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Safety and reliability analysis methods based on systemic-structural activity theory

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Abstract

This paper presents methods of safety and reliability analysis based on systemic-structural activity theory (SSAT), an alternative psychological framework to cognitive psychology. SSAT understands human activity during task performance as a structured system of mental and motor actions and operations in which cognition, behavior and motivation are integrated by self-regulation mechanisms toward achieving a conscious goal. SSAT methods of algorithmic, time-structure and complexity analysis incorporating the use of the MTM-1 system to describe motor actions are demonstrated and discussed using the example of a small-serial production operation. These methods, which generate detailed models of human activity during task performance, are particularly useful at the early stages of the design and development process.

Keywords

Safety and reliability analysis, systemic-structural activity theory, algorithmic analysis, time-structure analysis, complexity analysis, MTM-1

1. Introduction

Currently, much reliability and safety analysis and design is based on cognitive psychology [1-4]. The methods described here draw on an alternative psychological framework or meta-theory, systemic-structural activity theory (SSAT) [5, 6]. SSAT understands human activity as a goal-directed system that integrates cognition, motivation and external behavior. A human goal is understood as a cognitive, informational mechanism which always includes some conscious elements. When combined with energetic-motivational components this creates the vector motive→goal that gives activity its goal-directed character. On this view a goal is not considered as a ready-made standard simply presented to the acting subject; rather, goals are perceived, interpreted, and subjectively adapted by the individuals concerned. The vector motive→goal is tightly interconnected with the emotional-evaluative mechanisms through which a person determines the personal significance of information perceived or tasks performed. The higher the subjective significance of a task for the performer, the more strongly motivated they are to attain its goal. The vector motive→goal also provides a way of filtering and interpreting information available in the task environment. Thus, for SSAT cognitive and motivational mechanisms operate in unity; externally-given instructions are interpreted differently by different subjects for whom the task and associated information have varying subjective significance.

According to SSAT, activity can be understood as a system consisting of a set of logically and hierarchically-organized interacting components, primarily cognitive and motor actions and their constituent operations [6]. Cognition is considered not only as a process, but also as a structured system of cognitive actions. Human activity unfolds over time; individual actions are each guided by their own goals, within the context set by an overarching goal associated with the performance of a particular task. A *task* can thus be defined as an overall goal given under specific conditions [7, 8].

Systemic-structural activity theory offers four stages of activity analysis: qualitative, algorithmic, time-structure and quantitative. SSAT methods can be used in the early stages of ergonomic design to create and compare analytical models of work activity. The SSAT approach to safety analysis described here combines activity-theoretical methods for the algorithmic description of human activity with the microelement analysis of MTM-1. The aim is to analyze subjects' task performance strategies, based on the study of self-regulation during activity [9].

Algorithmic activity analysis describes the logical organization of human activities based on the acting subject's choice of task performance strategy [10]. During the performance of a task humans often combine several actions into a specific subsystem, organized around a higher-order sub-goal of the activity. The range of possible action combinations is constrained by the capacity of working memory, or 'span of control' [11]. In an algorithmic description of activity during task performance a combination of actions around a sub-goal is called a *member of the algorithm*.

Motor actions are typically ensembles of shorter operations or motions. For example, the motor action 'take the object' includes two motions/operations: (1) 'reach the object' and (2) 'grasp the object'. These two elements are integrated by the action-goal 'obtain the desired object'. Empirical research has shown that motions and motor actions usually include three basic stages: the program-formation, or latent stage; the executive, or motor stage; and the evaluative (evaluation of result of movement) stage [9]. Thus, from an SSAT perspective motor motions and actions always include cognitive elements [13]. The MTM-1 system offers a standardized and precise classification of motor motions according to their purpose [14].

2. Analysis of a press operator's transition from leg to two-hand control.

Modern mechanical presses used for serial and small-serial production processes typically provide for either two-hand or one-leg control. For example, a press operator in the standing position can start the ram moving down by simultaneously pressing two buttons, one with each hand. Alternatively, the ram can be set in motion by pressing a foot-pedal. The operator can switch between these modes of control by manipulating a two-position switch with the right hand. Safety rules determine which mode of control should be employed: leg control is permissible when the metal sheet feed and removal of blanks and finished parts are mechanized, as such a set-up does not require the operator to place his or her hands into the danger zone. An additional safety requirement for leg control mode is the use of a guard, which prevents inadvertent entry of the operator's hands into the danger zone. Guard removal is only permitted when hand-control mode is selected via the two-position switch. Once the press is in hand-control mode movement of the ram is only possible when both left and right hands are pressing their respective buttons, which must be held down until ram movement is complete. Any break in contact with either button immediately interrupts the movement of the ram or slide.

Clearly, this design incorporating mutually exclusive modes of control is well-justified from an ergonomic viewpoint. However, closer consideration reveals some drawbacks. Neither mode of control automatically deploys or withdraws the protective guard; the operator may ignore safety procedures and remove the protective guard while in leg-control mode, raising the possibility of inadvertently operating the press while their hands are in the danger zone. The risk is heightened by the fact that switching between control modes may not necessarily follow any regular pattern, the operator's choice of control mode being dependent on the technical requirements of the specific work process and their judgment as to the best way to tackle it. This suggests that the press design should be modified so that whenever the operator removes the protection guard the machine should be automatically switched from the leg control mode to two-handed control.

At first glance the foregoing conclusion may seem self-evident and the design flaw easily detected. However, experience shows that such insights are not always nearly so obvious at the equipment design stage; rather, there is often a mismatch between the designer's understanding of how the equipment will be used and what operators will choose to do in practice. One example of such a mismatch is offered by the 1986 disaster at the Chernobyl nuclear plant. Employees at reactor four were highly motivated to test the system within an allotted schedule. This led to the numerous violations of the safety requirements laid down by operating rules and regulations, including the disabling of essential safety systems [15]. Incidents such as this suggest that in order to ensure that safety considerations are fully incorporated at the system design stage it is vitally important to analyze users' preferred strategies of task performance during the work process, which depend not only on cognitive but also on emotionally-evaluative and motivational factors.

2.1 Qualitative and algorithmic description of task performance

In order to further explore this issue we now present the SSAT-based safety analysis of a machine press production operation involving the manual loading of a blank. Prior to any design innovation the performance of this production operation is as follows: the press operator works in a standing position; a table to their left holds uncut metal pieces, while a similar table on their right holds finished pieces. The uncut blanks weigh 10 kg. In order to take a blank from the left table or deposit a finished piece on the right the operator must make a body rotation of 45°; taking a blank from the left requires a hand movement of 80 cm, while depositing a piece on the right requires a hand movement of 50 cm. The hand movement required to reach the two-position switch (as described above) is 30 cm. The calculated distance of the hand movements includes some body motion in the same direction; the effect of the body movement is to diminish the magnitude of the hand movement distance – other distances of movement are considered during the more detailed time-structure analysis below; at this early stage a simplified narrative description of the work process suffices.

The operator selects two-hand or leg control by turning the two-position switch to the required position with his or her right hand. They then take one blank from the left table with both hands, move it onto the work surface of the press, push it against the stop, and activate the press by simultaneously pressing the left and right buttons. When the cutting process is complete the operator releases the buttons, takes the work piece with both hands, and deposits it on the table on the right. As noted above, if the operator forgets, or chooses to ignore the safety regulations, it is possible to use the leg control without the protection of the safety guard.

Table 1. Algorithmic description of the production operation performed by a press operator involving transfer from one mode of control to another without automatic switching to guard protection.

Member of Algorithm	Description
O^{μ}_{1}	Recall safety rules or forget/ignore them intentionally
$l_1^{\mu}\uparrow^{1(1\text{-}2)}$	If safety rules are forgotten or ignored decide to perform O^{ε}_{3}; if recalled decide to perform operator O^{ε}_{2}.
$\overset{1(1)}{\downarrow}O^{\varepsilon}_{2}$	Move two-position switch to the required position with the right hand (for two-hand control of the press) and remove protection guard

$\overset{1(2)}{\downarrow} O^{\varepsilon}_{3}$	Take a blank from the left table with both hands and put it on the work surface of the press.
O^{ε}_{4}	Push the blank to the stopper
$\boldsymbol{l_2^{\mu}} \overset{2\,(1\text{-}2)}{\uparrow}$	If safety rule is performed (O^{ε}_{2} is performed) decide to turn on the press with two-hand control (go to O^{ε}_{5}). If O^{ε}_{2} is not performed decide to use leg control (perform O^{ε}_{6}) even when protection guard is removed
$\overset{2\,(1)}{\downarrow} O^{\varepsilon}_{5}$	Turn on the press with two-handed control when protection guard is removed and go to ω_1.
$*\omega_1 \overset{\omega}{\uparrow}$	Always-false logical condition (go to $O^{\alpha\,w}_{6}$).
$\boldsymbol{\overset{2\,(2)}{\downarrow} O^{\varepsilon}_{6}}$	Turn on the press with leg control even when protection guard is removed; then go to $O^{\alpha\,w}_{7}$.
$\boldsymbol{\overset{\omega}{\downarrow} O^{\alpha\,w}_{7}}$	Wait based on visual control until ram completes its working movement
O^{ε}_{8}	Release the two buttons or pedal and move the finished piece to the right-hand position table

* The 'always false' logical condition is a syntactical device used to indicate the transition from one member of the algorithm to another (go to $O^{\alpha\,w}_{6}$). It does not represent any actual actions or operations during task performance.

** Symbols in bold designate danger points during the production process.

*** Logical condition l_2^{μ} (decision making) performs checking functions

Table 1 presents an algorithmic description of the production process. Individual members of a human algorithm are designated by special symbols. The arrows associated with the members of algorithm indicate the transition from one member to another [9]. An analysis of the algorithm discloses its potential danger points, understood as those cognitive or behavioral actions – or their combination – whose execution could lead to injuries to the operator. In Table 1, such members of the algorithm are designated in bold type, and comprise: $O^{\mu}{}_{1}$; $O^{\varepsilon}{}_{2}$; $O^{\varepsilon}{}_{6}$; l_1^{μ}; l_2^{μ}; $O^{\alpha w}{}_{7}$. The ‘active waiting period’ of task performance ($O^{\alpha w}{}_{7}$) is that time during which the operator observes the press in operation; although they do not perform any motor actions during this period, they are required to actively focus their attention on the machine's operation. Risks can emerge during this period, particularly if the operator has ignored the safety instructions and is working in leg/pedal control mode. If this is the case, as distraction can lead to injury, a higher level of focused attention is required, increasing the complexity of the task.

Now consider Table 2. It shows the same production operation after modifying the press design. In this improved design, the switch from leg to two-hand control mode is carried out automatically whenever the protective guard is removed. This means that it is no longer possible to carry out the production operation in violation of safety requirements.

Table 2. Algorithmic description of a production operation performed by a press operator involving transfer from one mode of control to another with automatic switching to guard protection.

Member of Algorithm	Description
$O^{\varepsilon}{}_{1}$	Take a blank from the left table with both hands and put it on the work surface of the press.
$O^{\varepsilon}{}_{2}$	Push the blank to the stopper
$O^{\mu}{}_{3}$	Recall safety rules or forget/ignore them intentionally
$l_1^{\mu}\overset{1}{\uparrow}$	If safety rules are recalled to perform $O^{\varepsilon}{}_{4}$. If safety rules are forgotten or ignored perform $O^{\varepsilon}{}_{6}$.
$\overset{2}{\downarrow}O^{\varepsilon}{}_{4}$	Move two-position switch to the required position with the right hand for two-hand control
$O^{\varepsilon}{}_{5}$	Turn on the press with two-handed control and go to ω_1.
$*\omega_1\overset{\omega}{\uparrow}$	Always-false logical condition (go to $O^{\alpha w}{}_{7}$).

$\overset{1}{\downarrow} O^{\varepsilon}_{6}$	Turn on the press with leg control even when protection guard is removed and go to l_2.
$l_2 \overset{2}{\uparrow} *$	If leg control does not work then return to O^{ε}_{4}
$\overset{\omega}{\downarrow} O^{\alpha\, w}_{7}$	Wait based on visual control until ram completes its working movement
O^{ε}_{8}	Release the two buttons or pedal and move the finished piece to the right-hand position table

* Typically a logical condition has two or more outputs; in this case one output option is set to 0.

A comparison of the algorithmic descriptions of the task performance before (Table 1) and after (Table 2) the design innovation demonstrates the removal of all dangerous points of the production operation. The decision-making associated with l_2^{μ} in Table 1 is eliminated and thus there is no need for later checks. As erroneous operation of the leg control is no longer possible, member $O^{\alpha\, w}_{7}$ is no longer a potential danger point.

2. 2. Time-structure analysis

In cases where an operator's task performance strategies are difficult to predict, or where in-depth assessment of possible risks and their associated prevention costs is required, further, more detailed stages of SSAT task analysis can be carried out. Time-structure analysis involves a description of the time structure of activity in tabular or graphic form. Table 3 shows the time structure of activity during performance of the production operation depicted in Table 1.

Table 3. Time structure of the production operation[a]

MoA[b]	Description				Cog[c]
	Right hand or leg	T (sec)	Left hand	T (sec)	T (sec)
O^{μ}_{1}	Extraction of information from memory				1.2
l_1^{μ}	Decision making (yes/no type)				0.3

$\boldsymbol{O^{\varepsilon}_{2}}$	*R30A+G1A+M2.5+RL1+R30E*	0.98			
O^{ε}_{3}	*R80ABA+G1B+M80B10/2BA+RL1* *(AS30) (AS30)*	1.86	*R80ABA+G1B+M50B10/2+RL1* *(AS30) (AS30)*		
O^{ε}_{4}	*R5A+G5+M35A(10/2)x0.4+RL2*	0.7			
$\boldsymbol{l_2^{\mu}}$	Decision making (yes/no type)				0.3
O^{ε}_{5}	*R40A+G5+AP2*	0.79	*R40A+G5+AP2*		
ω_1	Zero duration	--		--	--
$\boldsymbol{O^{\varepsilon}_{6}}$	One step and press pedal	1.47			
$\boldsymbol{O^{\alpha w}}_{7}$	Active waiting period	3.0			
O^{ε}_{8}	*RL2+R30A+G1B+M50B10/2BA+RL1* *(AS30)*		*RL2+R30A+G1B+M80B10/2BA+RL1* *(AS30)*	1.54	

a Time analysis for hand actions based on MTM-1 data [16]; other data from Lomov [17]
b Member of Algorithm
c Cognitive components of activity during task performance

In Table 3 members of algorithm O^{μ}_{1}; l_1^{μ}; l_2^{μ} include one cognitive action; operator O^{ε}_{3} includes two motor actions combined with body movements. For the right hand the first action is *R80ABA+G1B* and the second is *M80B10/2BA+RL1*. Both hand actions are combined with a body assistance movement *AS30*, where 30 indicates the distance through which the body moves; the operator reaches the metal blank and moves it a distance of 80 + 30 = 110 cms. Each motor action includes motions; the first motor action includes three motions integrated by one action-goal: motion *R80ABA* accompanied by body assistance and the grasping of the blank (*G1B* – 'grasp object lying close against a flat surface'). O^{ε}_{6} (move leg + press pedal) includes one motor action which is usually performed with the right leg.

2.3. Quantitative analysis of activity during task performance

In quantitative safety analysis the usual practice is to assess the probability of errors leading to injury; this approach may usefully be supplemented with the quantitative methods of task complexity evaluation developed within SSAT [9, 18]. The combination of probability and complexity evaluation methods arguably provides a more comprehensive safety assessment, allowing improved quantification of the degree of danger and thus more accurately targeted risk-reduction measures. Recognizing that non-subjective methods of obtaining the probabilistic characteristics of human performance are difficult and also tend to be insufficiently accurate, the method presented here combines probabilistic measures derived from subjective expert judgments with objective measurement procedures. It should be noted that what is being assessed using these methods is not the probability of an accident *per se* but rather the probability of potential danger points in the work process. Accidents will occur at such danger points only under certain combinations of conditions; quantitative safety measures provide useful tools for identifying, and thus better avoiding such conditions.

The first step in task complexity evaluation is to determine which, if any, elements of the activity under analysis are performed simultaneously; in the task under discussion all elements are performed sequentially, simplifying the analysis. The next step involves describing the probabilistic characteristics of the task. This allows calculation of the mathematical mean performance time of the various task components, making it possible to calculate the proportion of the overall task performance time associated with potential danger points. In order to do so we begin by calculating the probability of occurrence of individual members of the algorithm. Initial verbal estimates are translated into numerical values using the data provided by Zarakovsky [19] (a similar approach to obtaining subjective probability measures can be found in Kirwan [3]). In the example under discussion the accuracy of such estimates can be considered fairly high, as there are only two possible outcomes for each logical condition.

SSAT identifies two types of human algorithm: deterministic and probabilistic [9]. In a deterministic algorithm the logical conditions have only two possible outputs, each with an equal probability of 0.5. In a probabilistic algorithm the logical conditions can have two or more outputs, each of which may have a different probability of occurrence. The algorithm in Table 1 is thus a probabilistic algorithm. Logical condition l_1^{μ} has two outputs: the first has probability 0.9 and the second 0.1. Logical condition l_2^{μ} also has two outputs: the first (go to O^{ε}_5) has probability 0.9 and the second (go to O^{ε}_6) a probability of 0.1. From this it follows that the probabilities of occurrence of those members of the algorithm of task performance (see Table 1) which differ from 1 are the following:

$$P(O^{\varepsilon}_2)=0.9;\ P(O^{\varepsilon}_5)=0.9;\ P(O^{\varepsilon}_6)=0.1;$$

According to Table 3 the performance time of each member of algorithm can be designated (in seconds) as follows:

$$t(O^{\mu}_1) = 1.2;\ t(l_1^{\mu}) = 0.3;\ t(O^{\varepsilon}_2) = 0.98;\ t(O^{\varepsilon}_3) = 1.86;\ t(O^{\varepsilon}_4) = 0.7;$$

$$t(l_2^{\mu}) = 0.3;\ t(O^{\varepsilon}_5) = 0.79;\ t(O^{\varepsilon}_6) = 1.47;\ t(O^{\alpha w}_7) = 3.0;\ t(O^{\varepsilon}_8) = 1.54;$$

The performance time of the production operation prior to improvement can be determined from the following formula:

$$T = \Sigma P_i t_i$$

Where P_i - probability of i-th member of algorithm, and t_i - time of performing i-th member of algorithm.

Then T for performance of the operation can be determined as:

$$T = 1\text{x}\ t(O^{\mu}_1) + 1\text{x}\ t(l_1^{\mu}) + 0.9 \text{ x } t(O^{\varepsilon}_2) + 1\text{x}\ t(O^{\varepsilon}_3) + 1 \text{ x }\ t(O^{\varepsilon}_4) + 1 \text{ x } t(l_2^{\mu}) + 0.9 \text{ x } t(O^{\varepsilon}_5) + 0.1 \text{ x } t(O^{\varepsilon}_6) + t(O^{\alpha w}_7) + t(O^{\varepsilon}_8) = 1.2 + 0.3 + 0.9 \text{ x } 0.98 + 1.86 + 0.7 + 0.3 + 0.9 \text{ x } 0.79 + 0.1 \text{ x } 1.47 + 3.0 + 1.54 = 10.64\text{sec}$$

The duration of the executive components of the activity T_{ex} (total duration of all efferent operators with symbol O^{ε}) can be determined as follows:

$$T_{ex} = T = 0.9 \times t(O^{\varepsilon}{}_{2}) + 1 \times t(O^{\varepsilon}{}_{3}) + 1 \times t(O^{\varepsilon}{}_{4}) + 0.9 \times t(O^{\varepsilon}{}_{5}) + 0.1 \times t(O^{\varepsilon}{}_{6}) +$$

$$1 \times t(O^{\varepsilon}{}_{8}) = 0.9 \times 0.98 + 1.86 + 0.7 + 0.9 \times 0.79 + 0.1 \times 1.47 + 1.54 = 5.84$$

The time taken for logical conditions, afferent operators, the extraction of information from memory and the executive (response) components of activity can be determined similarly:

$$L_g = \Sigma P^{l}{}_{i}\, t^{l}{}_{i};\ \ T_{\alpha} = \Sigma P^{\alpha}{}_{r}\, t^{\alpha}{}_{r};\ \ T_{\mu} = \Sigma P^{\mu}{}_{\kappa}\, t^{\mu}{}_{\kappa};\ \ T_{ex} = \Sigma P^{o}{}_{j}\, t^{o}{}_{j}$$

Where $P^{l}{}_{i}$, $P^{\alpha}{}_{r}$, $P^{o}{}_{j}$, $P^{\mu}{}_{\kappa}$ - the probability of i-th logical conditions, r-th afferent and j-th efferent operators; $t^{l}{}_{i}$, $t^{\alpha}{}_{r}$, $t^{o}{}_{j}$, $t^{\mu}{}_{\kappa}$ - performance time of i-th logical conditions, r-th afferent, and j-th efferent operators.

The time spent on logical conditions (decision making) associated with potentially dangerous point of the production operation can be calculated thus:

$$`L_g = 1 \times t(l_1{}^{\mu}) + 1 \times t(l_2{}^{\mu}) = 0.3 + 0.3 = 0.6 \text{sec}$$

In fact, faulty execution of logical conditions during task performance may not result in injury. Thus, it is possible to calculate a mathematical mean for the performance time of all logical conditions using a similar formula. On this basis, if necessary, we can determine the fraction of time for the logical (decision-making) components associated with danger, using the following formula:

$$\Omega L_g = `L_g / L_g = 1$$

Where $`L_g$ – the mathematical mean for time performance of logical conditions associated with danger; L_g – the mathematical mean for time performance of all logical conditions.

Next we calculate the relationship between time spent on logical conditions associated with danger points and the time used for the executive components of activity (i.e. the time for efferent operators), or the time for overall task performance.

$$^{/}N_{I} = {}^{\text{‘}}L_g / T_{ex} \quad \text{or} \quad N_{I} = L_g / T$$

Where $^{\text{‘}}L_g$ - time for logical conditions associated with danger; T_{ex} - time for response (executive) components of activity; T – general time of task performance.

We calculate only $^{/}N_{I}$ as an example. This measure demonstrates the relationship between the logical and executive components of activity, giving the fraction of logical components in the task performance associated with potentially dangerous points of the task:

$$^{/}N_{I} = 0.6/5.84 = 0.1$$

When attempting to evaluate the complexity of logical conditions it is also necessary to distinguish between internally and externally-driven decision-making processes. In some situations the performance of actions and decision-making processes is determined largely by information retrieved from long-term memory. This is a more complex situation than those where the decision-making process is predominantly guided by stimuli or information external to the individual, and is therefore particularly undesirable when associated with danger [20, 21]. The following measure of complexity applies to logical conditions performed on the basis of information extracted from long-term memory:

$$^{\text{‘}}L_{ltm} = {}^{\text{‘}}l_{ltm} / L_g$$

where $^{\text{‘}}L_{ltm}$ - proportion of time for logical components of work activity depending mostly on memory and associated with danger; $^{\text{‘}}l_{ltm}$ - mean performance time for logical conditions predominantly governed by memory and associated with danger.

In the production operation under consideration both logical conditions are associated with danger points and both are performed based on information extracted from memory. Hence, l_{ltm} is equal to L_g and therefore $'L_{ltm} = 1$. In our example $'L_{ltm}$ indicates that the worker must rely on safety rules extracted from long-term memory during the decision-making processes, suggesting a lack of external information or stimuli to provide guidance.

There are no afferent operators (independent perceptual operators) included in the algorithmic description of the production operation. Hence, $T_\alpha = 0$. Instead of T_α we have T_μ = which is equal to 1.2sec (the time taken to actualize or extract the required information from memory). The information to be recalled concerns the rules of task performance, which may or may not be adequate for the specific situation. Such rules are important for safety. The relationship between the time required to extract safety-relevant information from memory and overall task performance can be calculated thus:

$$'T_\mu/T = 0.11$$

There is only one member of the algorithm which relates to an active waiting period associated with danger:

$$'T^{\alpha w} = 3\text{sec}$$

It is also possible to calculate the relationship between an active waiting period which can be considered as a potential danger point and overall task performance:

$$'N^{\alpha w} = 'T^{\alpha w}/T = 3/10.64 = 0.28$$

which indicates the fraction of the active waiting period associated with potential danger points.

When the elements of an activity generally follow a habitual sequence it can be considered as stereotypical. In contrast an activity is considered changeable or variable when its elements constantly alter their sequence and some unexpected elements emerge. Potentially dangerous and unexpected decision-making actions are generally undesirable. Hence, the last measure which we will consider is L_{ch}. To calculate L_{ch}, we must first determine the time allotted for the variable logical conditions. It is defined by the formula:

$$l_{ch} = \Sigma P^{l}_{chi} t^{l}_{chi}$$

where P^{l}_{chi} is the probability of the appearance of i-th variable logical conditions, and t^{l}_{chi} is the performance time of i-th variable logical conditions.

The technological process described involves the variation of machined parts and a random shift from foot to manual control and vice-versa. This means that the two logical conditions considered in this example are variable and require constant attention from the operator in order for them to be performed adequately. Each of the two variable logical conditions has a probability of appearance l and time of execution 0. 3. The measure of variability of logical conditions is determined according to the following formula:

$$‘L_{ch}.= l_{ch} / L_g$$

From this it follows that L_{ch} can be calculated as follows:

$$‘L_{ch} .= 0.6/0.6 = 1$$

This indicates that those logical conditions that can be considered as potential danger points are flexible and may occur randomly during transitions from one to another mode of control.

3. Discussion

In cognitive psychology task analysis has been defined as the description of what an operator must do, in terms of actions or cognitive processes, in order to achieve a particular system goal [3]. However, this leaves unclear exactly what is understood by the term 'action' – which is often only confined to the description of motor activity – or how individual actions can be isolated from the ongoing flow of work activity. To address these issues Systemic-Structural Activity Theory has developed a unified and standardized approach to the analysis of work, where human activity during task performance is the primary object of study and cognitive and motor actions provide the major units of analysis [22]. SSAT carefully differentiates between the concept of a system-goal and human goals; the latter always involve conscious elements and are associated with human motivation. There are various types of human goals, all of which are hierarchically organized: action-goals, goals of clusters of actions (as indicated by the separate members of a human algorithm), task-goals etc.

SSAT has developed multiple techniques for describing the cognitive and motivational components of activity [9, 10, 18]; in order to describe behavior it makes use of the standardized descriptions of motor actions in terms of motions provided by the MTM-1 system [16]. Usefully, MTM-1 also allows some consideration of the cognitive regulation of motions, inasmuch as individual motions are extracted from the ongoing flow of action according to their purpose. From an activity-theoretical viewpoint the term 'purpose' is considered close in meaning to the SSAT concept of 'goal', the main distinction being that whereas the goal of human action or activity is understood as always including some conscious element, 'purpose' may be wholly unconscious.

In contrast to traditional methods of using MTM-1, where the analyst typically immediately divides the task into its constituent motions, the SSAT approach focuses first on discovering preferable strategies of task performance. These strategies are then depicted algorithmically, describing the content of the actions contained in each member of the algorithm. Only once this qualitative analysis is complete are individual motor actions isolated and described using the MTM-1 system. When combined with the activity-theoretical understanding that the accurate classification of such operations also depends on an analysis of their regulation by cognition – particularly the level of attention concentration required for their execution – MTM-1 becomes a useful tool for the standardized description of motor actions and operations using SSAT terminology. This approach is iterative – that is, each step may involve reconsideration and modification of previous stages of the analysis – and takes into account the goal-oriented and hierarchically organized nature of work activity: activity during task performance is composed of members of the algorithm, each of which represents a cluster of actions combined by a common goal into a subsystem of activity.

The study of work processes demonstrates that current operations only rarely exhibit the same sequence of performance as has been observed in the past; rather, the logical sequence of action performance changes in response to incoming information and reflects ongoing decision-making. The algorithmic analysis of activity can provide task analysts with a useful technique to deal with this complexity and fluidity. In cognitive psychology the ability of a subject to perform the elements of work activity either sequentially or simultaneously is considered from the perspective of information processing; in SSAT this ability is considered from the perspective of strategies of performance (which are derived from mechanisms of the self-regulation of goal-directed activity), and of the complexity of the separate activity elements making up the work process. This provides the underpinning for developing accurate time-structure analyses of work activity, as the total time for the performance of a production operation cannot simply be derived from the addition of the performance times of individual motions or other activity elements. Rather it is necessary to understand the logic of transition from one activity element to another, the probability of a transition taking place, and the possibility of some elements being performed simultaneously rather than sequentially [23].

4. Conclusion

For ergonomists, evaluating the safety and reliability of a work process is especially challenging in the absence of any real hardware or actual task performance. In such cases appropriate analytical methods are essential. The methods described above demonstrate that an algorithmic description of activity, followed by a time-structure analysis and the quantitative evaluation of task complexity, can facilitate the detection of potential danger points in production tasks and operations. The value of this approach is that these points are detected not by observation or experiment, but by building models of human work activity. This can support more effective safety analysis and problem-solving in the early stages of the design process.

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Professor J. D. Andrews

10/31/2012

Dear Professor Andrews

Attached please find the manuscript 'Safety and reliability analysis methods based on systemic-structural activity theory' by G. Z. Bedny and S. R. Harris which I hope you will consider for publication in the Part O: Journal of Risk and Reliability'.

The paper, which has been written in response to an invitation extended by your journal to Gregory Bedny, describes and demonstrates qualitative and quantitative methods of safety and reliability analysis based on systemic-structural activity theory (SSAT), a psychological framework of which Dr. Bedny is one of the founders and leading researchers. As SSAT (which is built on the activity approach initially developed in Russian psychology, ergonomics and industrial design during the Soviet era) provides an alternative to the cognitivist approaches that dominate in this field, we hope the methods presented may be of some interest to your readership. The techniques presented in the paper have been developed and tested in experimental and applied research b y Dr. Bedny, myself and other colleagues over the past decade; we appreciate the opportunity to share our efforts with the wider engineering and design community.

As we appreciate that the approach outlined in our paper may be unfamiliar to many, we have provided suggestions for reviewers through the online Editorial Manager; I hope these will prove useful. Please don't hesitate to contact me, as corresponding author, should you require any additional information.

Yours Faithfully

Steven Robert Harris
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