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Information Load Revisited: A Theoretical Model

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Abstract

The objective of investigating information load is to predict and improve individual performance, since performance deteriorates when information load exceeds the overload point. Models of mental workload (an alternate term for information load) developed in psychology feature mostly task and subject-related influences on mental workload. These models, however, have not yet migrated into management research. The current research develops an improved model of the antecedents of information load that explicitly recognizes, in addition to time pressure, the influence of both information technology and information attributes such as uncertainty, turbulence, and complexity. Selected propositions are presented. Such a model offers an intellectual framework to which future research can relate.

1. INTRODUCTION

Advances in information technology have increased the availability of information in electronic form. The resulting ease of access has many times led users to complain about the vast oversupply of information, not all of it relevant. This phenomenon, also referred to as information overload, is not new. In fact, the connection between information technology (IT) and overload has aroused research interest, particularly because of the double barreled relationship implied: IT may contribute to increase or mitigate overload, depending on critical design decisions. Although usually implemented to simplify a complex task or the analysis of complex information (and therefore improve human performance), the complexity of the system itself has a detrimental effect on human performance (Collins 1993), leading to somewhat mixed productivity results. Evaluation of information load for different system implementations might improve this situation and help bring about real productivity gains.

According to Hancock (1989), measures of information load can also be used to assist designers and operators of man-machine and information systems (as in Gopher and Donchin 1986; O'Donnell and Eggemeier 1986). These measures can be used as a diagnostic tool by the ergonomist trying to evaluate the efficiency of competing designs.

The conceptualization in this paper advances our understanding in three directions. First, it brings the mental workload literature into mainstream business research. The role of information in individual information load has only been studied from a relatively limited perspective, i.e., *how much* information has to be processed. In fact, a number of research pieces in the management literature take the definition of information load for granted and discuss only information overload. Second, the paper reexamines the antecedents of mental workload. Third, the paper addresses the largely unexplored issue of the interaction between IT and the information content presented in their effects upon mental workload.

In the next section, the theoretical background is presented. Some of the more common problems both in empirical approaches as well as in previous conceptualizations of information load as used in the business literature are raised. An improved conceptualization of information load antecedents and the relationship with information technology follows. Some relevant propositions and their implications are identified.

2. THEORETICAL BACKGROUND

2.1 Nature of Information Load

A critical analysis of the literature (particularly in psychology) makes it clear that information load is really a continuum in which both extremes are detrimental to human performance. When there are too few stimuli, information underload ensues. A body of literature on information underload, or *vigilance* (e.g., Mackie 1977), addresses problems like those faced by night guards or submarine sonar operators.

The other extreme is called information overload. Information overload in decision making has been researched considerably in the management literature (e.g., Malhotra 1982; O'Reilly 1980), but, for the most part, without a detailed discussion of the underlying information load construct. The implications of information overload for design, operation and use of some specialized information systems, such as electronic mail, have also attracted the attention of MIS researchers (e.g., Hiltz and Turoff 1985).

2.2 Definition of Information Load/ Mental Workload

Psychologists have investigated the construct of information load under the term "mental workload," which will be used from now on. Proposed definitions differ in the sources of mental workload, the causal variables, their impact on human behavior, and recommended measurement tools.

In the management literature, mental workload has been defined as the *variety* of stimuli in type and number to which the receiver must attend (e.g., McCormick 1970; O'Reilly 1980) equating mental workload with volume of information.

A more comprehensive definition that is widely accepted will be adopted here: "*mental workload* refers to that portion of the operator's limited capacity actually required to perform a particular task" (O'Donnell and Eggemeier 1986, p. 42-2). From this definition, there are two ways to change the mental workload an individual is experiencing: (a) by changing the level of requirements or (b) by changing the amount of available mental resources devoted to a given task.

3. RESEARCH MODEL AND THEORETICAL UNDERPINNINGS

Figure 1 expands the higher-level concepts of capacity and demand into a detailed set of theoretical constructs. An overview of the model will be followed by a more detailed discussion of each model part. The proposed improvements to the mental workload conceptualization focus on the demand for information processing resources.

3.1 Information Processing Capacity

The term *information processing capacity* denotes a maximum limit of processing resources that an individual can bring to bear to perform certain tasks. Although it is not clear to what extent this maximum capacity varies among individuals, the fact that different individuals — with maximum different information processing capacities — perform differently when accomplishing equivalent tasks suggests that maximum capacity is not the most important effect upon the level of performance. The use of this maximum limit is rarely, if ever, achieved (Jex 1988). Instead, different individuals are able to allocate different amounts of the total aggregate information processing resources to certain tasks. The portion of the total information processing capacity allocated to a given task is defined in this work[1] as the *available information processing resources* (AIPRs — the wavy line inside the box labeled "capacity" on Figure 1).

One theoretical distinction that bears upon the magnitude of AIPRs is between controlled and automated modes of processing (Shiffrin and Schneider 1977; Schneider 1985). Controlled processes are described as slow, attention demanding, requiring considerable involvement of short-term memory, exhibiting a large degree of voluntary control by the subject, and requiring little or no training to develop. Automatic processes, on the other hand, do not require as much attention, are not limited by short-term memory, can be processed in parallel, are not amenable to direct control by the subject, and require extensive training to develop. The implication for capacity is that only controlled tasks are competing for the AIPRs.

Determinants of Resource Allocation: Attentional and Physiological. There are two main categories of resource allocation determinants: physiological and attentional. Physiological determinants of resource allocation include fatigue and stress. Attentional determinants encompass psychological states that an individual experiences, such as happiness or anxiety. These psychological states impact the individual's motivation to allocate information processing resources to the task at hand.

Motivation is commonly described as regulating one's activities with respect to three components: (a) *direction* of behavior, (b) *intensity* of effort, and (c) *persistence* of effort over time (Campbell and Pritchard 1976; Kanfer 1990). Motivation has also been defined as a cognitive resource-allocation process. Kanfer and Ackerman propose that "the amount of capacity utilized and policies for allocation of attention are accomplished through [conscious] motivational processes" (p. 103). This is the paradigm adopted in this research.

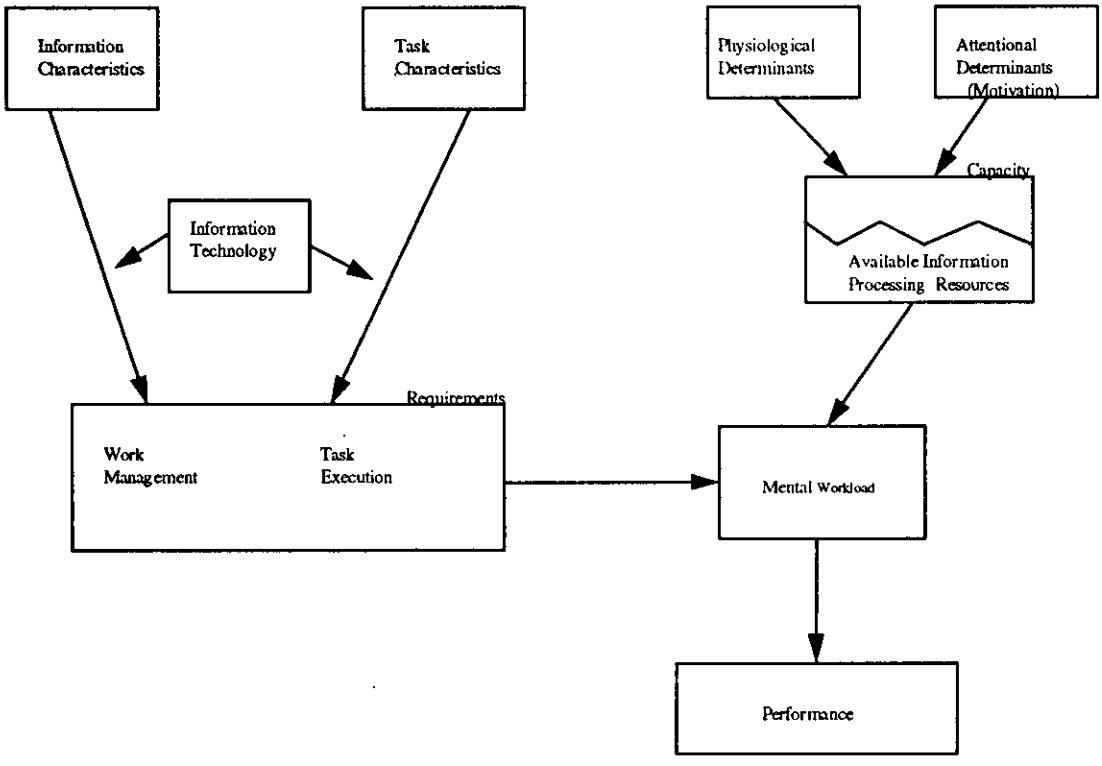

Figure 1. Theoretical Research Model

3.2 Demand for Information Processing Resources

Broadly speaking, demand for the AIPRs is proposed to be caused by both information characteristics and task characteristics. Information technology is proposed to moderate the relationship between both information and task characteristics and demand.

Both demand determinants have (a) an objective, or primary component, and (b) a subjective, or secondary, component arising through the interaction of individual differences with the objective component (Down and Mohrs 1976). This model is concerned with the latter, i.e., with perceived information and task characteristics.

In the remainder of this section, the determinants of demand will be discussed in detail. Demand itself is created by two subprocesses: work management and task execution (Figure 1). Work management is the meta-task thought, i.e., thinking about the task and managing the task (Davis et al. 1991). Therefore, it involves task selection and planning prior to work, and monitoring, evaluation and adjustment of activities during work. Task execution consists of operations performed by the knowledge worker while engaged in a task, contributing to the completion of the task and not classified under work management. In knowledge work tasks, both work management and task execution place demands simultaneously on AIPRs. This distinction will be used to discuss how the various determinants affect demand.

Task Characteristics. Each task has a set of characteristics that differentiates it from other tasks (Davis et al. 1991). The relevance of task characteristics to mental workload has been established in the literature (e.g., Hancock 1989). In this section, some of the most relevant task characteristics — time pressure, task formalization and task complexity — are discussed, as well as their impact on mental workload.

Time Pressure. The first relevant task characteristic is *time pressure*, or time available to perform the task. Real or perceived (Svenson and Edland 1987) decreases in time available for task performance have been shown to affect demand. Experimental evidence shows that choices made under time pressure differ significantly from those made under conditions of no time pressure (Svenson and Edland 1987; Wright 1974). Even researchers who do not use time pressure as a variable recognize its importance (Malhotra 1982). Moreover, under increased time pressure, people adapt by filtering and omitting additional information (Huntley 1982), by shedding or lowering performance of certain tasks (Miller 1978; Hart 1986), and by being less risky (Ben Zur and Bresnitz 1981). On balance, time pressure is probably the variable whose effect on demand for

AIPRs and, therefore, on mental workload has been best established.

Task Formalization. Another relevant task characteristic is *task formalization*, or the level of specification and structure afforded by the task. Jobs being performed by individuals are sometimes defined in a structured way; in others, the activities that are required to perform the task, or even the specific goals of the task, are ambiguous and left open to judgment.

Individuals have to exert less effort in work management when the task is structured. For instance, a long number division task has structured rules to be followed. The structured task affords the development of automated responses requiring little overhead cognitive effort. In contrast, work management makes a sizable contribution to the level of demand for AIPRs in unstructured tasks. On balance, all other factors kept constant:

P1. Higher task formalization leads to lower mental workload.

Task Complexity. The final relevant task characteristic is *task complexity*. Wood (1986) defined three types of task complexity: component, coordinative and dynamic. Each task complexity type affects demand for AIPRs in a different way. *Component complexity* is a direct function of the "number of distinct acts that need to be executed in the performance of the task and the number of distinct information cues that must be processed in the performance of those acts" (p. 66). All other things being equal, a situation in which more acts have to be processed is perceived as generating a higher demand for AIPRs.

Coordinative complexity refers to the nature of relationships between task inputs and task products. The more difficult it is to coordinate relationships between task inputs (e.g., information) and task outcomes (e.g., decision making), the higher is the level of demand for AIPRs. Most of the effect of coordinative complexity on demand for AIPRs stems from the increased work management necessary to coordinate or plan the sequencing and timing of specific acts.

Finally, *dynamic complexity* is a function of changes in the states of the world which have an effect on (a) the relationships between task inputs and products, and/or on (b) the task inputs and products themselves. Changes affect work management because new plans have to be worked out, and it also affects task execution as a function of the new plans. Therefore, demand for AIPRs increases through the influence of both work management and task execution. Given the arguments presented above (and assuming all other factors kept constant), we expect that:

P2. Higher task complexity leads to higher mental workload.

Information Characteristics. The second category of factors affecting the demand for AIPRs and therefore mental workload contains the characteristics of the information, or inputs, used in performing a task. The only information characteristic that has in the past been proposed as affecting mental workload is information volume. Other information characteristics have been conceptualized and empirically investigated, but not in the context of mental workload. Through an extensive review of the literature, the following information characteristics were identified: information volume, uncertainty, complexity and turbulence.

Information Volume. Volume of information is the most commonly cited determinant of information load. In fact, several researchers (Jacoby, Speller and Berning 1974a, 1974b; O'Reilly 1980) have used volume of information as the only indicator of workload, even to the point of ignoring the role of time pressure. Under certain conditions this assumption might be appropriate. General managers, however, can rarely afford the luxury of spending unlimited time on any given decision.

Other findings associated with volume of information are also available. For instance, Casey (1980) found that bank loan officers with the heaviest information load took longer and were not significantly better predictors than officers with lower information loads. On the other hand, Snowball (1980) found that higher information loads tended to be associated with more confident and less varied predictions. Dickson, Senn and Chervany (1977) found that users of detailed data took longer to make decisions but were more confident in their decisions, whereas users of aggregated data, although making better decisions, were not as confident.

In summary, although information volume seems to clearly relate to mental workload, and to have been studied as one of its determinants (or even the *only* one), the typical empirical approach used in the mental workload literature has been to keep the volume of information constant and to change time available to perform a given task instead of purely manipulating volume of information.

Information Uncertainty. Uncertainty is usually defined as a knowledge inadequacy (Montagna 1980), which may arise from several sources. Among them, (a) unavailability or incompleteness of information, (b) low information reliability, or (c) information novelty (Smith, Benson and Curley 1991). A result of uncertainty is an individual's perceived inability to predict something accurately.

Although uncertainty is predominantly considered as a subjective characteristic in the literature (Perrow 1970; Starbuck 1976; Achrol 1988; Achrol and Stern 1988), the sources of uncertainty mentioned above can be either objective or subjective.

Table 1. Definitions of Complexity

Variables Used	Authors: Payne (1976)	Huber & Daft (1987)	Schneider (1987)
Group A – "Volume"			
a.1 Numerosity		X	
a.2 Number of decision alternatives	X		
a.3 Amount of information	X		
a.4 Diversity		X	
Group B – "Interconnectedness"			
b. Interdependence		X	X
Group C – "Others"			
c. Aspects of environment			X

Both a direct and an indirect relationship between uncertainty and mental workload are proposed. These relationships have not been discussed before in the literature. The direct effect is based on the fact that an individual's AIPRs are limited, and if one is concerned that one does not have all the information or knowledge necessary to make a decision, part of one's AIPRs is spent managing the planning efforts of how to increase the completeness or reliability of the information. Therefore, fewer AIPRs will be available for task execution and, for the same level of demand, mental workload will be higher than if uncertainty was absent.[2]

There are also indirect effects of uncertainty on mental workload. For instance, a decision to search for information will add these efforts to the demands previously identified in the task execution process. Even though this extra information has the potential to mitigate one's uncertainty about task outcomes (decreasing mental workload), it increases future volume of information to be processed (increasing mental workload). The net result is likely to be a lagged increase in mental workload.

On the other hand, there is a second possible indirect effect of uncertainty on mental workload. Higher uncertainty might cause individuals to ignore certain alternatives, thus reducing the number of possible choices and therefore decreasing the volume of information to be processed. The final result in this case might be lower mental workload.

On balance, the first situation is likely to predominate, because in unfamiliar situations people are less likely to discard information. Therefore:

P3. Higher information uncertainty leads to higher mental workload.

Information Complexity. Numerous definitions of information complexity have been offered in the literature. For instance, Schneider (1987) defines complexity as those specific aspects of the environment that can have an impact on the organization. The interrelatedness of these aspects is reflected in the complexity construct. According to Payne (1976), complexity is related to the number of decision alternatives and the amount of information about them. Huber and Daft (1987) conceptualize complexity as having three components: *numerosity*, *diversity* and *interdependence*. Numerosity refers to the "number of relevant actors or components in the environment, such as the number of competitors, suppliers and so forth" (p. 134). Diversity is conceptualized as the differences among the information items to be processed. Interdependence is based on Miller's conceptualization that the increased specialization of individuals in processing certain types of information results in greater interdependence among individuals with different competencies.

As summarized in Table 1, the available definitions of information complexity are remarkably similar, although different authors choose different terms to characterize complexity. In Table 1, terms with similar meanings are grouped. For the purpose of definition of the complexity construct, "numerosity," "diversity," and "amount of information" are not used to avoid an overlap with the operationalization of "volume of information." Therefore, the definition of information complexity adopted in this research includes only interdependence of information cues. The last dimension — aspects of the environment -- is too vague to be included in the definition.

When an individual is faced with complex, interdependent information, more resources have to be allocated to elaborate a strategy on how to alleviate this complexity. Similar to uncer-

tainty, information complexity is proposed to affect mental workload both directly and indirectly. Therefore, stated in the expected direction,

P4. Higher information complexity leads to higher mental workload.

Information Turbulence. Huber and Daft use the term "information variety" to refer to the complexity and turbulence of the information stream. Information complexity was discussed above. Turbulence reflects the frequency and unpredictability of change in an organizational environment, caused by instability and randomness.. In a decision task performed by experts, Biggs, Bedard, Gaber and Linsmeier (1985)found that a smaller number of alternatives were considered due to early discarding of similar alternatives. This suggests that highly similar information — or low turbulence information — decreases demand for AIPRs. Therefore, stated in the expected direction:

P5. Higher information turbulence leads to higher mental workload.

The discussion above clearly demonstrates the overlap in the way information characteristics have been defined. The lack of conceptual distinction can be seen in the definition of, for instance, variety, which has been defined as a function of the separate characteristics of turbulence and complexity. This has not been an issue before because no research has attempted to discuss all of these information characteristics concurrently. One contribution of the present work is to provide a conceptual clarity which has been lacking.

Effect of the IT on the Demand for Information Processing Resources. Information technology (IT) is proposed in this research to moderate the relationships between both information characteristics and task characteristics and demand for AIPRs, consequently affecting an individual's mental workload (Figure 1). Of course, information technologies with different capabilities might affect this moderating relationship in different ways (for instance, a CAD system will have a different effect than an on-line relational database). These moderating effects will be discussed next.

Moderating Effect of the IT on the Relationship between Information Characteristics and Mental Workload. The effects of perceived information characteristics are proposed in this research to be moderated by the use of IT in several ways. For instance, two sources of information *uncertainty* are incompleteness and unreliability. Certain types of IT allow faster search for information -- e.g., on-line databases -- potentially increasing completeness, decreasing information uncertainty and decreasing demand for AIPRs. For example, suppose that an individual is in charge of forecasting new product sales. Analysis of seasonal sales for similar products for certain areas of the country may be a well-suited starting point. Such a point might be available. Reliability of the information can be increased by checking the source of information or by checking how often similar inputs led to the desired outcomes in the past, or statistical analysis of that analogous information. Comparison between past predictions, which may have been recorded, and actual sales may be source of even finer adjustments. Although IT might not be appropriate for checking or evaluating sources of information, comparisons among data are tailor-made for IT support.

The presence of IT also affects the impacts of *information volume*. On the positive side, IT allows quick processing of large volumes of information (say, statistical examination of sales forecast/actual sales of a much larger number of products). On the negative side, the existence of IT affords faster information acquisition, potentially forcing a much higher volume of information to be processed (increasing demand for AIPRs) — even summarized results may be overwhelming. Moreover, in the absence of adequate filtering, a substantial part of the acquired information might be irrelevant. Therefore, the higher volume of information to be processed might offset the increased rate of processing afforded by IT, with a net increase in demand for AIPRs and therefore on mental workload.

A similar situation occurs with information *complexity*. The use of IT increases total perceived complexity (increasing demand for AIPRs) because in addition to the information complexity, one has to deal with the complexity in the technology, potentially increasing mental workload. On the positive side, IT can reduce complexity through data reduction techniques, different presentations, summarization, quick evaluation of relationships in the data, regression, and graphs (Jarvenpaa 1986). On balance, it seems that IT implementations which tend to be less complex to use will have a lowering effect on demand for AIPRs and therefore on mental workload.

Since the type or magnitude of the effect of IT presence on different information characteristics may vary, only a general proposition will be provided. Empirical analysis would require operationalization of the proposition for a specific information characteristic.

P6. IT use will affect the magnitude of the effect of information characteristics on mental workload.

Moderating Effect of the IT on the Relationship between Task Characteristics and Mental Workload. The relationship between *task characteristics* and demand for AIPRs is also proposed in this research to be moderated by the use of information technology. For instance, IT can affect formalization in different ways. More commonly, IT affords higher formalization in a task in view of the relative ease with which rules and procedures can be implemented. Following up on our previous example, an individual who has never been involved in sales

forecasting can still be aided by the structure built into the system and come up with a crude prediction. In other words, the variability of the task is considerably reduced, since individuals can be taken through the task step-by-step and prompted for input. This results in less effort being spent on work management, resulting in a lower mental workload for the same performance level. Moreover, IT enables an individual to free her time from execution of repetitive or highly quantitative tasks, potentially decreasing mental workload. In other cases, IT might decrease task formalization. The use of CAD/CAM stations is an example. Instead of dealing with complex hand-made drawings which are hard to prepare, file and retrieve (let alone the problem of duplicate non-current versions), designers can concentrate on the project itself. The reduction in work management demands might potentially decrease mental workload.

The situation for task *complexity* is similar to that discussed above for information complexity. The use of IT increases total perceived complexity (increasing demand for AIPRs) given that, in addition to task complexity, one has to deal with the complexity inherent in the technology. Since some of the features in a complex IT technology are rarely employed, it is difficult to automate their use, and people still need to consciously allocate attention when using them. As soon as one becomes proficient in the use of a new tool, this effect partly wears off, and one is less likely to be overburdened by the complexity of the technology. However, this is only true for IT features that are commonly used. In other words, even experts do not automate all the processes involved in the performance of a given task. Work management is more likely to be affected before IT use becomes automated, whereas afterwards the effect is more likely to be on task execution.

The critical issue seems to be whether a given IT implementation can be used in an automated mode most of the time or if the user has to switch back to controlled mode. Therefore, the general propositions, presented in the expected direction, are:

P7a. For IT implementations used in automated mode, IT presence will decrease the magnitude of the effect of task characteristics on mental workload.

P7b. For IT implementations used in controlled mode, IT presence will increase the magnitude of the effect of task characteristics on mental workload.

3.3 Task Outcomes/Performance

An outcome of performing a certain task is a given level of performance, which is here proposed to be affected by the mental workload experienced by the individual. It is noted that the relationships between some of the independent variables presented in the theoretical research model and performance have been investigated before. For instance, the association between information technology and productivity has been exhaustively studied under different perspectives (for a review, see Brooke 1991), without clear results. One possible approach is to try to understand the cognitive processes which IT users employ when using a certain piece of technology.

Collins proposed two competing relevant impacts of IT on productivity. On the one hand, individuals using information technology have to learn the application, which takes considerable effort. During the learning process, they have to deal with the complexities of both the task as well as the complexity of the information technology. Some of the IT characteristics may become automated and not use AIPRs in the long run; however, this is not true for all IT features. The burden of remembering or relearning non-automated features every time they are needed implies an on-going resource cost in using IT, which negatively affects productivity. On the other hand, IT offers tools that can increase productivity. The critical issue is the tradeoff between these impacts. However, neither this nor other studies have explicitly investigated the associations when including mental workload as an intervening variable. This is the new perspective afforded by the current conceptualization.

Although it is expected that the level of mental workload will have an effect on task outcomes/performance of the operator, this expectation has to be carefully qualified by certain concerns. First, certain processes do allow an increase in performance for an increase in the amount of resources allocated to its execution, whereas others do not. These processes are respectively resource-limited and data-limited processes (Norman and Bobrow 1975). Data-limited processes are those in which performance is limited by the quality of data and not by the level of resources invested. An example is sound detection. Subjects cannot detect certain low-intensity sounds (performance is non-existent) because of the quality of that data. However, after the sound reaches a high enough intensity and the subject is able to detect it, further increases will not affect detection. Resource-limited processes, on the other hand, are those in which performance might change when resources are added or reduced. Many knowledge worker tasks arguably belong to this category. However, different individuals can, for a given task, perform differently because they could be working in different regimens (data-limited versus resource-limited). The effect of this phenomenon is a partial decoupling between the level of mental workload and performance.

In fact, this reason is just part of the rationale for not using performance in a primary task as a measure of mental workload (Meshkati and Loewenthal 1988). Other possible causes of this dissociation were pointed out by Vidulich and Wickens (1986) and by Yeh and Wickens (1988). Basically, even if an individual performs the same task at different times with the same level of

performance, his or her perception of mental workload level may vary depending on how much resources were being devoted to the task. This variation may occur due to differences in level of motivation, for instance.

Therefore, we will tentatively posit that higher workload will be accompanied by higher performance up to the point of overload, when performance might level and then, for further increases in workload, decrease. This is basically the same as hypothesized and tested by Miller.

4. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Although current computer hardware and software systems are more reliable than in the past, most human capabilities have not changed. Increasingly, the performance and reliability of man-machine systems is limited by human capabilities (Hart 1986). Therefore, prediction of performance for different workload levels and, in particular, for the overload point and beyond, is an important reason why workload has been researched (Hart 1986).

Critical in this prediction ability is the understanding of what affects mental workload and how. This paper has addressed some of the problems with existing conceptualizations, and extended them to include the relationships between both information content and information technology on mental workload. Moreover, the inclusion of mental workload as an intervening variable between the antecedents mentioned above and task performance suggests interesting research directions. In particular, the study of computer interfaces and information presentation techniques seems to be a ripe area for empirical application of the proposed conceptualization.

Additionally, emerging technology adoption, a problem widely researched in the last few years, may also benefit from the inclusion of mental workload as a possible cause of success or failure. Although commonly accepted that innovation characteristics affect the way innovations are evaluated by would-be adopters, no research has studied the impact of new technologies on individual mental workload (or information load) and the influence of the ensuing mental workload on the adoption decision. Technologies that might have otherwise many advantages but induce high levels of mental workload, leading an individual dangerously close to the point of overload, could cause higher resistance to adoption. Therefore, a possible study may cover a model of the relationship among individual mental workload (information load), innovation attributes, and the evaluation and acceptance of innovations.[3]

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6. ENDNOTES

1. The concept behind it, though, is not new: for instance, see Kanfer and Ackerman (1989).

2. This statement assumes that these tasks are not automated and therefore both work management and task execution efforts are drawing from the same resource. Conceivably an increase in information uncertainty might throw an already automated task (e.g., driving) back into a controlled state.

3. This study is currently under development by the first author.