islands of various size, population and culture/ethnicity near the epicenter of the seismic event that caused the tsunami. The operator must choose which islands to alert in order to save the population from the disaster. Each island may have the same or different language, telephone or radio communications. Each of these factors can be modeled as tasks, resources or requirements and can be analyzed through the scheduling system and the optimal alerting system can be developed to warn the most islands. The situation can be evaluated and sensitivity analysis conducted to illustrate the impact of adjusting the task times and resource allocations. And, in principle, this would provide guidance to a human operator on how to best allocate his or her resources in this situation. Yet again, unless the heuristic employed is very simple, it might be too difficult for the human to schedule the correct sequence of tasks. An alternative is to use a computer program to run the optimal heuristic then the human only needs to act according to the schedule.

Or, another alternative is to use scheduling theory to determine the resources required to perform the necessary tasks. This way, the goal is defined first and the resources necessary to support the goal are the results of the heuristic. But, this presupposes an existing knowledge of the resources, constraints, requirements, and possible solutions; these are all elements which may or may not be known apriori in the real world. However, scheduling theory can accommodate for uncertainty in the parameters, which allows greater flexibility. Dessouky and Moray point out that the complexity of parameters involved in scheduling theory highlight the difficulty of human operators in making strategic decisions in real time.

This method does not specifically address the issue of cognitive load and cognitive capability, which are important variables when discussing human behavior. It is currently impossible to really know how the human allocates internal resources at any given time (e.g. 50% perception, 25% memory, 25% active communication). It is also impossible to know the exact capabilities of each individual at a given time, since there is not decisive evidence about how external forces affect behavior and ability. Therefore, this theory is best applied to allocating the person as a unit/single resource in a multi-person task.

In further research regarding scheduling theory and human behavior, Shakeri determined a need to define the difference between monitoring tasks and discrete tasks. Shakeri asserts that monitoring tasks are never fully completed and this cannot be treated in scheduling theory in the same manner that discrete tasks can be. Since a monitoring task cannot be removed from the task list, it must be revisited upon occasion and must be considered in a special way within the treatment of scheduling tasks. Shakeri's solution to this is to use a linear program to determine the optimal number of times and sequence in which the monitoring tasks must be accomplished. However, Shakeri stops short of integrating both monitoring and discrete tasks into a single theory. Due to the nature of task requirements within an EOC, there is a need to address both discrete and monitoring tasks. However, it could be possible to considering the monitoring type events as discrete events, and simply have those events appear at regular intervals in the scheduling problem.

Shakeri approached the human scheduling issue with a different perspective. He addressed the issue that some while tasks have many similarities to jobs in a manufacturing scenario, there are also tasks that do not have the same characteristics. Specifically, there is a major difference between discrete tasks that are finished once they are worked on and no longer need to be addressed and monitoring tasks which are continuous and are never really finished until the total completion of the mission. Most jobs in a manufacturing setting are discrete jobs and once the object is complete it leaves the system and no longer needs to be tended to. However, monitoring jobs can never leave the job queue and must be reinserted into the queue after each time they are addressed. This aspect presents a particular complication for scheduling theory.

In order to address monitoring tasks, Shakeri developed a linear program that scheduled when the best times were to address monitoring tasks in order to keep the system operating at maximum strength. Monitoring tasks had characteristics of deviation rate if task was not attended to, corrective rate at which the task could be brought back to full operating status, the status of the task just before being attended to, and the weight / importance of the task, and the overall goal was to maximizing the quality of performance (Shakeri, 2002).

2.3 Risk and Consequences of Decision Making

White and Sage created a theory that allows decision makers to partially order sets of alternatives in order to choose the best alternative without further external assessments. This theory, called MOOT (Multi-Objective Optimization theory) offers a means of removing dominated alternatives from the total set of alternatives at a relatively early stage in the decision making process. By using MOOT, a decision maker can eliminate alternatives which are clearly inferior. Ultimately, this process, which can be used with MAUT (Multi-Attribute Utility Theory), may reduce the trade off information required for competent decision making.

- Risk Assessment
- Influence of perception of risk
- Valuation Methods

2.4 Communication in Emergencies

2.4.1 Trained first responders

2.4.2 Untrained humans under stress

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