A Simulation Model of a Human as a Material Handling Task Performer with a Colored Petri Net Model

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ABSTRACT

In this paper, a framework for a simulation approach to develop a formal representation of control and analysis of human-involved computer integrated manufacturing systems (Hi-CIM) is presented. Important properties of a human material handler within manufacturing systems are discussed and human tasks and errors are identified to build a simulation model. Based on the number of locations where a human operator is required to move to complete a task, material handling tasks are classified into two sets which include an on-the-spot task set and an around-the-system task set. For human errors associated with the task sets, a location error set and an orientation error set are defined. These task sets and error types provide a framework for developing a simulation model of a human material handling task-performing process. To represent the model, a colored Petri net model is used because it provides a good graphical and analytical representation of a system. Human tasks and error types are represented using color tokens. A simulation model of the system can be implemented based on the proposed colored Petri Net model.

Keywords: Formal Model, Colored Petri Net, Human Material Handling Task, Simulation Framework.

1. INTRODUCTION

Computer Integrated Manufacturing (CIM) systems are have played an important role in manufacturing. By running several pieces of computer-controlled equipment in a highly automated way, CIM systems have made contribution toward increased the productivity of manufacturing systems. CNC machines, industrial robots, AGVs, and conveyors are typical pieces of automated pieces of equipment found in CIM systems. Thus, development of intelligent equipment and effective control of a system with a high degree of flexibility has been a critical issue. However, in most manufacturing systems, even highly automated ones, a human operator plays a vital role as both a task-performing agent and a supervisor because a human operator: 1) adds flexibility, 2) is better at perceiving patterns, 3) improvises procedures when congestion occurs, 4) reasons inductively to avoid deadlock and bottlenecks, and 5) exercises judgment concerning critical activities [1]. In addition to these afore mentioned advantages that a human operator brings to a manufacturing system, he or she also brings additional overhead to the control system. Because a human's behavior may be unpredictable and it is also difficult to predefine all human behaviors, human involvement can not be modeled in the traditional deterministic manner. As such, human resources need to be considered as an important component that has distinctive characteristics.

Manufacturing systems where a human operator is involved need sophisticated control schemes since they are typically quite complex. In this research, a term, Human-involved Computer Integrated Manufacturing Systems (Hi-CIM), is used to describe systems where a human operator collaborates with a computer-controlled manufacturing system. This type of a system can be considered as a joint system that consists of mixed components, namely humans and machines, interacting with and affecting each other [2]. Both of technological and psychological aspects play an important role within the joint system and abundant research has been conducted from the human factors' perspective.

As advances in computer technologies have been achieved, domains of simulation application have broadened. Simulation model is used to predict system performance characteristics and it has been considered as a useful tool in various research areas. To develop an effective simulation model, it is critical to understand the fundamental behavior of a system, especially for the design and control of a complex system. As such, it is highly desirable to build a formal model that can describe Human-involved CIM systems. This formal model can provide a base for developing simulation models.

Consideration of a human in a system makes a simulation modeling more complex since it is usually difficult to predefine the behavior of a human. Recently research on incorporating human behavior within simulation models has received attention [2].

To develop a simulation model of a system in which automated equipment and human operators cooperate, it is required to consider the unique properties of human operators and to include these in the simulation model. In this paper, human is considered as a task-performing agent and a task-performing process is represented in terms of task types and human error types associated with each type of task.

For this purpose, a colored Petri net model is adopted because it provides a good graphical and analytical representation of a system. Each human task and error type is represented using color tokens and they are included in the model. A simulation of the system can be implemented based on the colored Petri net model developed.

2. MOTIVATION

A human resource is one of the most important components in manufacturing systems, and integrating humans into a manufacturing control system is a critical aspect of computer integrated manufacturing (CIM). Especially since material handling equipment and tasks play an important role from a control view point [3], and a human operator as a material handler is one of the most vital aspects.

A human material handler can perform a large variety of physical tasks from simple material handling tasks such as loading and unloading materials onto or from machines and moving a part to other material processors to complex tasks that include inspection, packaging, maintenance, etc. A human operator can act as mobile temporary buffer space as well as a task-performing agent. As such, most of parts within a system can be affected by human physical activities in the form of a material handler. Specifically, a human material handler affects part flow within or between systems in various ways.

Besides physical activities, a human operator frequently plays an important role by performing intellectual tasks (planning), which require extremely flexible and intelligent procedures. A human operator improvises procedures when congestion occurs, reasons inductively to avoid deadlock and bottlenecks, manages faults, and exercises judgment concerning critical activities by perceiving patterns. When a computer scheduler issues an improper task command, a human operator can modify the original plan by making several decisions based on system information and know-how gathered from experience.

If all parts are handled only with automated equipment, possible locations of a part are obvious as they are specified by a predetermined shop floor control system. In contrast to automated pieces of material handling equipment, a human material handler can have access to almost every equipment and possibly improper locations. This means that a human can change a part routing in a complicated way even if it is fixed and predefined beforehand.

In addition to the importance of a human material handler, a formal functional characterization of manufacturing systems with a human operator is highly desired since a system controller needs to be developed on the basis of a generic model if it is to be integrated with other systems in a systematic way. A formal approach for developing a control system should be addressed with consideration of both of manufacturing engineering and human factors. A formal shop floor controller that is called Message-based Part State Graph (MPSG) controller was developed at Penn. State [4]. It was developed as a formal model for shop floor control. The MPSG system uses a part view (part-state graph) where the transitions in a manufacturing environment are modeled as a Mealy Machine. Although it provides an efficient controller by enabling a generation of a shop controller in a semi-automatic way, it assumes that all the connected equipment within a shop floor is automated one which is not always a case in reality. Therefore, incorporating a human resource into a system in a formal way is needed for control of real manufacturing systems.

3. RELATED WORK

As the level of automation and computerization increases, characteristics and a scope of human tasks have changed in a significant way. Task analysis within a work system that is primarily related with human-machine interaction has become a critical issue and much research has been conducted from human factors' perspectives. Landau et al. present task analysis from the organizational aspect. [5]. Job analysis as task analysis is presented and several task analysis procedures are reviewed in [6]. The authors suggest that a task is characterized by five elements which include action, object, work aids, location, and time from organizational perspectives. Furthermore, an organizational task is broken down into subtasks that comprise of other subtasks recursively to achieve a given goal [7]. Readers can refer to [8] for task analysis related with several issues such as temporal, structural, and implementation issues. Schilick et al. [9] report a dynamic task network to assess several attributes of a task in work processes within autonomous production cells.

Although a significant amount of research has been conducted on task analysis of a human, researchers have primarily focused, however, on theoretical approaches of human cognitive task analysis and development of an abstract framework for human interaction.

Petri Net models have been widely used in manufacturing systems, especially from control view points. Recently, several researchers have utilized Petri Net models for representing task analysis, work flow management, and human errors [10], [11]. A Petri net model of work flow is proposed by Aalst in [12]. Kontogiannis adopts Colored Petri Nets to model ergonomic tasks using different tokens such as tools, goals, and staffs with a purpose of analyzing adaptation of tasks and plans to system changes [13]. Most works that adopted Petri Net models for simulation of work flow management, work processes and ergonomic task analysis have focused on a description of tasks.

4. HUMAN IN MANUFACTURING SYSYTEMS

Human tasks

As Rasmussen suggests[14], identification of human tasks provides a basis for understating the sources from which human errors originated. This author also classifies task types according to cognitive activities into skill-based, rule-based, and knowledge-base levels. In this research, a different view point is applied so that the categorization fits to describe human material handling tasks in manufacturing systems, and the types of tasks that a human operator can perform in manufacturing systems for producing discrete parts are classified into two sets of tasks. All possible tasks should be included in these sets so that the proposed model can be formal and generic. The classification of human task types is based on the number of locations for a human operator to move to complete a task since material handling tasks mostly consist of geographical activities within a system.

Human tasks are classified into two different sets, namely a set of on-the-spot tasks (OT) and a set of around-the-system tasks (AT). The on-the-spot task set includes tasks that a human operator can complete without a need to move around the system. For example, just "pick a part", "put a part", or "fix a chuck" can be an on-the-spot task. The human operator can perform these kinds of tasks at the fixed position where he is currently working. On the other hand, if a task requires a human to visit at least two places around a system to finish the task, it is classified as an around-the-system task. Tasks such as "move or transport a part to a specific destination location" can be considered as an around-the-system task. Thus, task sets are defined as following;

Tasks(T)=On-the-spot task(OT) ⋃ Around-the-system task(AT)

If a human operator performs a task based on an available task list which is generated by a computerized controller, then there are two cases in which a human operator performs an around-the-system task. The first case is when the controller issues an around-the-system task and a human operator performs the task based on the command from the controller. For the second case, a human operator performs an around-the-system task based on a decision made by him or her. For example, even though just a "pick" task is issued by an automated controller to load a part onto a machine, the human operator may continue the task until he or she finishes "move" and "put" tasks based on human reasoning that the task is a part of a series of "pick", "move", and "put" tasks. In this case, the original intended task is an on-the-spot task, "pick" task, but the performed task would be an around-the-system task. This argument points out that a human operator should not be considered as only a manual laborer that behaves in a deterministic way. Indeed, human task performing activities are closely related with human decision making process.

When a human operator is included in a manufacturing system, it changes several characteristics of the system. When a human picks a part from one equipment to transport it, it cannot be guaranteed that he or she would move to the destination equipment which is exactly in a "waiting" or "idle" state. The human operator may move to a machine or a port, which may not be in "waiting" state, or even other machine that is in a "waiting" state, but not a destination machine. This can cause unexpected system state changes. Unexpected transitions do not occur in automated system that is controlled by computer. It should be noted that this unexpected situation is different from a machine error (e.g., dropped part), which means a system goes to an unexpected situation while performing a predetermined operation.

Human errors

Control depends on the complexity of the system since it needs to recognize systems status and provide proper commands in accordance with varying states of the system. Human errors affect system complexity considerably due to the variety of cases involved. Therefore, a formal approach for defining human errors from a control point of view is highly desired.

As is commonly known, human errors have significant influence on system reliability, sometimes more than the technological ones[15]. Much research has been conducted to classify human errors and to develop mechanisms for reduction of the human errors, especially from the human factors point of view[16], [17]. Reason [18] states that when the intended results are not attained by human activities they are defined as human errors and that no universal agreed classification of human errors exits. Park [17] suggests an approach by considering human errors from two different points of view, prospective and retrospective. Extensive review of human error identification techniques for high risk systems such as nuclear power plants, chemical plants, etc. is presented in [19]. However, human errors from the manufacturing control point of view have not received much attention.

As an important aspect of human errors in a manufacturing system context, human errors associated with temporal characteristics need to be carefully addressed while considering the control system and the non-determinism of a human operator in performing tasks in manufacturing systems. A temporal aspect of human errors is related with the time a human requires to adjust to system requirements or changes, especially involving human cognitive activities [20], [21]. A human operator within a manufacturing system may perform a task in several different ways including different amount of time spent to complete a task. For example, when a command of "put a part in a certain machine" is issued by a computerized controller, and a human operator chooses to perform the task, the human operator may delay in completing it. Whether this situation should be considered as a human error or not depends on how a controller cooperates with a human operator. If the controller can continue to run a system by performing an alternative task without a need to wait, and it issues other proper commands for the system running, the delay in performing the human task may not be a human error. Since there are usually several parts being processed in a system, more than one available task usually exists, which means the controller can issue another task command to process other parts in a system while the operator is still performing the "put a part in a certain machine" task. However, if the controller should wait and stop subsequent operations until a task is correctly completed by a human operator, it can be considered as one of potential sources of a human error. Therefore, time-spending of the operator is not considered as an error until a system stops and a correct response from an operator is required to run the system.

For computerized equipment which is runs in a deterministic manner, if a task is executed by a robot and it takes more time to complete than a predefined for the task, this is considered as a robot error. This exemplar situation shows that human errors from a temporal aspect should be addressed in context of the system under consideration, in this case a shop floor system.

As such, when a system stops and waits for a recovery action, there are two possible error sources, one is an equipment error and the other is a human error. An error source is identified by checking states of equipments that are involved in the task which caused a halt of a system. For example, when a machine can not process a part due to a set-up problem, checking the previous state of the part can determine which state it was in a part-state graph for the part. A part-state graph specifies state changes of a part whenever it is processed or handled in a system.

In this paper, two categories of human material handling errors are considered; orientation errors and location errors. This classification approach is generic enough to include any human physical errors during material handling activities. These errors can occur while a human operator performs tasks. Orientation errors can occur when a human operator performs tasks associated with loading or unloading a part. They are mostly related with on-the-spot tasks. It can be assumed that orientation errors can be identified and corrected locally by the human operator. Thus, this type of error can happen at most once. Location errors are caused while a human performs around-the-system tasks that require a human operator to move to other locations from his or her current one. The human will need to find a correct destination point and move to the location to finish an around-the-system task. Unlike orientation errors, a human operator can make multiple numbers of location errors since the destination point depends on an around-the-system task that he or she performs. However, the maximum number of location errors for a task is finite because the number of available equipment locations related with a task is finite and the human operator is assumed to be intelligent enough to recognize the location which has been tried before.

In other words, a human operator is assumed to try to find a correct destination among the unvisited locations. Thus, two types of errors can be defined as follows:

Error set (E) = Orientation Error(OE) $\cup$ Location Error (LE)

With these classifications for tasks and errors, task-performing activities related with material handling processes of a human operator can be modeled.

Whether an error is caused on the way a human operator performs an on-the-spot task or an around-the-system task is also determined by checking a part state that the operator handles. A part state in the system provides information about a human error type. Every part in a system is in one of the states that are specified in the part-state graph and the status of the part is updated at each node in the graph when it enters a node with electronic devices such as a bar code system. Therefore, it is always possible to keep track of a part in the system up to the current state. Every node is connected with a message and each message is related with a task. Hence, a task type that an operator has performed is determined by checking the flow path of the part.

5. SIMULATION FRAMEWORK

Conventional Petri-net model

In this research, different types of human errors are defined and they are used to represent a human state in a process of material handling task-performing. Figure 1 shows a conventional Petri Net model for human task-performing processes. Although an orientation error can be made only once, location errors can be made in several different ways. The proposed model shown in Figure 1 incorporates multiple sources of errors by providing for multiple error tokens at place p_1. If transition t_1 is to be enabled then there must exist a task token at place p_2 and at least one error token at place p_1. Transition t_1 represents an event when an error is made. Thus, for an error to be made there should be a task at hand and a source of error. Transition t_2 represents a performance of a task and requires an existence of a task for it to be enabled. If a task token reaches p_3 and not all error tokens have been eliminated then transition t_4 facilitates the removal of the remaining error tokens. Since all error tokens are removed, the task completion transition t_3 is fired leading the task token to its final place p_4. To describe a task-performing process for each task type, the Petri net models as shown in Figure 1 need to be applied separately in accordance with a task type, which may be inefficient.

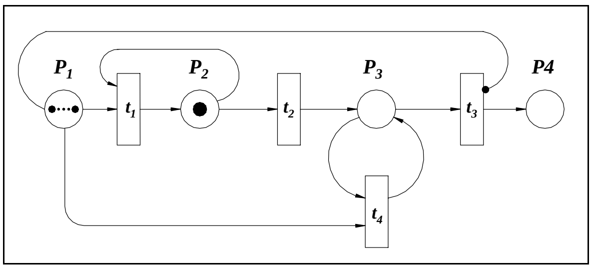

Figure 1 Petri net model for task-performing process

Colored Petri-net model

Colored Petri net (CPN) is considered as a useful modeling tool to describe complex systems in a manageable way, [22],[23]. In particular, since it allows multiple different types of colored tokens to be accommodated, it has more dominant capability of modeling a complex system in an effective way. Color tokens can have various data values, which enables a powerful representation of a system in a compact way [24].

By defining a color token according to task type, two separate models can be integrated in one colored Petri net model shown in Figure 2. To develop a model which incorporates both of types of errors, we introduce several variables which keep track the number of times each of the error types have occurred (*i*,*j*) and the task description *x*. We associate these variables with a task token in the model.

In the initial marking, there always exits a task token in the place p_1, regardless of a task type. However, the number of tokens in the place p_2 depends on a task type. If an on-the-spot tasks is to be performed by a human operator, only one token is placed in place p_3 and no tokens in place p_2. For an around-the-system task, there are as many tokens as the number of possible wrong locations for the task in place p_2. For an orientation error to occur there must exit an orientation error token at place p_3 and a task token at place p_1. However, the transition is inhibited by the presence of a task token at place p_4. Place p_4 corresponds to a place reached after a task is performed by a human operator. Once transition t_3 is fired, it changes a color by increasing the number of occurrences of orientation errors by one. The task token returns to place p_1 with different colors.

For a location error to occur there should be at least one or more location error tokens at place p_2 and a task token at p_1. The location error transition, represented by t_2, is also similarly inhibited as the orientation error transition t_3 is by the presence of a task token at place p_4. Once t_2 is fired it changes the color of the task token by increasing the number of occurrences of location errors by one. After firing t_2 the task token returns to place p_1. For the task to be performed, transition t_1 requires the presence of a task token at place p_1. Upon firing, the task token reaches place p_4. Firing transition t_4 moves the task token to completion place p_5. However, transition t_4 is inhibited by any error tokens still present at either p_2 or p_3. These error tokens are removed by firing transition t_5 and t_6. As explained above, once all error tokens are eliminated, the task token is moved to p_5, which means the completion of the task.

To coordinate these two types of errors, it must be realized that an operator can make an orientation error only once he or she has located the correct destination. Also the operator can make location errors only if he or she still has not already made an orientation error. Thus, transition t_2 of the combined colored Petri Net model has an extra prerequisite of the presence of an orientation error token. And once transition t_2 is fired the orientation error token is returned to place p_3.

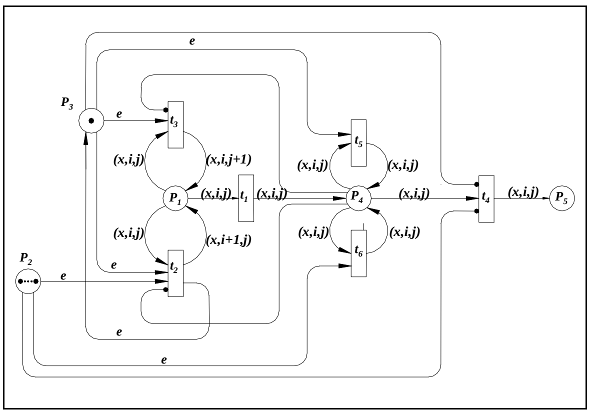

Figure 2 Colored Petri net model of task performing process

6. CONCLUSION

A formal model which describes the impact and changes of a human-involved system can provide a basic understanding of generic issues related with integrating a human operator into computer controlled manufacturing systems. This paper presents the first step toward the development of a formal model for control and analysis of Human-involved Computer Integrated Manufacturing Systems (Hi-CIMS) by describing fundamental human task-performing activities.

Human tasks are divided into two different sets which include an on-the-spot task set and an around-the-system task set. This categorization is attributed to the fact that human material handling operations are closely related with locations of an operator. Human errors are also classified into two different sets, an orientation error set and a location error set associated with the task types.

A Petri Net model is presented to describe a human material handling task-performing process. To incorporate two different types of human errors into one model, a colored Petri Net model is proposed. It can be used to identify a state of a human during task-performing process by providing a type of a task and the number of occurrence of error types.

Since it is mostly straightforward to incorporate a formally established model into other systems, the presented human task-performing process model is expected to be integrated to computer controlled systems. Furthermore, a formal model which describes a human-involved system can provide basic understanding of generic issues related to integrating a human operator into computer controlled systems.

As future work, human decision making processes need to be addressed. They are important since the types of human tasks and errors depend on a decision made by an operator. Based on a human decision, a task type is determined and accordingly human errors would be caused.

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