A Multi-Agent Based Approach to Dynamic Scheduling of Machines and Automated Guided Vehicles (AGV) in Manufacturing Systems by Considering AGV Breakdowns

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Abstract

In a competitive business environment, producing goods on time plays a very important role. In addition to regular control complexities in manufacturing environments, some unforeseen technical problems may affect the efficiency of production. The breakdown of automated guided vehicles (AGV) during manufacturing is one of these problems. This problem generally requires an instantaneous solution while the system is operating. However, traditional production control systems and algorithms handle this kind of problem centrally and usually are not able to provide effective solutions promptly. This paper proposes a multi-agent based scheduling approach for AGVs and machines within a manufacturing system where the AGV breakdowns are considered. After implementation, this approach is designed to work under a real-time manufacturing environment and feasible schedules are supposed to emerge from negotiation/bidding mechanisms between agents.

Introduction

Producing goods on time plays a very important role in manufacturing control and planning. Production plans and schedules are generally interrupted with unexpected events around or within the system. These problems may affect the efficiency of production planning or they may collapse all the plans of operations. The breakdown of automated guided vehicles (AGV) in flexible manufacturing systems is one of those problems. AGV systems are industrial transportation systems used in various industrial contexts: container terminals, part transportation in heavy industry, and manufacturing systems [1-3]. They have considerable functionality in manufacturing systems and container terminals. They may be the source of unexpected events within a manufacturing or logistics system.

The operational decisions of AGVs especially attracted researchers to design and implement cost-effective operating decisions. However, the complexity of the problem has led the researchers to use distributed methods other than central optimization approaches. Multi-agent-based systems, a newly maturing area of distributed artificial intelligence, provide effective mechanisms for the management of such dynamic operations in manufacturing environments.

As is expected from a fairly young area of research, there is not yet an universal consensus on the definition of an agent [4]. However, the Wooldridge and Jennings' definition is increasingly adopted in this field: "An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives" [5]. An agent is a component that can exhibit reasoning behavior under both proactive (goal-directed) and reactive (event-driven) stimuli. When an agent is instantiated, it will wait until it is given a goal to achieve or experiences an event that requires a response [6].

Some of the authors of this paper have previously addressed a multi-agent based simultaneous AGV and machine scheduling approximation and tested it on test-bed problems [7]. Multi-agent based approximation has proven its success in dynamic and volatile business environments. However, AGV breakdown occurrences are not considered in their previous studies. The AGVs are assumed as being operational without breaking down throughout the entire manufacturing process.

In this paper, the breakdowns of AGVs are considered to extend the scope of the previous studies. The intention of this study is to get closer to real manufacturing environments. This paper is organized as follows: a brief literature survey about the studies that consider AGV breakdown, the multi-agent based design of the proposed problem, the algorithms that the agent types uses under AGV breakdown condition and a summary with future research possibilities.

Literature Review

The studies about AGV control have a wide scope in the literature and range from traffic control on the AGV paths to AGV deadlock prevention [8, 9]. The application areas range from manufacturing floors to container terminals [7, 10]. The solution approximation for AGV control is also encompasses a wide research domain, from integer programming to meta-heuristics and from Petri-net to multi-agent systems [7, 8, 10-13]. However, the literature review in this paper focuses on the AGV breakdown during the real-time manufacturing operations. To the authors' knowledge, there are few studies in this area.

AGV failures are neglected in most literature on automated transportation systems. According to Mark Ebben (2001), when an AGV break downs, it may stop any other AGVs. There are two options when the AGV breaks down: it can be fixed on the system or removed from the system to the repair section. Choice depends on repair time [14].

Taghaboni and Tanchoco (1995) noted that routing flexibility allows a quick recovery to breakdowns and other disruptive events, but their study does not examine failures. According to their study, failures can be neglected in AGV systems when the AGV workload is low and failures can be resolved quickly [15].

Another study about AGV control that considers disturbances is by Badr et al. (2010). They presented five steps to clarify the disturbance handling during dynamic scheduling: disturbance detection, disturbance analysis, action selecting, action announcement, and schedule repair [16].

Merdan et al. (2013) proposed an approximation for conveyor and machine failures in workflow scheduling by using a multi-agent system. They tested dispatching rules in combination with the all re-routing re-scheduling policies under machine and conveyor failures. They then ranked the rules based on their performance results at the simulation [17].

Design of AGV Resource Agent during Breakdown

In this study, AGV breakdown situation is modeled under a multi-agent based system approach. The proposed is designed by using the Prometheus methodology that defines a detailed process for specifying, designing, implementing, and testing/debugging agent-oriented software systems. This methodology is developed for specifying and designing agent-oriented software systems, and it is general purpose in that it is not tied to any specific software platform. Prometheus distinguishes itself from other methods by supporting the development of intelligent agents, providing "start-to-end" support, evolving out of practical industrial and pedagogical experience, being used in both industry and academia, and, above all, being detailed and complete [4]. Figure 1 presents the phases of Prometheus design methodology.

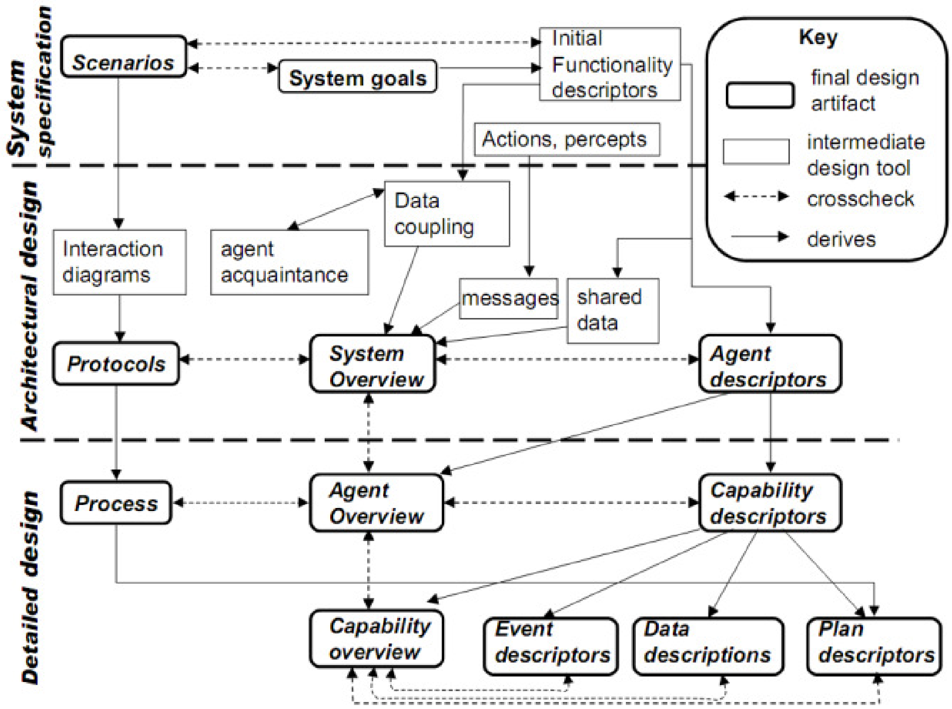

Figure 1. The phases of Prometheus methodology [4]

System Specification

The agent types are decided and designed through this design methodology stages. The following are the agent types in the proposed system.

Machine Resource Agent, Machine Scheduler Agents, AGV Resource Agent, AGV Scheduler Agents, and Operation Agent

In the system specification stage of Prometheus, negotiations between agent types, system goals, agent roles in the system, and scenarios are identified. Figure 2 shows the system specification stage of Prometheus methodology. There are four main roles in the system: AGV management, machine management, system management, and negotiation management.

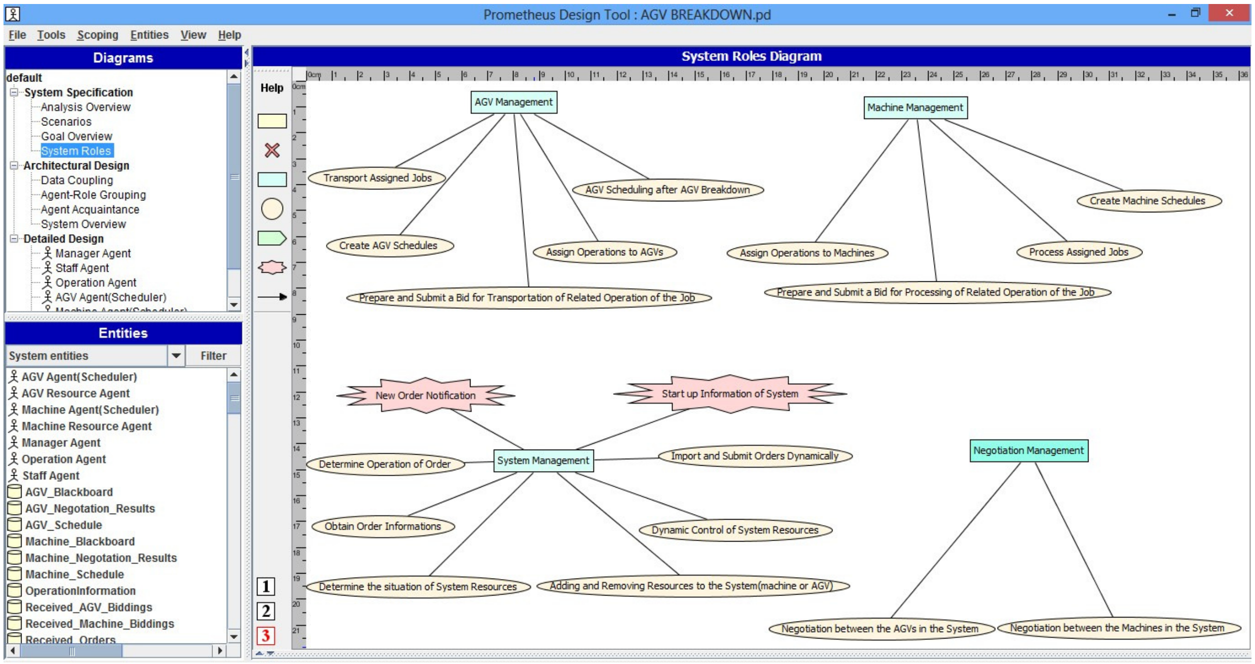

Figure 2. System roles in PDT

This study focuses on AGV management role in system specification stage. The circles in Figure 2 show the goals of system elements. One of the goals of the AGV management role of the proposed system is "AGV Scheduling after AGV Breakdown" (see Figure 2).

The subgoal is also designed in the system specification stage. Three subgoals of the "AGV Scheduling after AGV Breakdown" goal are given in Figure 3:

1. AGV that is loaded and has a task in its blackboard
2. AGV that is free and has a task in its blackboard
3, AGV that is loaded and has no task in its blackboard

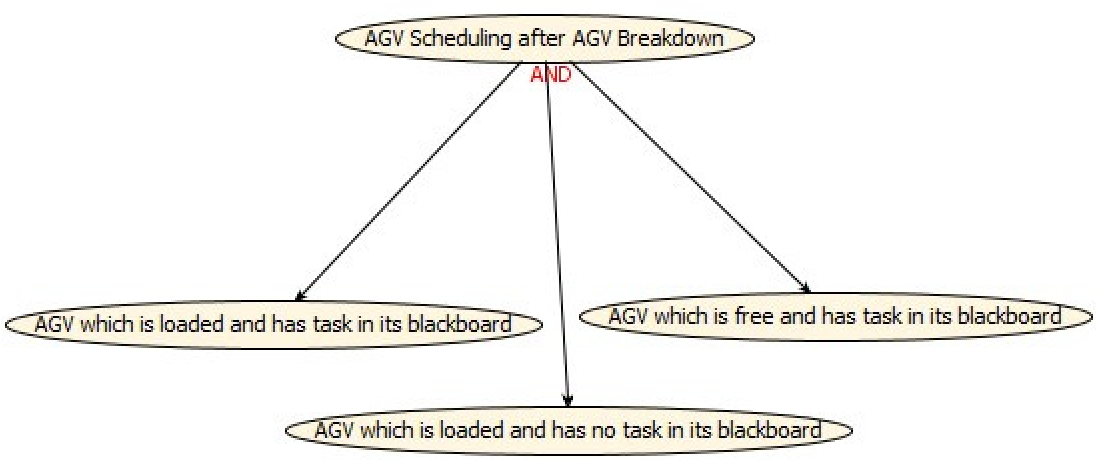

Figure 3. Subgoals of "AGV Scheduling after AGV Breakdown" goal

Architectural Design

The negotiation protocols between agent types are designed in this stage of Prometheus methodology. A system overview diagram is given in Figure 4. The AGV scheduler agent negotiates with operation agents in order to find real-time operation transportation and processing schedule.

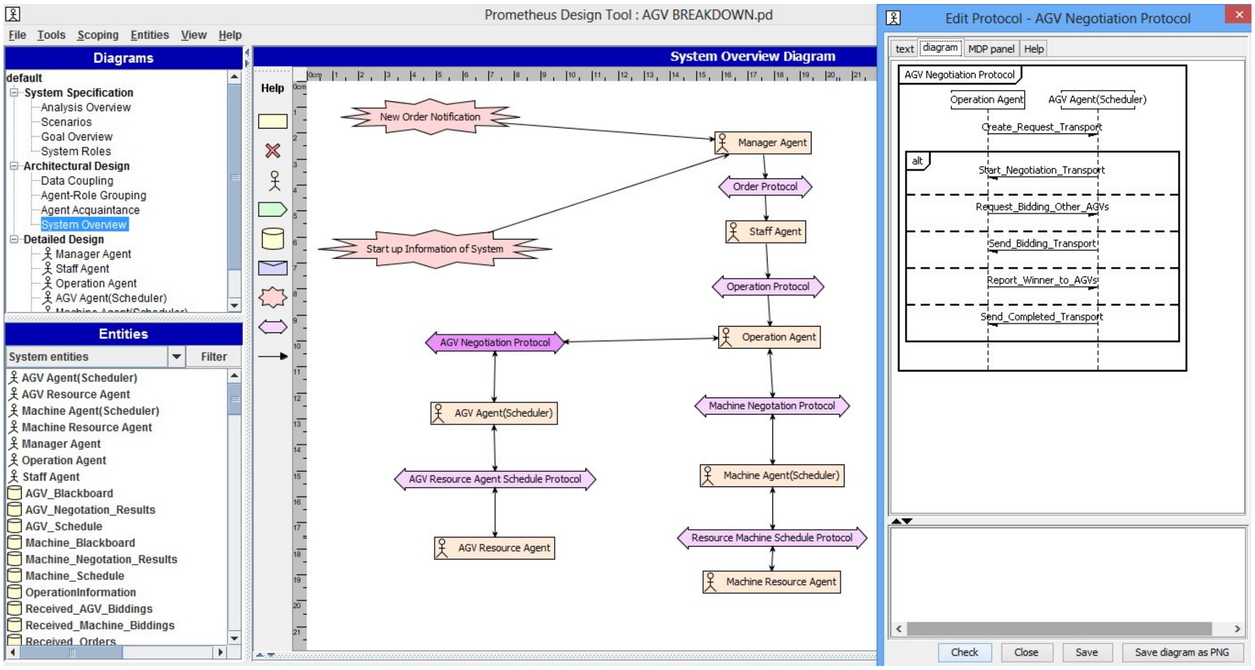

Figure 4. System overview

Figure 4 also shows an example negotiation protocol between operation agents and scheduler agents. When an operation agent enters to proposed multi-agent based system then it calls for proposals for the machine and scheduler agent that are available in the system. When the order agent finds a proper machine agent to be processed, it then calls for a proposal to a scheduler agent to be transported to the machine.

Detailed Design

In detailed design stage, the capabilities of the scheduler agent type are defined by the breakdown condition.

A resource agent would be in any following states in a flexible manufacturing system:

1. Idle and ready
2. Transportation of an operation
3. Deadheading trip (going to take a job from machine)

While AGV resource agent is operating, it can break down. The AGV resource agent has an attribute of working status of either “in working condition” or “broken down.” Status changes to “broken down” from “in working condition” when it breaks down.

In all three states, the resource agent updates its status attribute. The resource agent sends the breakdown information to the scheduler agent after updating its attribute. Figure 5 shows the detailed design for the resource agent.

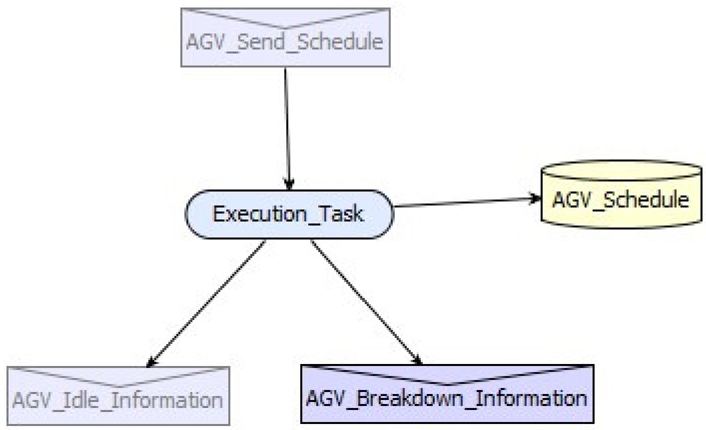

Figure 5: Detailed design of AGV resource agent

Figure 6 shows the negotiation protocol of resource agent and scheduler agents.

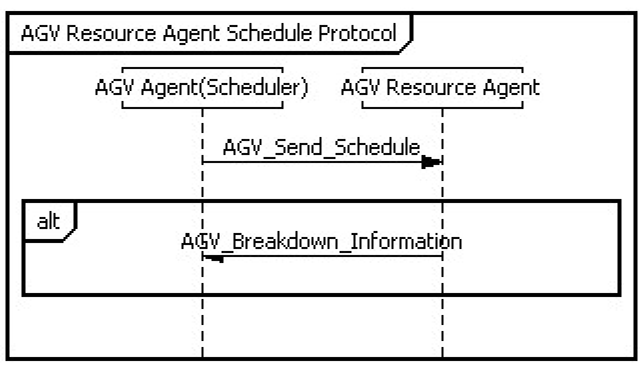

Figure 6. Negotiation protocol of AGV resource agent and AGV scheduler agent

When the scheduler agent receives the breakdown message, it reasons in one of three ways by controlling the blackboard. Figure 7 shows a detailed design for the scheduler agent.

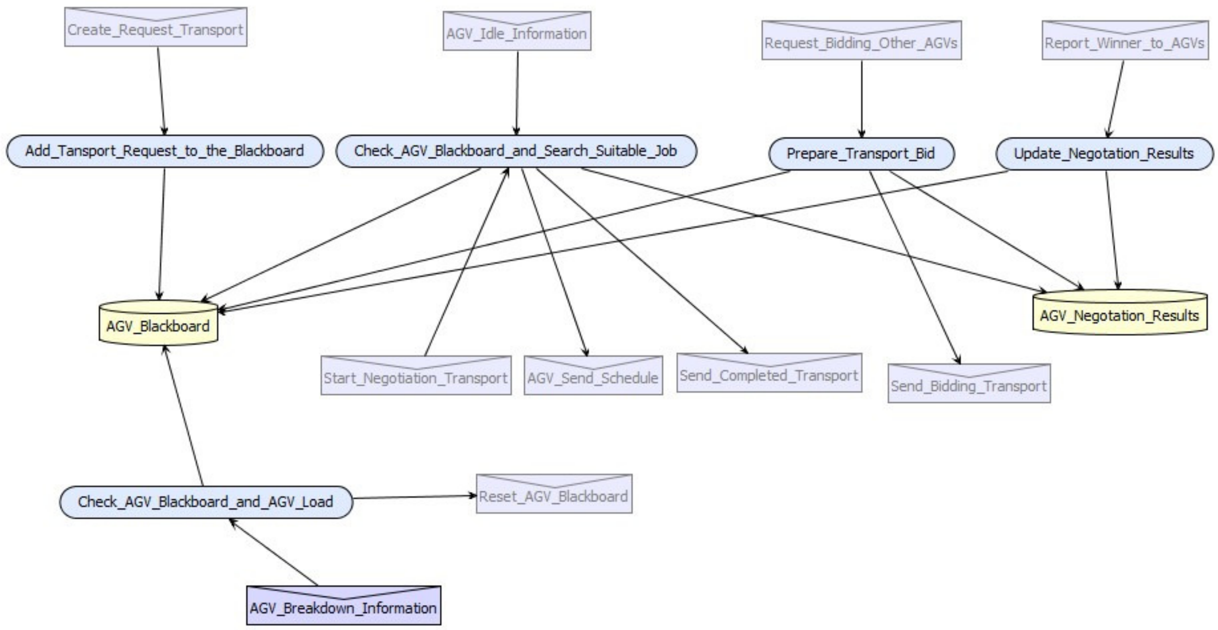

Figure 7. AGV scheduler agent with details

When the scheduler agent takes the breakdown message from the resource agent, it sends the message to the operation agents in its blackboard, which then start a new negotiation with the scheduler agents in order to be transported. Figure 8 shows the standard negotiation protocol between operation and scheduler agent.

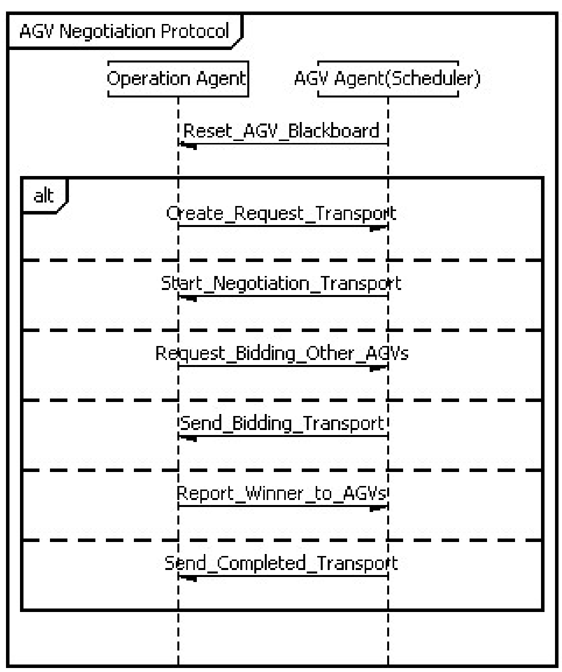

Figure 8. Negotiation of operation agent and AGV scheduler agents

Algorithm for AGV Breakdown Condition

This section details the scheduler agent's decision-making. The operation agent informs the scheduler agents when the AGV broke down. The scheduler agent then assesses the coordination information inside the messages and performs a reward.

Scheduler agents consider the proposal of machine operations broken-down AGV according to the equation 1. After the AGV breaks down and the blackboard resets, the current time must be equal to the earliest pickup time of operation *i*:

$$t = EPT_i, \text{ so } ELT_i = \{t + \Delta t(CL, AGVBDP_i)\}, \qquad i = 1 \ldots n \tag{1}$$

In the first equation, ELT_i denotes earliest loading time of operation *i*, CL is current location of AGV resource agent, *AGVBDP* is AGV's breakdown point for operation *i*, t is current time, Δt(.,.) is the required time between two locations, and EPT_i is the earliest pickup time of operation *i*.

Scheduler agents evaluate the proposal according to following equation:

$$ELT_i = \begin{cases} t + \Delta t(CL, PCP_i), & t > EPT_i, \\ t + \max\{\Delta t(CL, PCP_i), (EPT_i - t)\}, & t \le EPT_i, \end{cases} \quad , \qquad i = 1 \ldots n \tag{2}$$

In the second equation, ELT_i denotes earliest loading time of operation *i*, *CL* is current location of AGV resource agent, PCP_i is pick up point of operation *i*, t is current time, Δt(.,.) is the required time between two locations and EPT_i is the earliest pickup time of operation *i*.

Then, an operation is selected from the AGV blackboard by using the following equation:

$$ELT_s = \min\{ ELT_i \}, \qquad i=1\ldots n \tag{3}$$

The scheduler agent then proposes a time to respective operation agents by adding *ELTs* to the related loaded trip time as shown in equation 4:

$$PR = ELT_s + \Delta t(PCP_s, DP_s) \tag{4}$$

After the start of the negotiations, operation agents call to all scheduler agents to submit a proposal. This plan first checks whether an operation has already been rewarded. If there is not a rewarded operation, then it prepares an offer. When preparing a proposal, the scheduler agent finds the operation that has the minimum *ELT* using equations 5 and 6, where *EFT* and *NL* denotes earliest free time and the next location of the AGV resource agent, respectively.

$$ELT_i = \begin{cases} EFT + \Delta t(NL, PCP_i), & EFT > EPT \\ EFT + \max\{\Delta t(NL, PCP_i), (EPT_i - EFT)\}, & EFT \le EPT \end{cases} \qquad i = 1 \ldots n \tag{5}$$

$$ELT_s = \min \{ELT_i\}, \; i=1\ldots n \tag{6}$$

If the operation in the current negotiation matches the selected operation in the scheduler agent's blackboard belief set, the scheduler agent proposes operations by adding *ELTs* the related loaded trip time, as in equation 7:

$$PR=ELT_s + \Delta t(PCP_s, DP_s) \tag{7}$$

Conclusion and Future Research

Resources that are used in flexible manufacturing systems pose unforeseen technical problems in addition to regular control and maintenance complexities. The breakdown of AGVs during real-time manufacturing affects many related schedules of operations and machines. This problem generally requires an instantaneous solution while the system is operating. The proposed multi-agent based design is developed in order to solve these complexities during the manufacturing process. The design uses the capabilities of multi-agent systems in order to solve real-time scheduling complexities. Feasible and effective schedules are supposed to be emerged from negotiation/bidding mechanisms between agents. Future research directions include

- Implementing the proposed design on a multi-agent programming language.
- Finding test-bed studies in order to compare the results of multi-agent systems with other approximations.
- Developing multi-agent based simulation models in order to test the effectiveness of the proposed model

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