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Integration of human behavioral aspects in a dynamic model for a manufacturing system

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The computational simulation of human intelligent behavior has been one of the main research topics in (AI) artificial intelligence domain. Therefore, a great number of behavioral models were proposed considering emotional, cognitive and psychological factors to simulate the human behavior in different domain such as military or manufacturing systems. In addition to psychological factors, the social state of a group of workers plays a critical role in rational decision-making, perception, human interaction and human intelligence. Thus, it is judicious to analyze the workers' behavior at work and to integrate their needs and requirements in manufacturing systems models in order to improve the simulation accuracy. In this context, this paper suggests a graphical and a mathematical representation model of workers' behaviors as well as the ties that can exist among them. The model is also extended to consider inter-worker social relations that can influence the individual performance.

Keywords: Simulation, Modeling, Manufacturing systems, Worker's behavior, Graphs, Sociometrics, Psychometry.

1 Introduction

Traditionally, the simulation of manufacturing systems has focused on technical aspects (e.g. machines, conveyors) representing them with deterministic and stochastic data. Nevertheless, the computational approaches don't reproduce with high fidelity the real dynamic behavior of human-centred manufacturing systems and this can be justified by the lack of applicable models of human behavior integrating psychological and emotional factors. These factors are related to each other besides to individual performance in such a way that attempts to study one effect in isolation is likely to be misleading.
Accordingly, the improvement of accuracy and reliability of simulation prediction can be insured by the integration of some human aspects in models (Elkosantini and Gien 2006a,b). For that reason, this paper deals with the specification of the theoretical and methodological framework to conceptually enable the representation and simulation human behavior. Furthermore, it is important to extend this study to the analysis of group behavior, which is also known as the social network analysis.
The structure of social networks is different from the structure of other kinds of networks such as biological networks, food webs, the world wide web or computer networks. Boguñá (Boguñá et *al.* 2004) confirms that these differences are in three specific issues:

- Transitivity of the relationships between peers (clustering);
- Correlations between the number of acquaintances (vertex degree) of peers;

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- Presence of a community structure with patterns closely resembling the fractal organization present in many natural phenomena.

Therefore, the first step in creating a human behavioral-based model is to determine the different aspects that can be considered and then the framework relating them to the performance and the productivity of workers.

The paper is structured as follows. Section 2 came with a brief bibliographical survey of different works and studies made around human behavior. It presents also an overview on some models analyzing social networks. In section 3, the graphical and the formal representation of workers behavior is detailed. This work is completed in section 4 by representing and studying relationships that can exist in a group of workers.

Finally, the creation and the validation process of the model as well as the case study, which is used to illustrate its applicability, are studied in section 5 and the obtained results are commented and discussed. The paper is completed with a conclusion and some perspectives.

2. Human and group behavior model: Bibliographical survey

2.1 Human behavior models

The human aspects of manufacturing systems were always poorly supported in some simulation tools in which workers are assimilated to a simple resource with a failure rate, mean-time-between-failure and a repair time. Psychological and sociological aspects were neglected in several models and only few studies considered them due to the complexity of their evaluation and quantification.

According to T. Bains (Baines *et al.* 2004), workers are treated as a pseudo-technological element and expected to behave in much the same fashion as an item of equipment. In the practice, workers behavior is more complex and this can justify the error margin between the simulation results and the reality.

In spite of this complexity, the simulation of human behavior has been an interesting and important area of research and application for a long time (Elkosantini and Gien 2006a,b, Seck *et al.* 2005). The interest of those works is to understand and test the mechanisms of several sociological and psychological aspects of the behavior to be able to incorporate them in models called Human Behavior Models (HBMs).

HBMs are being used in increasingly complex and collaborative domains such as the military simulator systems where the human behavior is an essential key that must be controlled. Therefore, several architectures dealt with HBMs were proposed in military such as SAMPLE (Situation Awareness Model for Person-in-the-Loop Evaluation) architecture (Mulgund *et al.* 2000) that focuses on the Situation Awareness (SA) of a pilot. The key component in this architecture is the belief network, also is known as Bayesian network or inference net, which is used to model the pilot's situation assessment/awareness behavior centers on human reasoning under uncertainty. SAMPLE "can capture and computationally model all of the critical SA concepts and processes, including: situations, events, event cues, event propagation, event projection, situation assessment, and situation awareness". (Mulgund *et al.* 2000)

SCALE-UP (Social and Cultural Analysis and Learning Environment for Urban Pre- and Post- Conflict Operations) is another system developed by McDonald *et al* (McDonald *et al.* 2006) providing a training capability to enhance force effectiveness in urban settings through the use of multiple HBMs. Thus, a five-level language was developed for describing agent behaviors and enabling HBMs to communicate information about their actions and intents between them.

Zachary *et al.* presented in (Zachary *et al.* 2001) a model of human multi-tasking behavior, called COGNET/iGEN™, in a stylized Air Traffic Control. It was built using the CFG-COGNET integrative executable cognitive architecture and was based on the decomposition of the human competence on processing mechanism, internal expertise and external context.

A great number of approaches that were found in the literature were usually limited to one or two behavioral aspects such as emotion. Models of emotion have been developed in a broad range of fields and the earliest one was developed by Simon (Simon 1967) using Artificial Intelligence (AI) and was based on motivational states, such as hunger and thirst. El-Nasr *et al.* (El-Nasr *et al.* 2000) proposed a computational model of emotions, called FLAME – Fuzzy Logic Adaptive of Emotions – that can be incorporated into intelligent agents and other complex interactive programs. It uses a fuzzy-logic representation to map events and observations to emotional states and fuzzy rules to infer the desirability of events from its impact on goals and the importance of these goals. The impact of an event on a goal is described using five fuzzy sets.
Other models were centered on intentional mental such as the work of Jonker *et al.* (Jonker *et al.* 2001) that was based on Belief, Desire and Intention (BDI) model. It used a real time temporal language to model, simulate and analyze the internal dynamics of intentional mental states that were ignored in some studies.
Personality representation was also the core of some human behavior models. Indeed, there are several theories describing personality such as the personality representation model of Ören and Ghasem-Aghaee called OCEAN (Ören. and Ghasem-Aghaee 2003). It was based on five traits: Openness, Conscientiousness, Extraversion, Agreeableness and Negative emotionality and each one is defined by six personality facets. In (Ören. and Ghasem-Aghaee 2003, Ghasem-Aghaee and Ören 2003), the authors used the fuzzy logic and OCEAN model to represent the dynamics personality for the simulation of human behavior.

2.2 Social network models

Traditional human behavioral models are limited to some individual aspects and neglect the inter-worker ties. Thus, the improvement of the manufacturing systems simulation results can be insured by extending the study to the social networks in companies. In fact, the analysis of social networks has been used since several decades to advance research in some social and behavioral sciences such as military domain, political science, education, marketing, ecology and community or social psychology. One of the goals of analysis is to detect and evaluate relationships among individuals that may be part of the same network.
Several works dealt with social network analysis tries to answer to some social questions by giving precise formal definitions to the behavioral and cognitive aspects. Concretely, the modeling of such system consists of representing individual or entities, their environments as well as the interactions among them and/or their environment. Some social models were inspired from the physical field with the adaptation of physical laws to the modeling of social systems. For illustration, cellular automata (Bagnoli 1998) is used by Flache and Hegselmann (Flache and Hegselmann 2001) to test their models on irregular grid. The cellular automata framework is a useful tool to explore the relationship between micro assumptions and macro outcomes in social dynamics.
It is important to note that the aim of modeling social phenomena and structures has two reasons. First, to clarify relationships that can exist among parts and members. Second, social models are usually implemented using computer programs and tools to exploit better their results and to simulate the behavior of a social structure. Simulation results can be compared to the collected data in order to verify the accuracy of the proposed models.
Some predictive models that have studied social networks and especially the interaction among members of a same group are enumerated in this paragraph. Parker and Asher (Parker and Asher 1993) conducted a study to investigate the mutual friendships relations between elementary school children and peer group acceptance. They also studied the differences between children with respect to the acceptance and friendship quality while other works have focused on the notion of homophilous attraction (Kandel 1978) and social influence. Therefore, according to Marsden and Friedkin (Marsden and Friedkin 1993), the interpersonal influence operates through social ties, engendering common attitudes or behaviors among friends and other close

relations. Kitts (Kitts 2006) has tried also to study the interactions within a social network and focused especially on the amity and enmity notions. He proposed a model based on neural network that are originally used in artificial intelligence.

In comparison with the models described above, many social scientists choose to build interactions models using statistical approaches (Wong *et al.* 2006, Boguñá *et al.* 2006). Since 1970's, the statistical analysis of social networks has been the subject of a great number of works. One domain of research was to model probabilities of relational ties between interacting units (social actors) though in the beginning only very small groups of actors were considered. In our days, the well known statistical models are the family of p* models (Anderson 1999), also are known as Exponential Random Graphical Models (ERGMs). "The strong point of these models is that they can represent structural tendencies, such as transitivity, that defines complicated dependence patterns not easily modeled by more basic probability models."(Snijders *et al.* 2006).

Other statistical models can be considered as a special case of ERGMs such as Markov Random Graphs (Frank and Strauss 1986) as well as the dyadic interaction model p_1 (Holland and Leinhardt 1981) or the model p_2 (Van Duijn and Snijders 1995). The ERGM model was extended by Snijders *et al.* (Snijders *et al.* 2006) in order to represent structural properties such as transitivity and heterogeneity of degrees by more complicated graph statistics than the traditional star and triangle counts.

In statistical approaches, social networks are modeled as a set of *n* entities – called *agents* or *virtual actor* – and information about binary relation between them. Binary relations are represented by a matrix Y, where Y_{ij} is 1, if agent *i* is somehow related to j and is 0 otherwise. For example, $Y_{ij} = 1$ if "i considers j to be friend". In extension of this model, the relations Y_{ij} are valuated and not just binary (Robins *et al.* 1999).

Social networks can also be studied with sociometrics approaches. The sociometrics is defined as a quantitative technique that involves mapping the inter-relationships between individuals in a social system. It is the mathematical study of psychological properties of populations. The results of sociometric tests are represented graphically on a sociogram. It analyzes interpersonal emotive relationships within a group. This method can be used to identify informal leaders, social rankings and isolated individuals.

Up to our knowledge, the proposed models of human and group of workers' behavior focused only on one or two human aspects such as emotion or culture. They tend to neglect some psychological and/or sociological aspects that we consider it as the core of each human-centered model.

Finally, the aim of this paper is to analyze the relationships that can exist among behavioral elements and to predict how a worker will react in some situations. Consequently, graphical representations of intra and inter-personal (see figure 1, figure 4 and figure 5) is presented next paragraph that can be considered as a tool insuring the understanding of worker's and group's behavior. It may be regarded as an aided-decision-making tool improving the workers' productivity and efficiency.

3. Human worker behavior model

This paragraph is devoted to the description of the methodology leading to better describing the behavioral elements of a worker. An example of graph is given with some interpretations as well as a mathematical formulation of the problem.

As noted above, the improvement of efficiency and productivity of a manufacturing system can be insured by considering constraints linked to the human behavioral aspects. Some of them can directly (or indirectly) affect the performance and the productivity of workers. For example, job satisfaction is known to impact work performance, but it is mediated by psychological and environmental factors. The performance can decrease with the increasing of the workers age (Klein *et al.* 2000, Snel and Cremer 1995). According to Shephard (Shepard 2000), Aging is associated with progressive decreases in aerobic power, thermoregulation, reaction speed and acuity of the special senses. These changes can reduce productivity (Gaudart 2000).

After a bibliographical survey, several works found in the literature tried to study some human behavioral aspects separately (Ryan et al. 2000) and there are few models studying the relationships that can exist between such aspects. So, a graphical representation for the human worker behavior (figure 1) is defined and discussed in this paper illustrating the existing links among cognitive, psychological and sociological aspects (Elkosantini and Gien 2006a,b). This graph can be considered as a decision support system that helps a user to make a choice or a decision between alternatives to improve the stability of workers. Therefore, this cognitive map enables the visualization of the influence of some action, such as doing some meetings, on behavioral aspects such as motivation or satisfaction.
Finally, it is important to outlines that the quantification of some psychological aspects of our model will be insured by using the psychometry that suggests some measurement tools and methods. It is a science involving the evaluation of the psychological abilities of a person using tests and other scientific techniques. It concerns all psychological measurement methods and theories. Usually, the measurements are made by some questionnaires and tests on some persons and concern some psychological aspects such as: satisfaction, stress, motivation, etc.

3.1 Graphical description

The behavioral graph is inspired from the causal loop diagram taken from the system dynamics domain that can be used to get an overview of the causal relationships of a problem. System dynamics combines the theory, methods and philosophy needed to analyze the behavior of systems, not only in management, but also in other fields such as environmental change, politics, economic behavior, medicine, and engineering (Hjortha and Bagheri 2006). Another important feature of system dynamics lies in its applicability in building and running systems simulation to analyze system performance under different scenarios.

Insert here the Figure 1. Example of a behavioral graph

The behavioral graph is defined in this paper by the triplet $G_{hb} = < E, A, R >$ where:

- $E = \{E_i\}_{i=1..n}$ is the set of all elements of a worker's behavior where n represents the number of elements of a worker's behavior (n = 9 in the example of the figure 1). For example, E_i can be the motivation (i^{th} element) of a worker.
- A is the set of arcs symbolizing connections and relations between the elements E_i.
- $R = [r_{il}]_{i,l=1..n}$ and each $r_{il} \in [0..1]$ represents the degree of the relation connecting the elements E_i to El. As it will be detailed in paragraph 5.1, these degrees are the result of some questionnaires and interviews done with the concerned workers. An identification algorithm is applied to the collected data in order to determine the global structure of the graph.

An illustrative example of a behavioral graph is given in the figure 1. It is constituted by a set of nodes E = {2, 3, 4, 6, 7, 8, 9, 10, 11} symbolizing psychological factors. The nodes 1 and 5 called, "entry nodes", are considered as external factors such as perturbation events or some "correction actions" that can directly affect the behavior. Let us outline that such graph can differs from a worker to other. It can depend, for example, on the worker's personality or its role in the company, etc.
The graph is composed from a set of elements (nodes) represented by circles that represent the degree of each behavioral elements. These elements are connected between them by arrows. As detailed in (Elkosantini and Gien 2006a), two kinds of relation can be distinguished in the graph: positive and negative relations. The

arrows are accompanied by one sign "+" or "-". The sign "-" means that the relation is "negative" (see Fig.2.a). An increase of E_1 results in a decrease of E_2 and conversely a decrease of E_1 results in an increase of E_2. For a "positive" connection (see Fig. 2.b), in other word, the sign of this relation is "+". An increase of E_1 results in an increase of E_2 and conversely a decrease of E_1 results in a decrease of E_2. The arc accompanied by the symbol "NL_{ij}" means that the associated relation is not linear. In the example of the figure 1, the non-linearity of the relation between stress and motivation "NL_{76}" is detailed in the figure 3.

Insert here the Figure 2.a
-a- An increase in E_1 results in a decrease of E_2.

Insert here the Figure 2.b
-b- An increase in E_1 results in an increase of E_2.

Insert here the Figure 2.c
-c- Reinforcing loop: An even number of negative polarities.

Insert here the Figure 2.d
-d- Balancing loop: An odd number of negative polarities.

Figure 2. The four kinds of relationship in the behavioral graph

Two types of loops can be distinguished in the graph: Reinforcing (or positive) loops and balancing (or negative) loops (Elkosantini and Gien 2006a):

- The reinforcing loops (Figure 2.c) enhance everlasting growth (positive reinforcement) or decline (negative reinforcement). Generally speaking, positive feedback processes destabilize systems and cause them to "run away" from their current position. Thus, they are responsible for the growth or decline of systems, although they can occasionally work to stabilize them.
- The negative loops (Figure 2.d), also called balancing loops, describe goal-seeking processes that generate actions aimed at moving a system toward, or keeping a system at, a desired state. Generally speaking, negative feedback processes stabilize systems that seek to return to an equilibrium situation.

For example, the type of the ties between the "Work's conditions" (5^{th} element) and "Motivation" (6^{th} element) of the figure 1 is "positive". In fact, the decrease of "Work's conditions" has an influence on workers' motivation. However, the relation between "Stress" and "Satisfaction" is "negative". An increase of "Stress" of a worker reduces his "Satisfaction".

Insert here the Figure 3. Non-linearity of the relation: Motivation - Stress.

As illustrated in the figure 1, each arc is also accompanied by its degree r_{il} such as the degree of the "positive" relation between "effort" and "fatigue" that is equal to 0.62. The value of the degree is belonging to the interval [0..1]. In the example of the behavioral graph of figure 1, only the degree of the relation between "stress" and "motivation" is taken as non-linear (figure 3). All other relationships are constant and do not vary with time.

3.2 Mathematical description

In addition to the matrix R, a second matrix $S = [s_{hi}]_{i=1..n;h=1..q}$ is defined and each element s_{hi} represents the degree of the relation connecting an *entry node* E_h (or external factors; e.g. node 1 or 5) of the graph to the internal element E_i and q is the number of entry nodes in the graph. Besides, the graph is characterized by the set of degrees of all behavioral factors $\mathbf{d}=\{d_i\}_{i=1..n}$ where $d_i(t)\in[0..1]$ represent the evolution of the degree of E_i and N= {very weak, … , very strong} is the set of their linguistic values. A "Very weak" degree $d_i(t)$ is expressed by the numerical value 0 and the "Very strong" degree $d_i(t)$ is expressed by 1. This information is translated to numerical values. As noted above, the quantification of psychological aspect is guaranteed with questionnaires and psychometric tools.

The power of mathematics and differential equations has rarely been applied to human behavior and few studies used them to describe such complex dynamics. In his model, Jones (Jones, 2005) used differential equations to formalize the effect of moods and other behavioral factors on the evolution of the human motivation. A similar model was also applied to the stress to describe its progression (Jones, 2005).

Linear and non-linear mathematical models have also been used in social psychology to describe other kind of inter-individual relation. For example, Strogatz (Strogatz, 1994) tried to model mathematically the dynamics of romance by considering a love affair between Romeo and Juliet and proposed a linear differential equation to compute the degree of the love between them. Moreover, related discrete dynamical models of the verbal interaction of married couples were recently proposed by Gottman *et al.* (Gottman *et al.*, 2002).

In the same way, the worker's behavior is modeled in this paper by some mathematical formulation that is based on differential equations. Indeed, the equation (1) presents a generalized form of the ordinary differential equation describing the evolution of each behavioral element using the matrix R and S. It considers both linear and non-linear links.

$$\frac{d}{dt}\mathbf{d}(t)=R(\mathbf{d}(t))+S(\mathbf{e}(t)) \qquad (1)$$

$R(\mathbf{d})$ and $S(\mathbf{e}(t))$ are the matrix that depend on vectors $\mathbf{d}$ and $\mathbf{e}(t)=\left[e_h(t)\right]_{h=1..q}$ that is the vector describing the behavior of *entry nodes* symbolizing the external actions such as perturbation events or "correction actions". Since the link between two behavioral factors hasn't always been linear, r_{il} can be considered in some cases as non-linear and/or non-stationary relation:

$$r_{il}=r_{il}(d_i,d_l,t) \quad ; \quad \mathbf{i,l\ =\ 1..n} \qquad (2)$$

In non-linear case, the relation's level in only influenced by the degree of the two concerned factors d_i and d_l. The time doesn't have a great impact in the evolution of the links:

$$r_{il}=r_{il}(d_i,d_l) \quad ; \quad \mathbf{i,l\ =\ 1..n} \qquad (3)$$

However, in non-stationary case, the relation between E_i and E_l can be directly influenced by the time:

$$r_{il}=r_{il}(t) \quad ; \quad \mathbf{i,l\ =\ 1..n} \qquad (4)$$

In linear-stationary links case, the equation (1) became (5) and the evolution of each element d_i depends on its current state as well as the state of other elements d_l.

$$\frac{d}{dt}d_i(t) = \sum_{l=1,l\neq i}^{n} r_{li}d_l(t) + r_{ii}d_i(t) + \sum_{h=1}^{q} s_{hi}e_h(t) \tag{5}$$

Where:

- d_i is the i^{th} element;
- r_{li} is the degree of the link between l^{th} and i^{th} element;
- r_{ii} represents the influence of the current state on the evolution of the i^{th} behavioral element;
- s_{hi} is the degree of the impact of the h^{th} external factors (entry nodes) on the i^{th} behavioral elements and q is the number of theses factors (q=2 in the example of the figure 1);
- e_h is the evolution of the h^{th} external factors degree of the impact of external factors (entry nodes) on behavioral elements;

According to (5), the variation of the level of "satisfaction" (4^{th} element in the graph of the figure 1) is calculated by:

$$\frac{d}{dt}d_4(t) = \left[-0.73\times d_3(t) - 0{,}25\times d_9(t) - 0{,}75\times d_7(t) + 0{,}8\times d_6(t)\right] - 0{,}1\times d_4(t) \tag{6}$$

4. Group behavior model

The methodology introduced in the first part is limited to some individual aspects and some inter-worker ties are neglected. That is why it is more appropriate to integrate relationships among workers in the model and complete it by a sociometric approach that are used in several works in social networks to study groups' dynamics (Sonnemans *et al.* 2006).
The second level of the methodology insures the better integration of human aspects in manufacturing systems models and improvement of the comprehension and the study of worker and group behavior. It allows the visualization and the analysis of information concerning the state of interpersonal, sociological and subjective relationships in the group.

4.1 Graphical description

The graphical description of the social network that is used here is inspired from sociogram that enables visualization of the choices and the rejections revealed by the sociometric tests. There are some similarities between sociogram and the behavioral graph seen above. Indeed, this graph is composed of units called nodes, symbolizing actors or some human sets, connected by arcs symbolizing relations or ties.
These ties are characterized by their "contents" - or type - (i.e. friendship, knowledge, etc), their intensity or frequency. The graph is called "simplex" if it represents a single type of relations among the actors or "multiplex" if more.
Each tie or relation may be directed (i.e. originates with a source actor and reaches a target actor) or it may be a tie that represents co-occurrence, co-presence or a bonded-tie between the pair of actors. Directed ties are represented with arrows, bonded-tie relations are represented with line segments. Directed ties may be reciprocated (A chooses B and B chooses A). They may also be signed (represents a negative tie, a positive tie, or no tie) and valued. A graph with directed relations is called an oriented graph.

The graph of a group behavior will also be defined by a triplet $G_{gb} =< \mathcal{O}g, \mathcal{R}g, R >$, where:

- $\mathcal{O}g = \{\mathcal{O}g_j\}_{j=1..m}$ is the set of all workers (or actors) of the same group. m represents the number of workers in the group.
- $\mathcal{R}g = \{\mathcal{R}g_k\}_{k=1..p}$ is the set of interpersonal elements (or relations between workers). p is the number of inter-personal elements. $\mathcal{R}g_k$ can be the conflict between workers, communication between them, group cohesion, coordination, etc.
- The matrix R defined above must be defined in other way to take into account either the internal and inter-personal relationships. So the new matrix R is now defined as follow:

$$\begin{array}{c} \quad [\mathbf{E}_i]_1 \quad [\mathbf{E}_i]_1 \quad \cdots \quad [\mathbf{E}_i]_1 \quad \cdots \quad [\mathbf{E}_i]_1 \;|\; \mathcal{R}g \\ R = \left[\begin{array}{cccccc|c} [R^1] & . & . & . & . & . & [\mathrm{Re}^1]^T \\ . & [R^2] & . & . & . & . & [\mathrm{Re}^2]^T \\ . & . & \ddots & . & . & . & \vdots \\ . & . & . & [R^j] & . & . & [\mathrm{Re}^j]^T \\ . & . & . & . & \ddots & . & \vdots \\ . & . & . & . & . & [R^m] & [\mathrm{Re}^m]^T \\ \hline [\mathrm{Re}^1] & [\mathrm{Re}^2] & \cdots & [\mathrm{Re}^j] & \cdots & [\mathrm{Re}^m] & [\mathrm{Re}^0] \end{array}\right] \end{array} \qquad (7)$$

Where:

- $[E_i]_j = \{E_{ij}\}_{i=1..n}$ is the set of all elements of the j[th] worker's behaviour,
- $R^j = \begin{bmatrix} r^j_{11} & \dots & r^j_{1l} & \dots & r^j_{1n} \\ . & \dots & . & \dots & . \\ . & \dots & r^j_{il} & \dots & . \\ . & \dots & . & \dots & . \\ r^j_{n1} & \dots & r^j_{nl} & \dots & r^j_{nn} \end{bmatrix}$ and $Re^j = \begin{bmatrix} re^j_{1,1} & \dots & re^j_{1,k} & \dots & re^j_{1,p} \\ . & \dots & . & \dots & . \\ . & \dots & re^j_{l,k} & \dots & . \\ . & \dots & . & \dots & . \\ re^j_{n,1} & \dots & re^j_{n,k} & \dots & re^j_{n,p} \end{bmatrix}$;
- $Re^0 = \begin{bmatrix} re^0_{11} & \dots & re^0_{1l} & \dots & re^0_{1p} \\ . & \dots & . & \dots & . \\ . & \dots & re^0_{il} & \dots & re^0_{ip} \\ . & \dots & . & \dots & . \\ re^0_{p1} & \dots & re^0_{pl} & \dots & re^0_{pp} \end{bmatrix}$

Let's take an example a group of workers formed by three workers $\mathcal{O}p1$, $\mathcal{O}p2$ and $\mathcal{O}p3$. The figure 4 illustrates the conflict and the communication which exists between them. The thickness of each arc represents its level. Therefore, the thickness of the arc connecting workers $\mathcal{O}p1$ and $\mathcal{O}p2$ - symbolizing the relation $\mathcal{R}g_1$ - shows that the level of conflict between them is high. This can justify the low level of the communication between them. Contrary to $\mathcal{R}g_1$, the relation $\mathcal{R}g_2$ is weak that express the non-existence, or almost, of conflict between $\mathcal{O}p1$ and $\mathcal{O}p3$.

To best analyze the group behavior, the graph of the figure 4 can be more detailed as shown in the figure 5. It illustrates the effect of psychological factors on inter-workers relationships. The thickness of the arc $\mathcal{R}g_1$ (conflict) in figure 4 is represented by the degree dg_1 and each node in the sociogram (figure 4) represents a human worker that are replaced by their behavioral graph in the figure 5. Consequently, this graph enables a user to visualize and study in more detail the evolution of the worker in a psycho-socio-technique view. Moreover, it allows the creation of coherent and homogeneous working groups and better analyzing the relations that can exist between the employees.

Insert here the Figure 4. Conflict and communication in a group of workers.

Insert here the Figure 5. Example of a group behavior's graph.

4.2 Mathematical description

As illustrated in the figure 5, some links can exist between the workers behavior's graph G_{hb} defined by $<E,A,R>$ and the group behavior's graph G_{gb} defined by $< \mathcal{O}g, \mathcal{R}g, \mathrm{R} >$ that is mathematically summarized in the matrix (7). In a previous work (Elkosantini and Gien 2006a), a mathematical model computing the evolution of each inter-workers relation $\mathcal{R}g_k$ is given. This is represented by the equation (8):

$$\frac{d}{dt}\mathrm{dg}_k(t) = \sum_{i=1}^{n}\sum_{j=1}^{m} re_{ik}^{j}\, d_{ij}(t) + re_{kk}^{0} \times \mathrm{dg}_k(t) \tag{8}$$

Where:

- $\mathbf{dg} = \{dg_k\}_{k=1..p}$ is the set of the degrees of different kinds of studied relations between workers. So, $dg_k(t)$ represent the evolution of the degree of the kth relation (example: conflict) at instant t and M = {very weak, ..., very strong} is the set of its linguistic values. Identically to N (N is the set of linguistic value), this information is translated to numerical values.
- re_{ik}^{j} is the relations between the ith (internal) and the kth (interpersonal) element of the jth worker. If there is no relation between the ith and the kth element of the jth worker, then $re_{ik}^{j} = 0$.
- n are the number of elements of a worker's behavior and m is the number of actors or workers in the group.
- d_{ij} is the degree of the ith element of the behavior of the jth worker.

According to (8) and the figure 5, the evolution of sociological aspects depends on some internal elements and they can have an impact on some internal ones. The equations (1) and (5) don't consider the influence of some sociological aspect on the evolution of some individual elements. Subsequently, the generalized form of the equation (1) became:

$$\frac{d}{dt}\mathbf{d}_j(t) = R^j(d_j(t)) + \mathrm{Re}^j(\mathbf{dg}(t)) + S^j(\mathbf{e}(t)) \tag{9}$$

Where **d**j is vector containing the degrees of all behavioral factors associated to the jth worker. Likewise, if the behavioral factors are linked with linear relations, the last equation became:

$$\frac{d}{dt}d_{ij}(t) = \sum_{l=1, l\neq i}^{n} r_{li}^{j} d_{lj}(t) + r_{ii}^{j} d_{ij}(t) + \sum_{k=1}^{m} re_{ki}^{j} dg_{k}(t) + \sum_{h=1}^{q} s_{hi}^{j} e_{h}(t) \tag{10}$$

The added term $\sum_{h=1}^{q} s_{hi}^{j} e_h(t)$ express the influence of sociological factors such as conflict or communication on the internal and behavioral factors where s_{hi}^{j} is the degree of the impact of the hth external on the ith behavioral elements of the jth worker.

5. Simulation and results

This methodology is applied on a case study that is described below to evaluate its efficiency. The model presented in the figure 1, illustrating the worker behavior, is simulated using two appropriate tools and the obtained results are commented and analysed. Moreover, the creation and validation procedure of the model is presented. The second part of this paragraph is devoted to the simulation of workers' group behavior in a company.

5.1 The validation procedure

The first step of the creation of a behavioral model is the classification of all concerned employees in the company because the behavior of a worker differs from that of the administrative staffs. This dissimilarity is due to the difference of their work environment and the kind of their tasks. Then, a list of psychological and sociological factors must be established in order to form the nodes of the graphs that must be created to study the behavior of all concerned workers. At the same time, a simulation environment (computer software) must be developed to test and validate the model and that has the goal of reproducing the reality. In our case, the simulation environment will simulate a task of controlling product quality in a manufacturing system. The second step consists on testing the tool with a user that replaces the human worker. During the simulation, the user has to valuate their psychological, emotional and behavioral factors. This task is the main problem in the creation of the model and the quantification of nodes (psychological aspects) and links between them is usually insured by questioning and/or interviewing the employees. Moreover, the opinion of bosses about such aspects must also be considered to guarantee an objective evaluation. Therefore, questions like "*Are you motivated by your task*" are used to evaluate the motivation. In other hand, the quantification of links between nodes is done by other kinds of questions similar to "*do you consider that the increase (or decrease) of the motivation has an influence on productivity?*" and "*which importance degree will you give to this connection?*".

The first version of the model can be finally constructed after several tests and using information gathered from the questionnaires. Then, the model has to be tested with the same simulation environment with the aim of comparing the calculated and the real evolution of the behavior. If there are some differences, the model parameters (the degree of relations between psychological elements) must be modified to have a pertinent model that reproduces as realistic as possible the behavior of a worker.

Insert here the Figure 6. The validation procedure

5.2 Worker's behavior simulation: case study

The applicability of the model is demonstrated with a case study that is illustrated below. After the validation of the model of the figure 1 according to the procedure detailed above, it is simulated using some simulation tools resulting from two domains: the automatic - with Simulink - and the system dynamics - with Vensim (Ventana 2003).

Let us outline that in this graph, there is an explosive loop noted by B1. Therefore, an increase of an element results in an increase of the other and conversely. For example, if the absenteeism of the worker increases, then the stability of the working group decreases. As consequence, there is more and more workload for the group that tends to increase the imprecision in work. Thus, it is necessary to set up a correction action C such as a probation period, doing some meetings or more controlling the employees in order to regulate this problem (figure 7). The correction's action is used to attenuate the gravity of some problems. Hence, this creates a second loop (negative loop), noted B2 in the figure 7 that will stabilize the first one.

Insert here the Figure 7. Reinforcing and negative loops.

5.2.1 Simulation with Simulink. The example of the figure1 is simulated with Simulink (from Mathworks) and using models presented in this paper. The non-linearity of the link between motivation and stress, as detailed in figure 3, is also considered. The figure 8 presents a part of the final model of Simulink. This figure details how represents a relation using Simulink.

Insert here the Figure 8. Simulation with Simulink.

5.2.2 Simulation with Vensim. The same model is also constructed and simulated with Vensim (Ventana 2003). It is not detailed here but only a part of the final graph is illustrated in figure 9 that corresponds to the transformation of the loops B1 and B2 of figure 7 into a flow-stock diagram.

Insert here the Figure 9. Simulation with Vensim.

5.2.3 Results and discussion. First, in this case study, each worker works 8 h per days (the time unit is the hour). Hence, all time-constants in the two models (Simulink or Vensim) are equal to 1 except that for the absenteeism which is equal to 8. In this paragraph, the evolution of some behavioral element will be detailed and analyzed. The graphs of figure 10 illustrate the non-linearity of the relation between the stress and the motivation. In the time interval $t \in [0..1,5]$, the motivation continue to increase despite the increase of stress that have a level less than 0.3.
After that (t > 2h), the sign of the relation changes when the stress attains the level "40%" and become negative and the motivation decrease since stress increase as it illustrated in figure 10.

Insert here the Figure 10.a and Figure 10.b
Figure 10. The non-linearity between stress and motivation.

The correction action C (see figure 7) has an important role to stabilize the loop B1 and then the behavior of the human worker. Indeed, the graphs of the figure 11 illustrate that the behavior is strongly disturbed without this action. The absenteeism and the inaccuracy continue to increase and reach non-acceptable levels while the stability attains levels expressing a continual instability of the worker. This can have a bad influence on other workers of the same working group.
As noted in paragraph 3.2, the degree of each behavioral element belong to the interval [0..1] and a degree of 0 mean a "a very low" level and a 1 mean a "very high" level. In the figure 11, the degree of absenteeism begins with 0 that means the employee is concentrated on his work and do not quit it. However, after 8 h, the degree increase and reach very high level expressed by the value 1 and this mean that the employee is completely absent and don't work.

Insert here the Figure 11.a, Figure 11.b and Figure 11.c

Figure 11. Behavior evolution without the action C.

To solve such problem, the managers have to propose some correction action C such as doing some meetings or more controlling the employees. The evolution's graph of absenteeism, stability and the inaccuracy (see figure 12) show the effect of this action. In spite of the troubles in absenteeism at t = 3.5h and in inaccuracy at t = 1h, the worker behavior is stabilized and is more precise than before the installation of C.

Insert here the Figure 12.a, Figure 12.b and Figure 12.c

Figure 12. Behavior evolution with the action C.

5.3 Group behavior's Simulation: case study

The behavior of the group formed by $Op1$, $Op2$ and $Op3$ is analyzed as detailed in figure 5. It illustrates the effect of inter-personal factors on individual ones. The thickness of the arc $\mathcal{R}g_1$ (conflict) in figure 5 is represented by the degree dg_1.

The figure 5 illustrates that the variation of the conflict's degree dg_1 depend on the stability (10^{th} element of the behavior's graph) of workers $Op1$ and $Op2$. So, according to equation (11), the variation of the conflict is calculated by:

$$\frac{d}{dt}dg_1(t) = \left[re_{10,1}^{1} \times d_{10,1}(t) + re_{10,1}^{2} \times d_{10,2}(t)\right] + re_{1,1}^{0}(t) \times dg_1(t) \qquad (11)$$

The figure 7 shows that the growth of instability of workers can directly affect the relationships between them. So, managers have to find the appropriate actions to solve this problem by trying to decrease the effect of internal elements on conflict. For example, they have to identify workers whom are likely to be socially isolated and to reform the group.
According to figure 13.a the communication between the workers $Op1$ and $Op2$ increases and reaches an acceptable level in spite of the perturbations of capacity, effort or security sentiment Moreover, the graph of the figure 13.b shows that the conflict between workers decreases. It can be justified by the presence of the correction action C, the stability of some workers and finally the low level of stress.

Insert here the Figure 13.a and Figure 13.b

Figure 13. Evolution of conflict and communication between *Op*1 and *Op*2.

6. Conclusion

In conclusion, this paper tried to highlight the importance of integrating the workers' and groups' behavior as well as their needs on manufacturing systems models and simulation. The inclusion of psychological, sociological and behavioral aspects has an impact on the performance of workers. Nevertheless, some of existing models and approaches neglect some human constraints such as psychological and sociological ones and consequently, it is important to study and to analyze them in order to improve the accuracy of the simulation of manufacturing systems.
The aim of the study described in this paper is to provide a theoretical and a methodological framework to conceptually enable the representation and simulation of human behavior. First, a graph concept is proposed describing the behavior of each worker and represents all links that can exist among psychological aspects. Then, the second part the methodology outlines the importance of extending the study to social networks in the company. So, the first graphical representation is extended to takes into account all interpersonal and social aspects such as conflict, communication, etc. A mathematical framework is also proposed to facilitate the simulation of worker and worker's group's behavior.
The graphical representation and mathematical formulation detailed in this paper are simulated using Simulink. Managers and decision-makers can have general view on the evolution of human, sociological and psychological aspects of the company's and not only technical ones.
This methodology must be integrated in actual manufacturing systems models to improve simulation results. It can be used by companies' managers and decision-maker to increase both worker productivity and group's stability by deciding to install some actions such doing some meetings or more controlling the employees.
Currently, a simulation environment is developed with Visual Basic simulating a task of controlling the mobile phones quality. It is now being tested by voluntary students playing the role of workers in manufacturing system environment. During the tests, the students have to respond to some questionnaires

quantifying some behavioral aspects and the obtained results must be analyzed in order to construct and validate a behavioral model reproducing a part of the real behavior.

To improve this methodology, several directions must be explored. First, numerical values must be replaced by fuzzy intervals when quantifying the sociological and psychological elements to well express the vagueness of such information. The differential equation describing the evolution of each behavioral element must be considered as Fuzzy differential equation. Thus, the problem became the resolution of a Fuzzy Differential Equations (FDEs) with fuzzy parameters and/or variables and with imprecise initial condition. Second, the actual methodology is evaluated with some fictive case studies. Therefore, the approach must be applied on real case, i.e. on a real manufacturing system to have a pertinent behavioral model.

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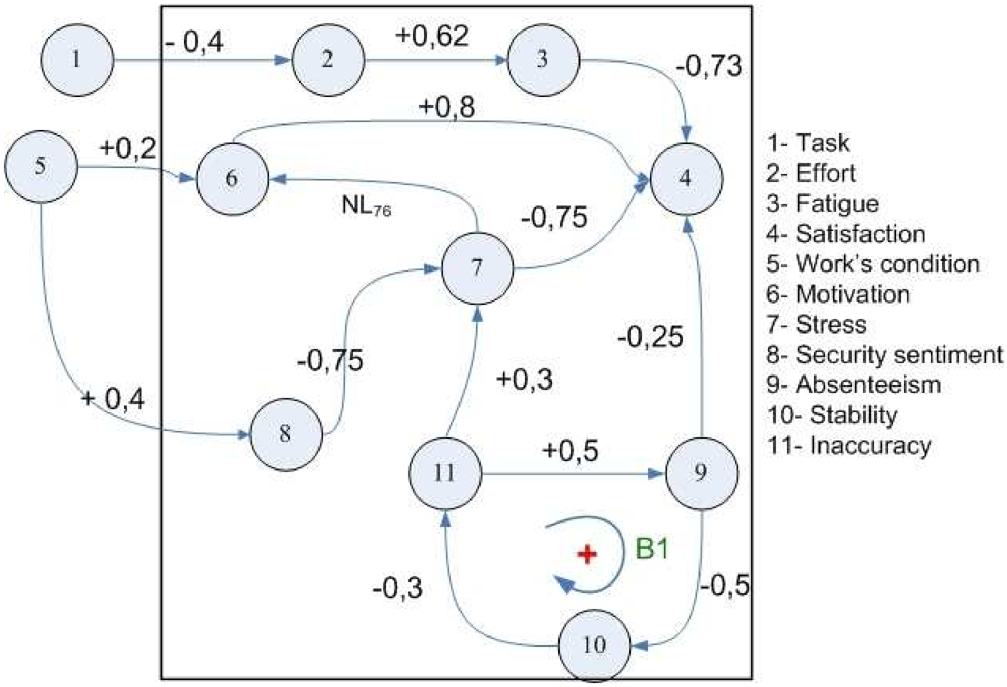

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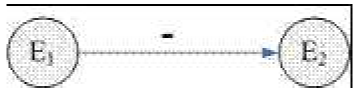

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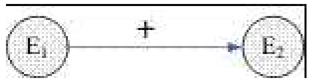

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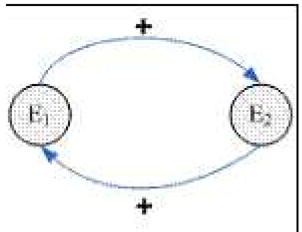

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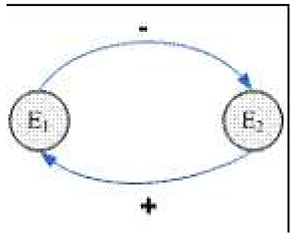

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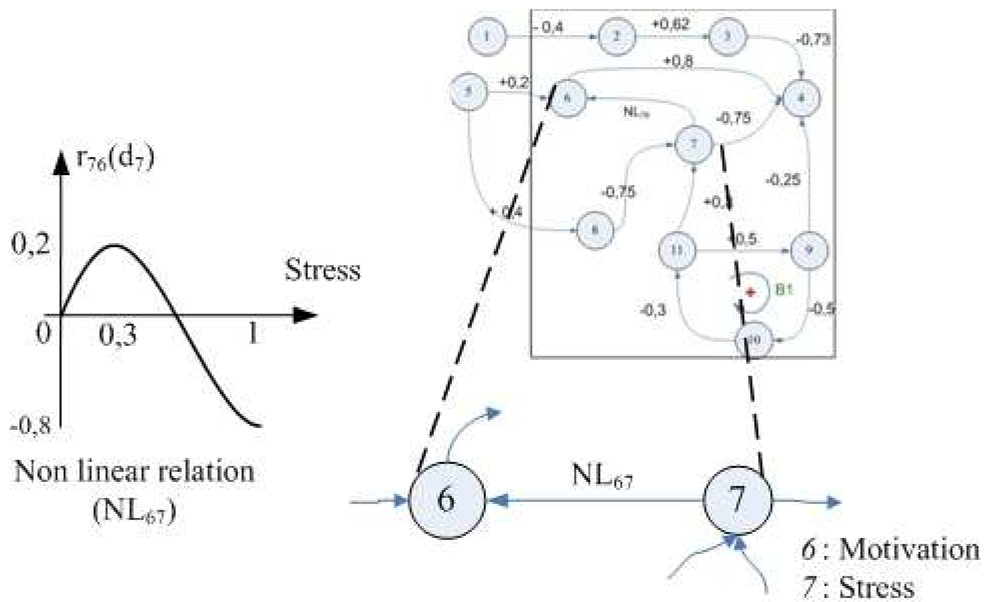

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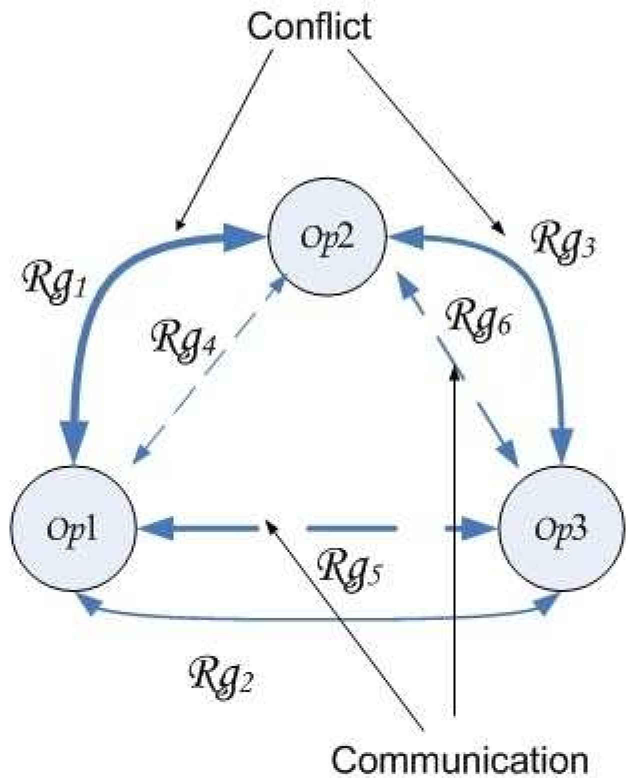

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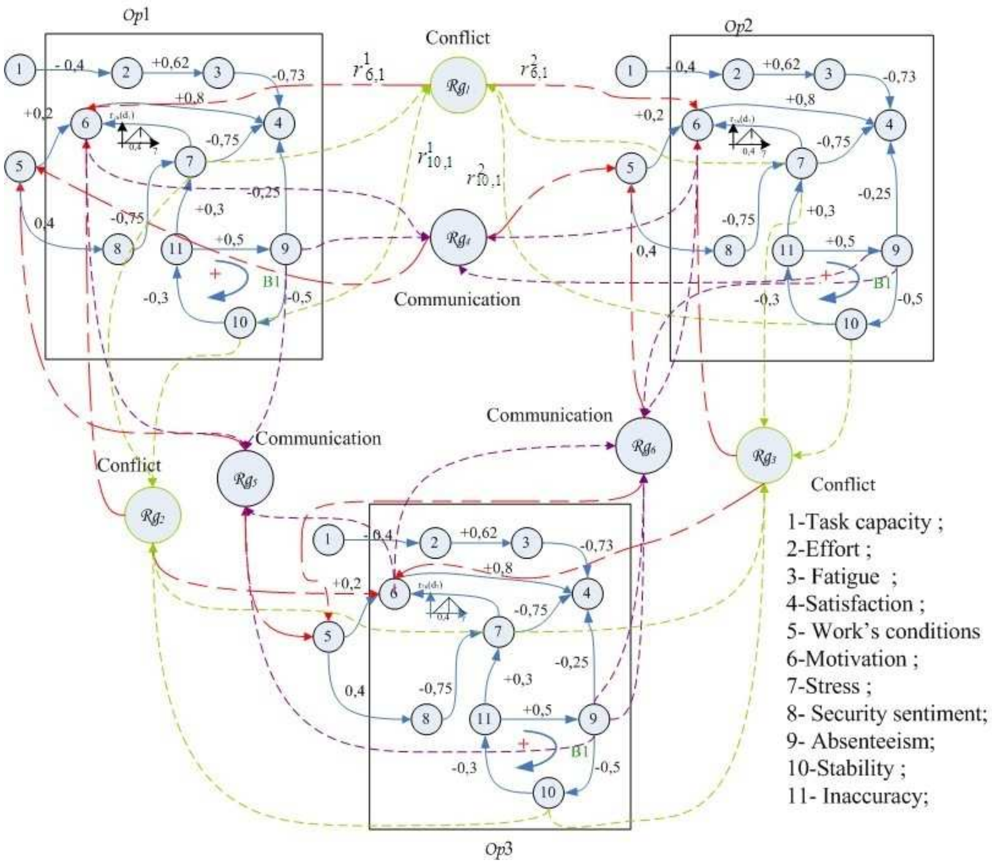

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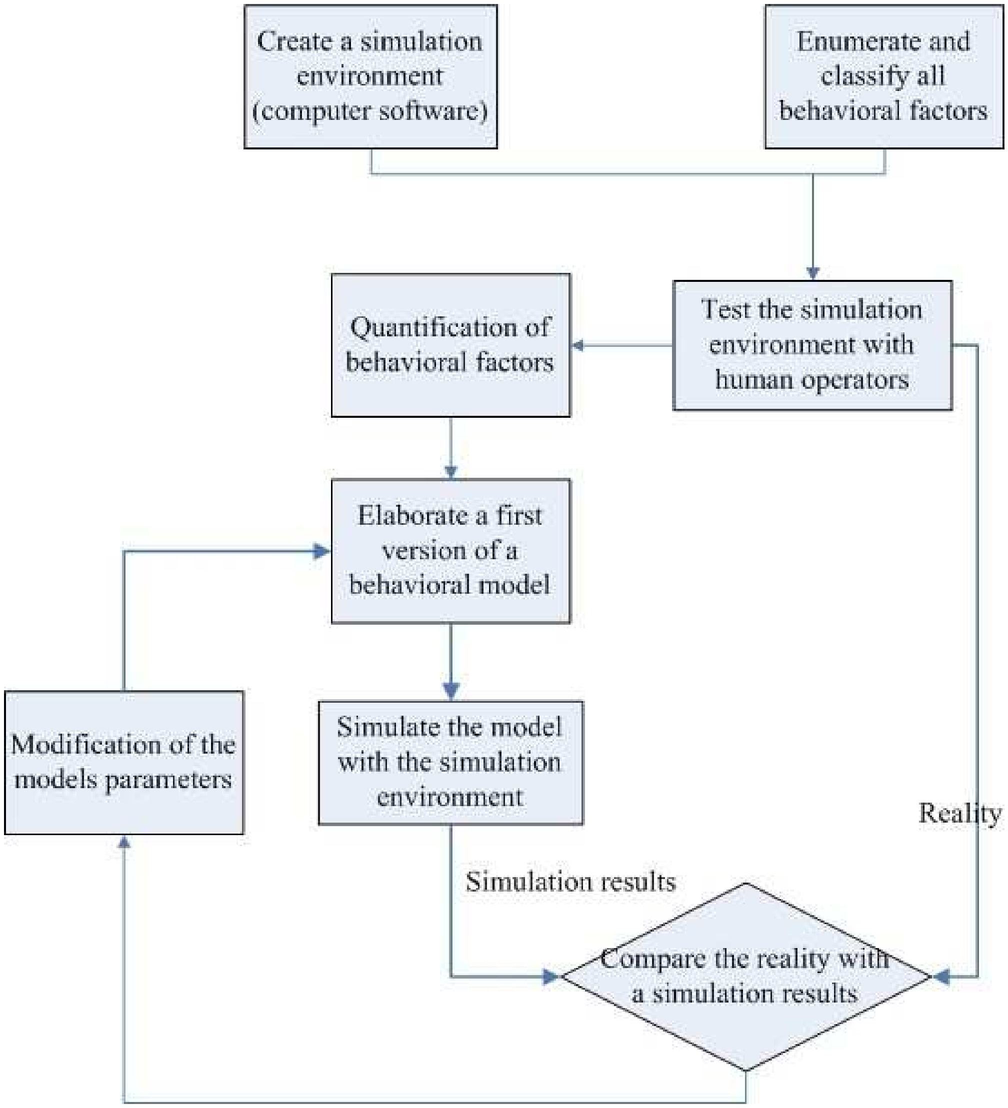

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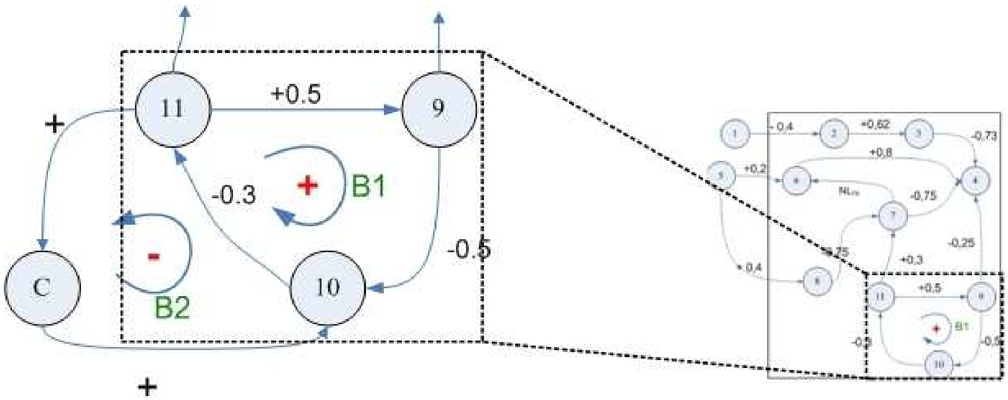

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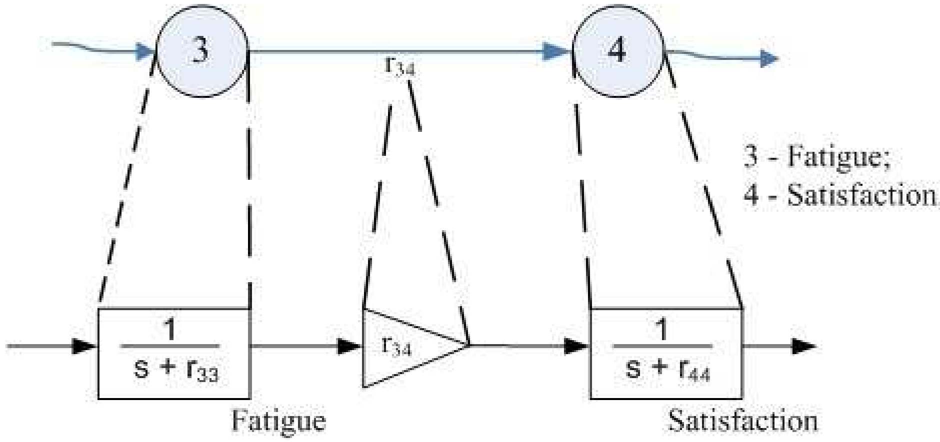

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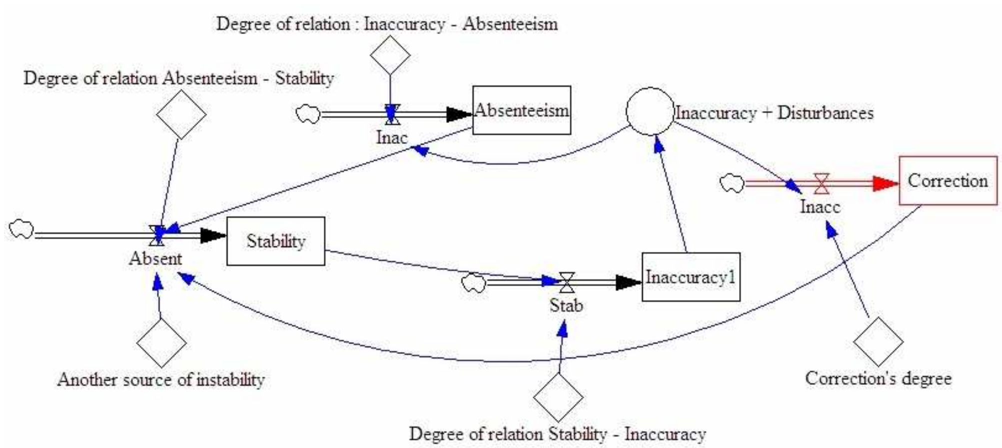

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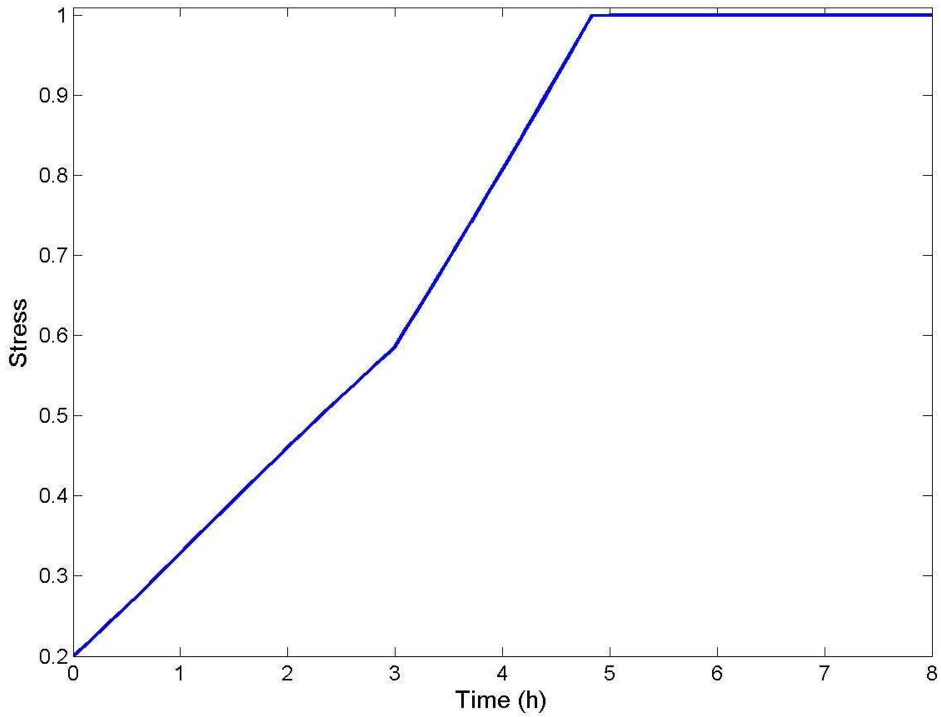

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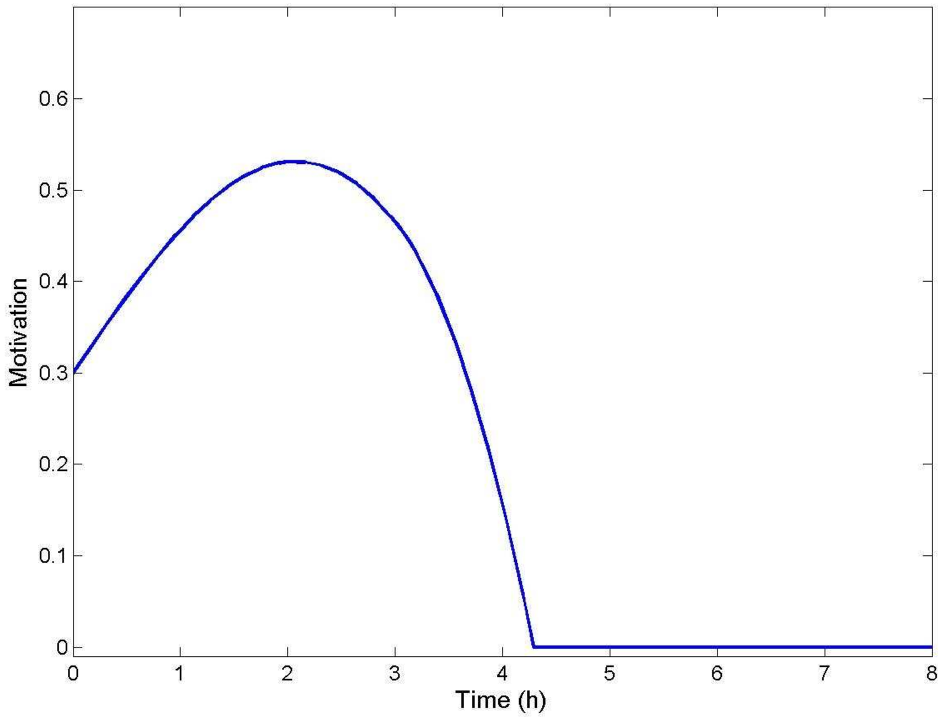

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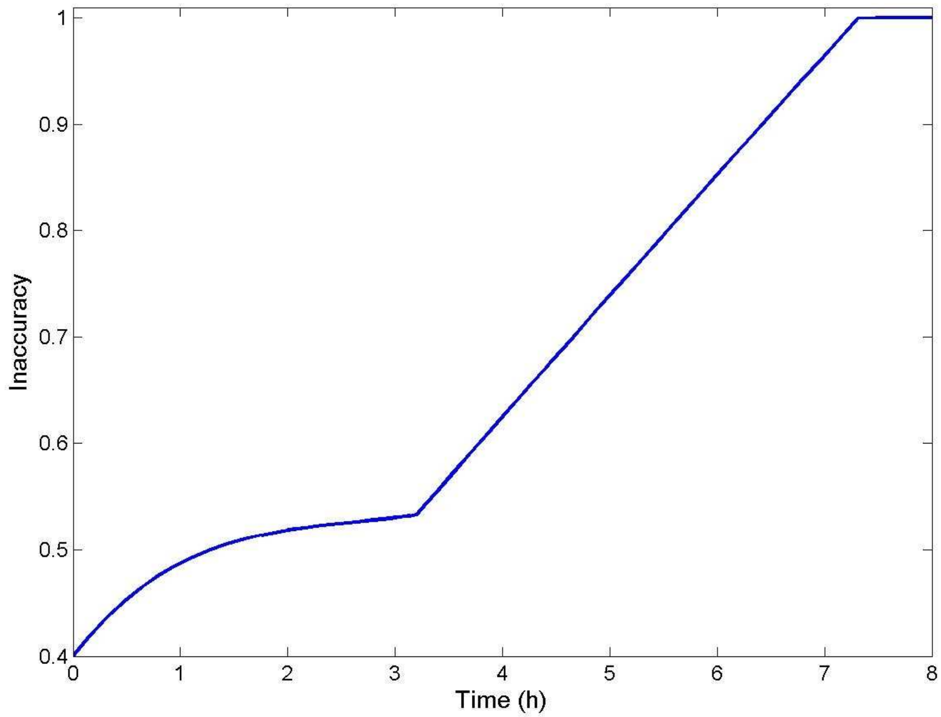

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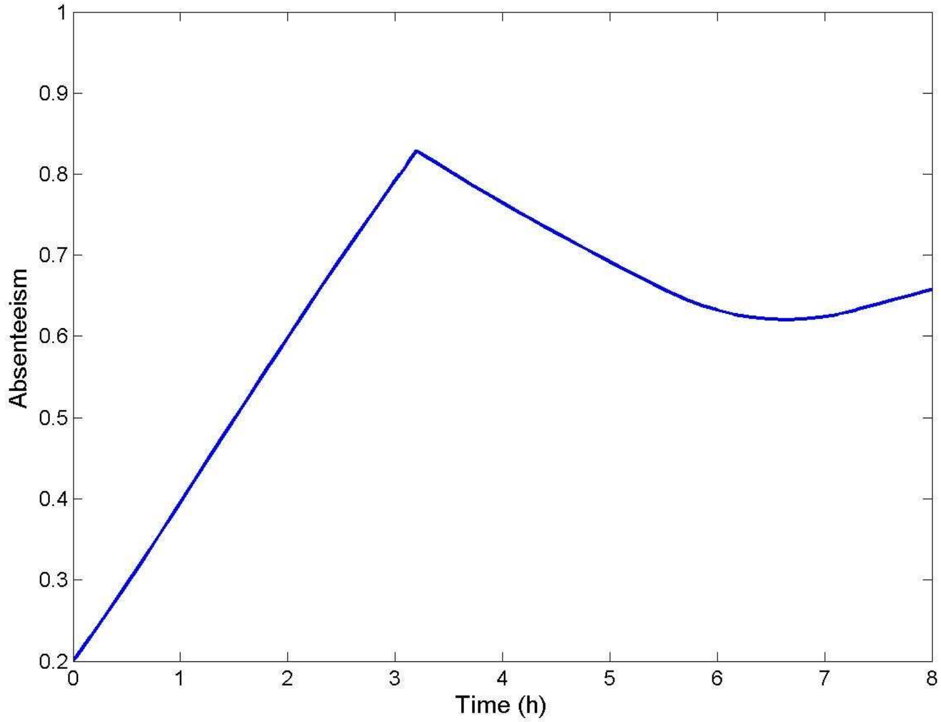

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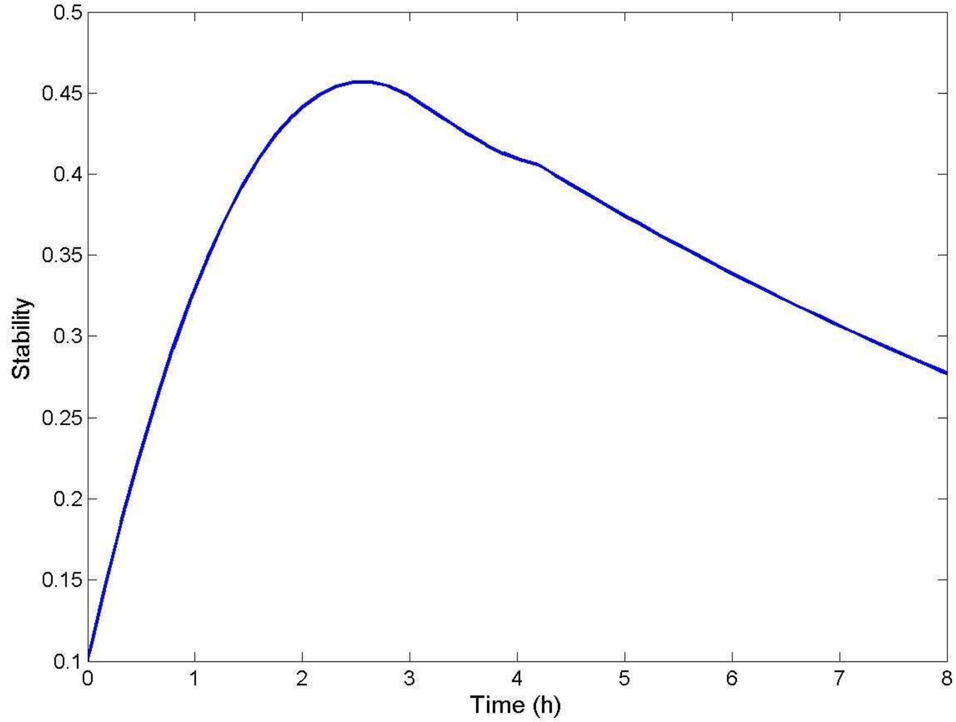

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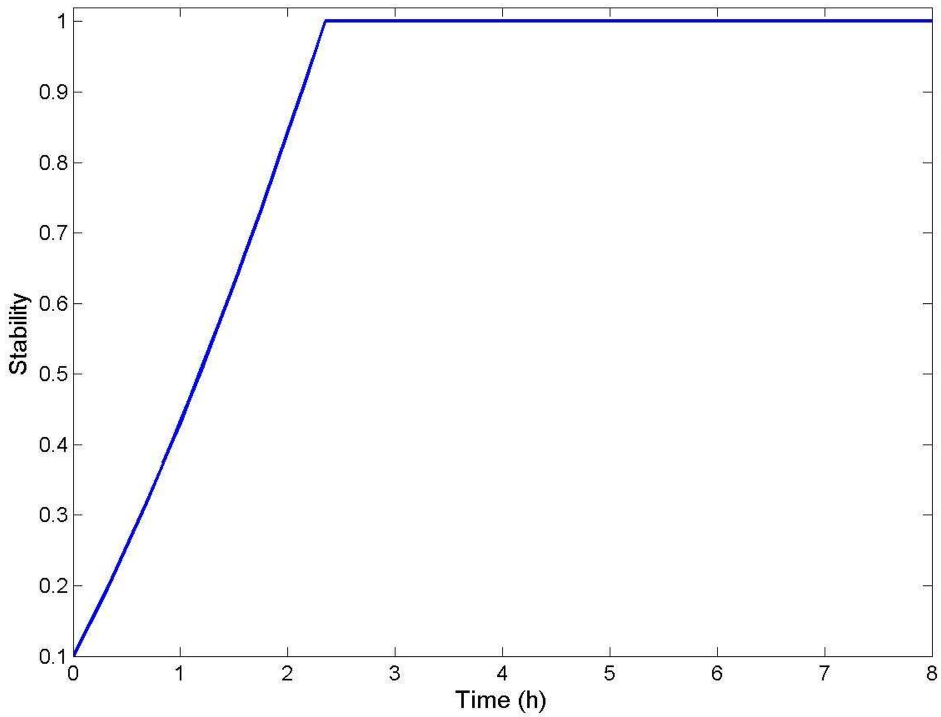

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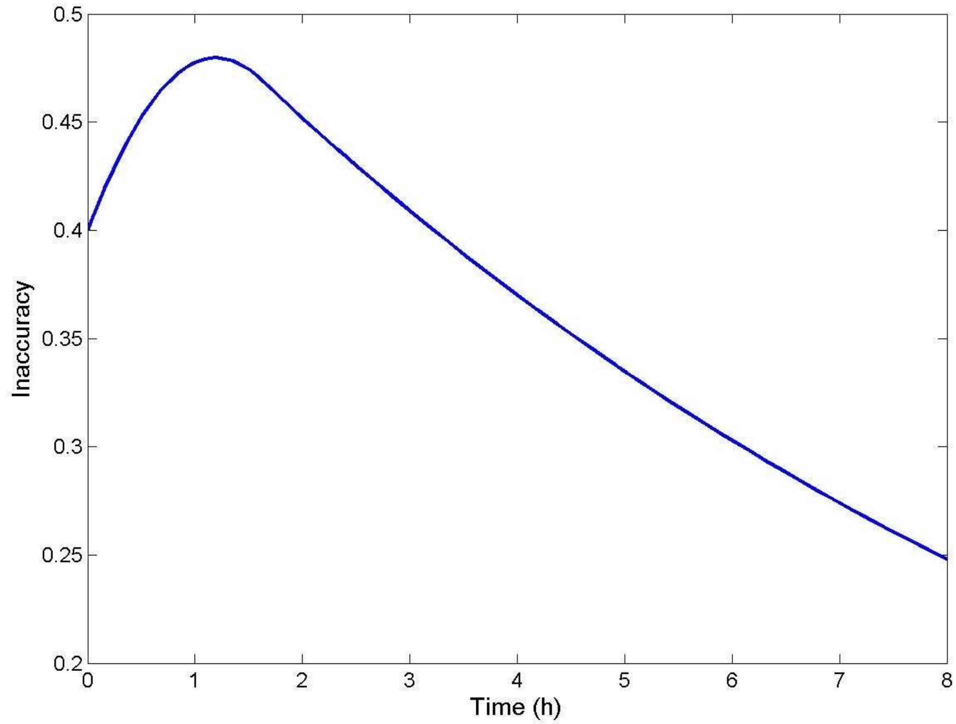

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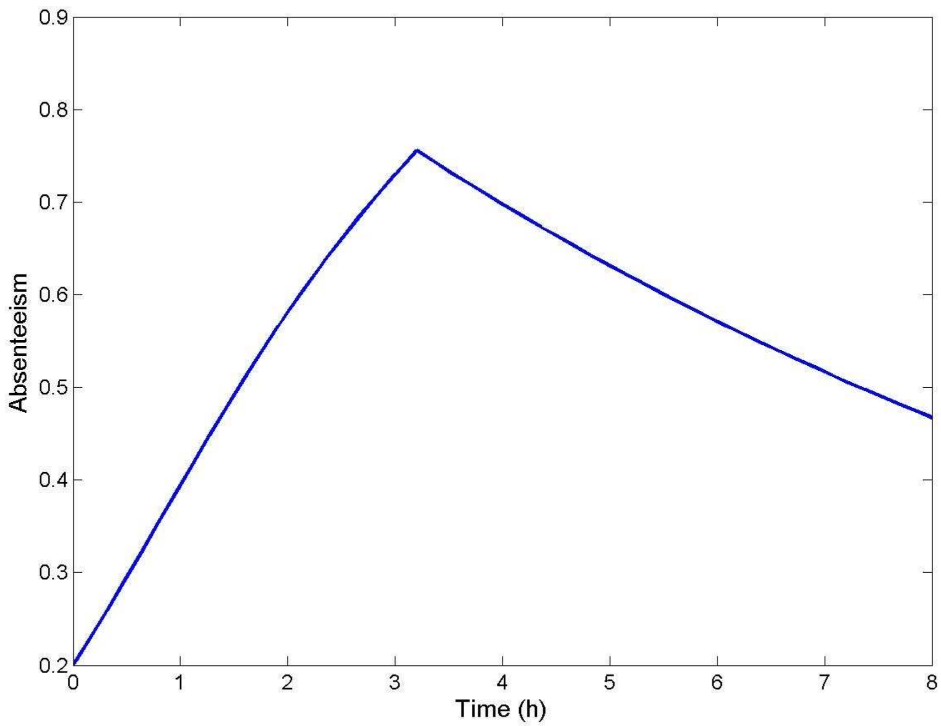

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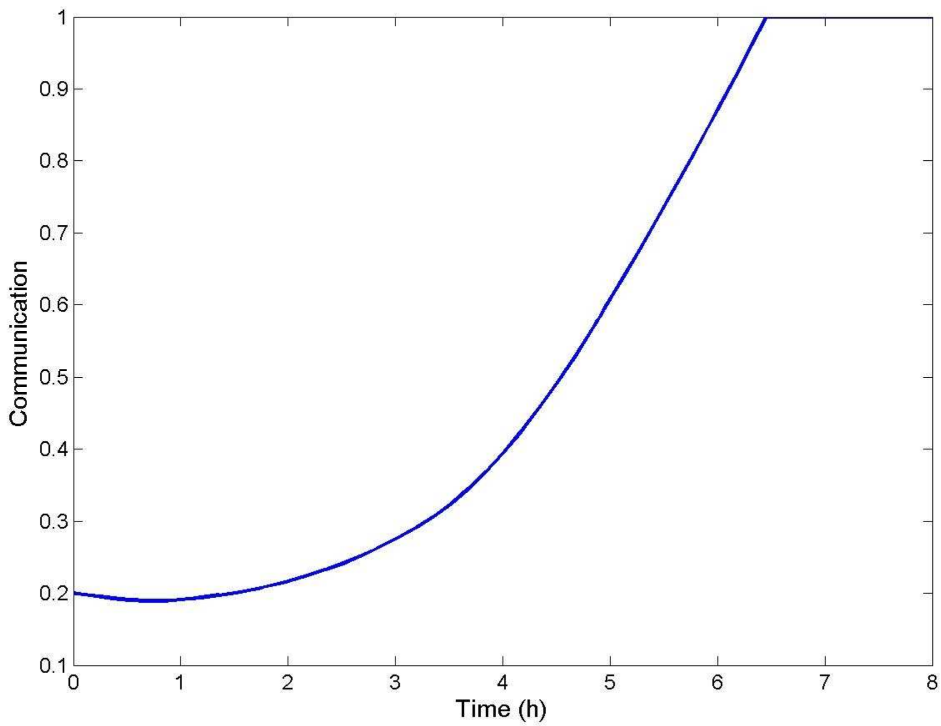

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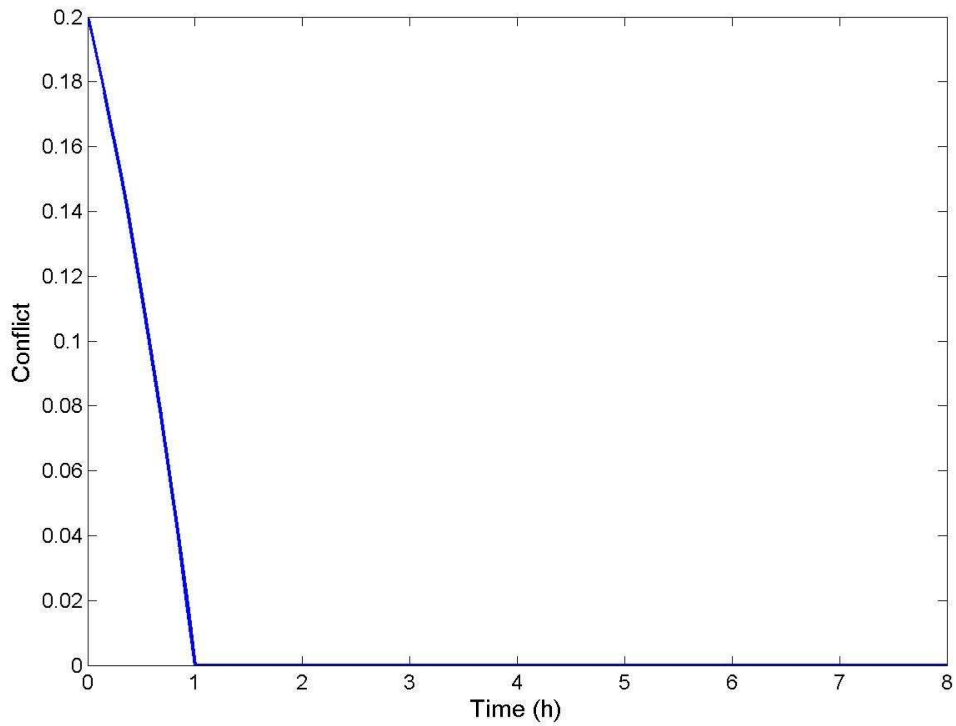

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