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博　士　論　文　概　要

論　文　題　目

Agent-based Material Transportation Scheduling of AGV Systems and Its Manufacturing Applications

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For years, manufacturing systems consist of cellular or process layouts have proven to be flexible and efficient in enabling mass customization. Nevertheless, the impacts of market and supply-chain globalizations have led not only to the increasingly demanding customers but also stiffer competition and fluctuating market. In order to successfully adapt into such scenarios, an advanced manufacturing system (AMS) needs to incorporate agile manufacturing paradigm by having distinctive attributes that will enable the system to exploit various dynamic factors in a timely manner. Some of the critical system attributes include decision-making autonomy, flexibility and reliability. In addressing those requirements, there is a trend of employing distributed architecture to control manufacturing operation. One of the best concepts to explain distributed architecture is Holonic Manufacturing System (HMS) where specific manufacturing system could be decomposed into autonomous functional components. Multi agent system (MAS) is one of the prominent technologies to realize HMS where each entity could have unique goal functions and be given autonomy in making decision to achieve the goals.

One of the crucial aspects of AMS is the scheduling of Material Transportation System (MTS) as it defines the continuity aspect of material flow. Thus, it is rational to focus the research in establishing an advanced MTS in a manufacturing workplace. Analyzing the outcomes of numerous researches on distributed-control MTS, the main drawback is that it can't provide competitive system performance compared to the centralized approach. It is due to the fact that decision-making in a distributed system normally is being made based on local viewpoint. As such, it is necessary to establish efficient cooperative distributed problem solving mechanism to improve the entire performance.

The central focus of this research is to propose an efficient scheduling method for dynamic and autonomous MTS based on MAS architecture. Automated Guided Vehicle System (AGVS) is used as a working example for MTS that operates in a manufacturing environment. Several substantial research problems have been studied in the thesis. (1) Existing task assignment protocol does not consider dynamism of AGV operation. This prevents the entity from making optimal assignment thus resulting in underperformance of the entire system. In order to achieve competitive performance, there is a need for an assignment protocol that could exploit latest information within the system. This is addressed in Chapter 4; (2) Existing researches on distributed-controlled AGV don't contemplate the deployment of vehicle with multiple-loading capacity. Due to the fact that existing scheduling mechanism of distributed-controlled AGV depended on single-task allocation per auction, it is less suitable to be utilized when dealing with multi-capacity AGV as bidders could not evaluate the complementary or substitutability attributes among tasks. This is the

central discussion for Chapter 5; (3) Most of the research models for AGV system design used simplified cases for evaluation. In order to design a realistic AGV system, it is necessary to consider a realistic production environment. Furthermore, in a typical industrial environment, there are multiple operational criteria that need to be handled. As such, there is a need to determine the best combination of design variables taking into account related critical operational criteria. This is addressed in Chapter 6.
This dissertation is organized into seven chapters.

Chapter 1 presents an overview for the study. This includes research background and motivation. Moreover, key research aims were explained and consequently general research goals were constituted. Besides, dissertation organization is also clarified in this chapter.

Chapter 2 provides a literature review on the theoretical components required to accomplish research objectives. These include overview on i) MTS for manufacturing industry; ii) AGV technology; iii) MAS technology; iv) Contract Net Protocol (CNP); and v) Combinatorial Auctions method.

Chapter 3 states the functionality requirements for advanced AGV that this thesis intends to address. Key technical problems were then identified. Accordingly, AGV control architecture based on MAS architecture was proposed.

Chapter 4 addresses the protocol to manage two important dynamic factors in AGVs operation. The factors are dynamic status of vehicle's capacity availability and the positioning advantage of certain vehicles in handling a particular transportation request. In addressing both factors, an Improved Contract Net Protocol (ICNP) mechanism has been proposed. Experiments have been carried out to demonstrate the effectiveness of the proposed protocol where three important transportation–related performance indicators were measured. Variation of AGV fleet sizes are used and the result proves that the ICNP outperformed Standard CNP (SCNP) method significantly where average system throughput is improved by 25%, loaded travel percentage of 80% is achievable and average pickup waiting time is consistently reduced (81% decrease for 4-AGV case) could be achieved by applying ICNP method compared to SCNP.

Chapter 5 proposes a market-based method to schedule fleet of autonomous AGV with multiple-loading capacity. The main goal is to overcome the weakness of conventional auction where only one job could be allocated in a single auction. Main problem inherits combinatory attributes and were decomposed into several sub-problems. Knapsack problem model was utilized to formalize AGV's capacity utilization. Meanwhile, combinatorial auctions (CA) mechanism was used in order to realize the task assignment protocol for the multi-load AGV scheduling. The functions have been divided into three components: bid generation, winner determination and auction coordination. Mixed Integer Programming (MIP) is used to obtain the solution.

Performance analyses of AGV with 3-, 5- and 7-loading capacities have been carried out with variation of fleet sizes. The result depicts that the proposed method could enable multi-load AGV to yield competitive system performance. Deployment of vehicle with bigger loading capacity directly contributes to improve throughput and waiting time. Comparison between 2-AGV with 2- and 4-capacities demonstrates that throughput could be improved by 83% and average pickup waiting time is reduced by 31%. Meanwhile, comparison between 2- and 4-AGV with 2-capacity each resulted in throughput improvement of 110% and average pickup waiting time is reduced by 37%.

Additionally, benchmarking studies have been carried out with the intention to analyze the improvement made when the proposed multi-load AGV is used compared to the single-load AGV. Comparison against the standard protocol shows that throughput improvement of 36% can be obtained (Case: 2-AGV).

Furthermore, comparison of the proposed method against centralized-approach optimization (solved using ILOG CPLEX software) for case: 4-AGV with 3-capacity shows that the proposed method could i) reduced computational effort by more than 90% relative to the centralized-approach optimization while ii) achieved 82% of the average throughput produced by the centralized system. The chapter summarizes that i) even though centralized-approach may provide better solution, it can't provide it in a timely manner especially when the problem size increases. This raises the feasibility issue particularly in responding to various dynamic factors ii) there is a need to further investigate the interaction of both design variables on the objective functions.

Chapter 6 presents the simulation of the proposed AGV system for a realistic manufacturing operation. The main goal is to conduct vehicle requirement estimation to design an AGV system. The problem is defined as to determine the best combination of AGV design variables (AGV fleet size and vehicle loading capacity) to achieve desired target performance. The experiment case is based on data of a tire manufacturing factory involving multiple transportation objectives: i) mean flow time; ii) throughput; and iii) total distance traveled. In optimizing the performance, combination of Discrete Event Simulation and Response Surface Methodology (RSM) were employed. The result obtained shows that determining proper variables combination is critical to acquire desired level of performance particularly when plural conflicting objectives were involved. For instance, the combination of 22-AGV with 14-capacity is predicted to produce throughput level of 508 jobs, mean flow time of 110 minutes with an average AGV traveled distance of 10 kilometers. Deliverable of this chapter includes the decision support mechanism to design an AGV system.

Chapter 7 summarizes the thesis by discussing the novelty and contribution of the study particularly on the implementation of autonomous multi-load AGVs. Additionally, this chapter also includes possible future research directions.