AGENT-BASED DISCRETE EVENT SIMULATION – SYSTEM DYNAMICS APPROACH TO OPTIMIZE MANUFACTURING SYSTEM WITH MAINTENANCE ACTIVITIES

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ABSTRACT: Traditional manufacturing processes are commonly executed without considering the requirements of other factors especially related to maintenance activities. Therefore, the processes are often interrupted due to machines breakdown and require reactive maintenance. This contributes to an unorganized scenario where the interruption will cause delay and affect the production schedule. The objective of this paper is to optimize the shop floor operation by integrating process planning with two maintenance approaches – preventive and reactive maintenances. Three crucial factors were considered: (1) maximizing throughput; (2) minimizing tardiness; and (3) minimizing makespan. A hybrid Discrete Event Simulation (DES) – System Dynamics (SD) approach is proposed for this purpose, based on multi-agent modelling for jobs and operating machines. This method allowed the implementation of an agent's hybrid behaviour, which takes into account both the agent's own return and the agent's own return. The authors look at systematic analysis approaches that incorporate a simulation-based analytic and system dynamics modeling to map system behavior and consequently use the information to optimize the system. Four dispatching rules are used to shows the performance variations. The result shows that the proposed approach, combined with appropriate dispatching rule is capable to yield competitive performances including 17% increment of throughput and 14% reduction of tardiness. The study proves that the proposed DES-SD approach is capable to optimize the performance of the system.

KEYWORDS: *Multi-Agent System; discrete-event simulation; system dynamics; dispatching rules; food manufacturing*

1.0 INTRODUCTION

As manufacturing supply chain becomes globally preferred, surviving in this setting is increasingly difficult since the number of competitors in the global marketplace is rapidly growing. For manufacturers to capture reasonable market share, they must produce high-quality goods at a low cost. As the price of finished products is influenced by a number of factors, there are needs to identify the critical factors. One of the capacity management aspects often overlooked is maintenance.

Reliability and maintenance efficiency are directly related to numerous uncertainty elements within manufacturing processes where machinery, equipment and tools are organized in complex production system [1]. As a result, the effect of carefully thought maintenance performance can reach far beyond equipment emphasis, potentially reducing lead times, reducing local production inventories, and thereby contributing to more lean supply chains.

Reactive Maintenance (RM), Preventive Maintenance (PM), and Condition-Based Maintenance (CBM) are some of the maintenance strategies that have been implemented to improve manufacturing performance [2]. Real-time prognostic systems, remote control, and self-maintenance have become emerging research topics in PHM technologies for manufacturing due to advancements in network connectivity, sensors, computing resources, and computer automation. RM is a corrective action taken in response to measurable errors or unexpected failure risks. Although RM has a low upfront cost, it can raise the costs of unplanned equipment downtime and production losses [3-4]. On the other hand, if a failure may endanger employees, disrupt production, or cause collateral damage, RM is not recommended [5]. Meanwhile, PM is the process of repairing, replacing and maintaining equipment to prevent unintended failure while it is in use. The aim of every PM program is to keep the overall cost of inspection, repair, and equipment downtime as low as possible (measured in terms of lost production capacity or reduced product quality) [5-6].

Surprisingly, even the most effective PM strategy for increasing equipment availability has two main shortcomings [6-8]: (1) time-based or operation-count-based PM plans can result in under- or over-maintained equipment, especially when the PM interval is set in advance without taking into account numerous operation regime changes; and (2) removing a part until it seriously degrades or fails prevents useful knowledge about the equipment's lifecycle from being gleaned. Therefore, the objective of this study is to optimize the shop floor operation by integrating process planning with maintenance requirements by both approaches – PM and RM.

To date, the three most commonly used system optimization approaches are [8-10]: (1) mathematical; (2) simulation; and (3) approximation methods. Mathematical models and heuristic algorithms are used in analytical methods. However, practical system optimization often requires solving a variety of combinatorial problems within a specific time period. For example, when deciding on the best design variable combination, various design parameters as well as complex operation parameters such as job arrival randomness, traffic congestion, alternative vehicle routing, and failure should be considered.

As a result, this caused the system to be highly nonlinear, making it difficult to analyze and verify the impact of each factor and their interactions using analytical methods, particularly when considering a large-scale transportation system. This emphasizes the importance of having simulation techniques to analyze dynamic factors realistically. One of the most efficient approaches to deal with occasional machine breakdown is to employ autonomous control. It is due to the reason that in general, autonomous control allows the system to react quickly to localized problems compared to the centralized approach. Nevertheless, at times autonomous control usually just settles with the local best solution. Hence, this research proposes a hybrid DES-SD approach in optimizing the system. To the best of our knowledge, there's no research that proposes a hybrid discrete-event simulation-system dynamics approach to optimize a manufacturing system accommodating maintenance activities. The outcomes of this study will contribute to the existing knowledge gaps in the area of preventive maintenance considering the dynamic behavior of the system.

Figure 1 illustrates the overview of optimization approaches applied to solve various manufacturing problems. The overview is produced based on a summarization of previous studies [9-16]. Meanwhile, some of the other related studies are summarized in Table 1. Due to space limitations, only several recent studies are included.

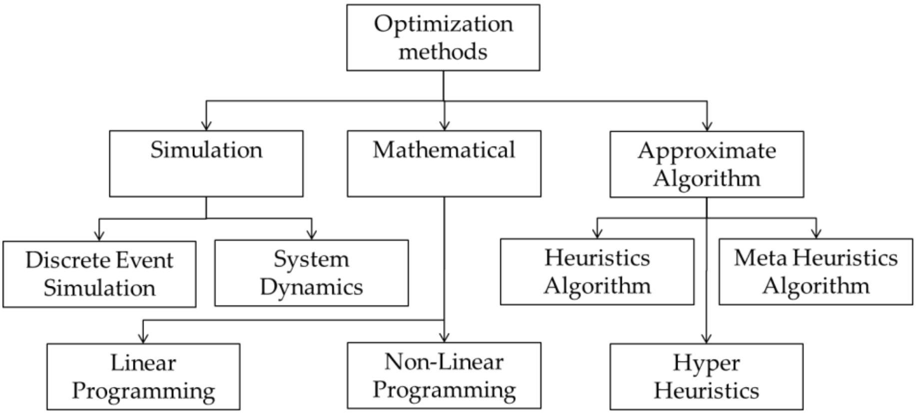

Figure 1: Overview of optimization approaches

Table 1: Agent-based Optimization for Manufacturing Problems

No.	Authors	Method	Problem	Multi/ Single Objective	Objective Functions
1	Li et al. (2018) [12]	Heuristic algorithms	Integrate manufacturing resources and conduct system optimization based on distributed control architecture	Single	Maximum service span
2	Giret et al. (2017) [13]	Simulation - Netlogo	Proposed a sustainable production system by incorporating sustainable mechanisms into device specifications	Multi	Tardiness, cumulative setup time and total energy utilization
3	Guizzi et al. (2019) [14]	Agent-Based Simulation Modeling (ABMS)	Focused on complex integration of a traditional Open Job-Shop manufacturing process planning.	Multi	Jobs mean waiting time and system throughput

4	Wang et al. (2018) [15]	Approximation - Genetic Algorithm	Scheduling optimization with resource constraints consideration.	Single	On-time delivery
5	Aminzadegan et al. (2019 [16])	Mathematical programming and Metaheuristic algorithm	Proposed a scheduling optimization for supply chain management considering logistics constraint.	Multi	Delivery, task assignment, penalty for tardiness and tardy orders costs
6	Hedjazi et al. (2019) [17]	Simulation - Java Agent Development Environment (JADE)	Developed a centralized scheduler based on Multi Agent System architecture.	Multi	Total cost, makespan, weighted tardiness cost
7	Gharaei and Jolai (2018) [18]	Approximation - Evolutionary Algorithm	Optimized delivery problem for inter-facilities supply chain.	Multi	Makespan or total tardiness, distribution costs

This paper is organized as follows: The next section describes the proposed methodology in assessing the requirements for the PM. Consequently, the results will be discussed in the following section afterwards. The final section concludes with some observations on the relevant key performance indicators resulting from the proposed method.

2.0 METHODOLOGY

2.1 Proposed Agent-based DES-SD Optimization Approach

There are several factors that need to be decided in optimizing a manufacturing system for food and beverages products. One of the key considerations is to minimize tardiness and delivery waiting time. Consequently, this will maximize the system throughput as a smoother production flow is achieved.

The functions of a food production system are modelled using a simulation-system dynamic approach in this paper. The interactions of design parameters and the resulting device performance were investigated as a result of the findings. The production of the method may be forecasted in relation to particular performance goals based on the findings.

After thorough consideration in establishing appropriate Agent-based Task Assignment, this study managed to assign specific tasks to specific types of agents. This study proposes four agent types for the system as illustrated in Figure 2. The agents are:

i. Task Controller Agent (TCA)

TCA is responsible to compute the machine schedule based on Daily Production Plan. In scheduling machine operations, TCA will determine the best sequence to minimize mean flowtime as in Equation (1), average makespan as in Equation (2) and consequently maximize the throughput. Variables involved include r_i and f_i which represent order release time and finished time respectively. Meanwhile, n represent number of finished orders and C_i represents completion time for job i.

$$\text{Mean flow time} = \left(\sum_{i=1}^{n} f_i - r_i \right) \Big/ n \tag{1}$$

$$\text{Average Makespan} = \max\left\{ C_i \middle| i = 1,\dots,n \right\} \tag{2}$$

ii. Machine Agent (MA)

MA is responsible to conduct auction for tasks need to be transported out to the next processing machine upon the completion of the process. MA will assign the best transporter to reduce the tardiness. Mean tardiness as in Equation (3) is used as the indicator. Variables involved include d_i and f_i which represent order due time and finished time respectively

$$\text{Mean Tardiness} = \sum_{i=1}^{n} \left[\max\left(0, d_i - f_i\right) + \max\left(0, f_i - d_i\right) \right] \Big/ n \tag{3}$$

Machine Agent will also be responsible in managing maintenance activities. As stated, there are two types of maintenance. For preventive maintenance, the downtime is pre-defined.

iii. Transport Agent (TA)

Upon receiving Call for Proposal (CFP), TA will determine the availability status. Available time will be communicated to MA for further selection. Binary variable, ta_a is used to determine transporter availability.

iv. Monitoring agent (MA)

MA is used as to monitor the status of all agents and to collect data generated by the system.

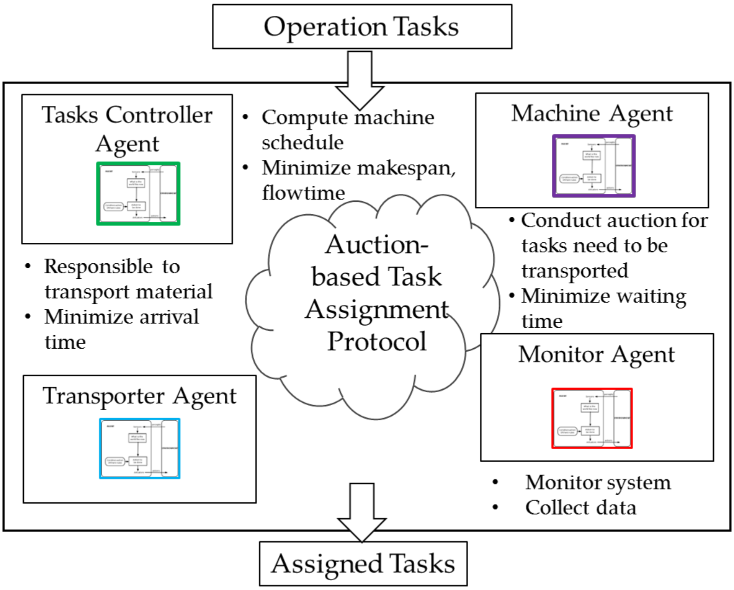

Figure 2: Proposed Multi Agent System

Table 2: Candidate Dispatching Rules (DP)

Dispatching Rule	Priority Formulation	Description
DP1	$z_{ij} = DD_j$	Earliest Due Date (EDD)
DP2	$z_{ij} = PT_j$	Shortest Processing Time SPT
DP3	$z_{ij} = RT_j$	First In First Out FIFO
DP4	$z_{ij} = 2PT_j + 2aTPT_j + nOps$	Composite Dispatching Rule (CDR) [19]

2.2 System Dynamics for Optimizing Maintenance Operation

In general, the system dynamics approach was preferred because it has the following advantages over other approaches, especially for business modelling: (1) Cause and effect analysis may be used to comprehend how various variables (elements) in the system interact. (2) Moreover, the parameters that change/improve the manufacturing system behavior can be investigated independently. The steps of developing a SD model was adapted from Adane et al. [20] and has been improved with manufacturing system in consideration.

The use of a hybrid simulation model has a number of advantages. To begin with, the agent-based approach enables the model to be scaled to analyze the system of key intermodal parameters at the micro-level. Furthermore, this method shortens development time and makes the established model universal [20].

Second, the system dynamics approach is used to analyze how the key variables change in response to the changes in other variables during the simulation. Conventionally, the approaches used to solve the problem are conducted independently using analytical approach, system dynamics or discrete-event simulation approach [21]. The dynamics of maintenance activities between the stocks, parameters, dynamic variables and flows were modeled in Anylogic software as in Figure 3. By using combined approach, each of the discrete-event can be modelled and the effect on variables could be investigated independently.

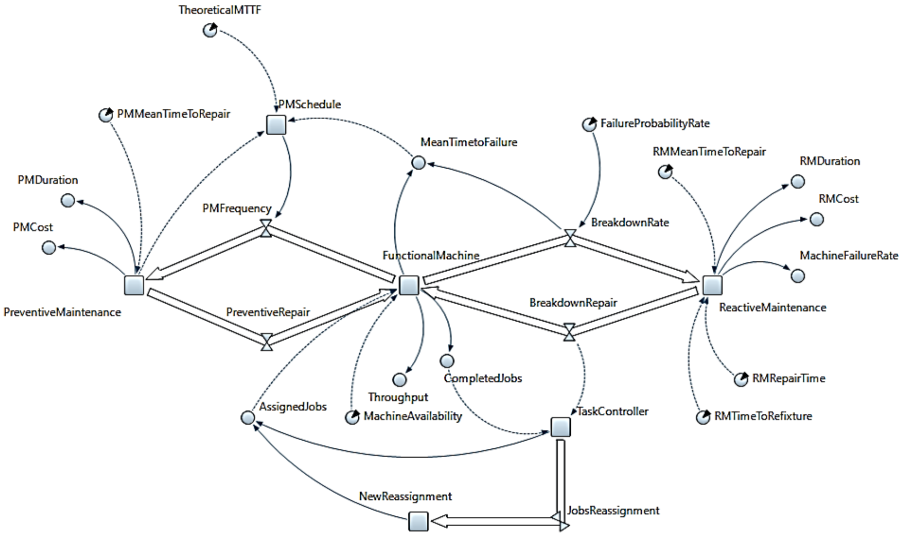

Figure 3: System dynamics model for maintenance activities

2.3 Case Study of Implementation in Food Manufacturing Factory

The case study is based on a food manufacturing factory. With the aim of studying the effects of dynamic maintenance characteristic in a food manufacturing system, a portion of the entire shop floor with process-based architecture has been modelled. The jobs dataset is illustrated in Table 3. The model includes the following technical parameters and assumptions:

i. Machine specification
   The number of machines, *m* in the system is predetermined. The loading and unloading times for each task are set to 0.5 minute. There are a limited number of input and output machine buffers. In order to prioritize tasks in queues waiting for a) computer processing and b) transportation, the input and output buffers use the First In First Out (FIFO) dispatching law.
ii. Material transportation specification
   The system's total number of AGVs, *v*, is known. The vehicle's velocity, vel_x, remains steady at 130 feet per minute. The processing machines are linked by bidirectional travel paths. All transport equipment is assumed to operate at 100% efficiency.
iii. Maintenance Specification
   There are two types of maintenances considered in this study – preventive and reactive maintenance. Weekly machine preventive maintenance time is set as 3 hours. Meanwhile, reactive maintenance is set at Normal (5, 2.5). Even though the reality of a machine reactive maintenance could be prolonged up to few days, 5 hours is used as the reference for study purposes.

Table 3: Job Data Set

Job No	Volume Mix (%)	Machine sequence (processing time in minutes)
1	20	P 1 (3) - P 2 (16) - P 3 (3) - P 6 (2) - P 9 (1) - P 11 (2) - P 12 (3)
2	20	P 1 (3) - P 2 (16) - P 3 (3) - P 6 (2) - P 9 (1) - P 11 (2) - P 12 (3)
3	15	P 1 (3) - P 2 (16) - P 5 (4) - P 7 (3) - P 9 (1) - P 10 (1) - P 12 (3)
4	15	P 1 (3) - P 4 (13) - P 3 (3) - P 8 (1) – P 9 (1) - P 11 (2) - P 12 (3)
5	10	P 1 (3) - P 4 (13) - P 3 (3) - P 7 (3) - P 9 (1) - P 10 (1) - P 12 (3)
6	10	P 1 (3) - P 2 (16) - P 3 (3) - P 6 (2) – P 9 (1) - P 11 (2) - P 12 (3)
7	5	P 1 (3) - P 2 (16) - P 5 (4) - P 8 (1) - P 9 (1) - P 11 (2) - P 12 (3)
8	5	P 1 (3) - P 4 (13) - P 5 (3) - P 6 (2) – P 9 (1) - P 10 (1) - P 12 (3)

Meanwhile, the characteristics of the processing times are summarized in Table 4:

Table 4: Machine processing times

Process	Processing times (min)	Process	Processing times (min)
P1	Poisson (3, 1)	P7	Triangular (2.5,3,3.5)
P2	Triangular (15,16,17)	P8	Normal (1,0.5)
P3	Uniform (3,4)	P9	Normal (1,0.5)
P4	Triangular (12,13,14)	P10	Normal (1,0.5)
P5	Normal (4,0.5)	P11	Normal (2,0.5)
P6	Normal (2,0.5)	P12	Triangular (2.5,3,3.5)

The manufacturing system has been modelled by using Anylogic software. The application has enabled the development of agent-based simulation with dynamics environment. The layout of the agent-based model is depicted in Figure 4.

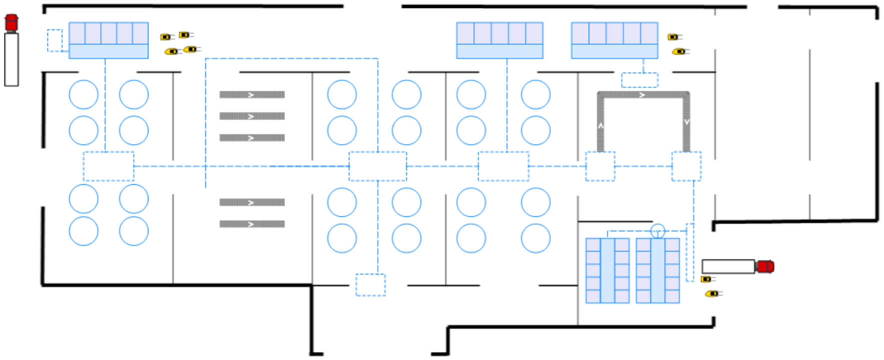

Figure 4: Layout of the shop floor modeled in Anylogic software

3.0 RESULT AND DISCUSSION

The results of the simulation experiment were analyzed using Box-and-Whisker plot to assess the effect of variables on output measurement. System throughput is one of the most important performance indicators to measure system efficiency [19,22,23]. Figure 5 shows the system throughput results of the simulations. Based on the results obtained, it is found that the DP4 rule emerges as the best for optimizing the throughput objective. Comparing against conventional DP shows that DP3 obtained the best result. The result is consistent with the one discussed by Tay and Ho [19] where FIFO has the ability to produce better throughput compared to others.

In the meantime, Figure 6 depicts the results for the average makespan when the dispatching rules were varied. The results show that the DP3 is the best option for minimizing the average makespan objective in all situations, notwithstanding the variation of the problem instances. This is due to the fact that FIFO refers release dates/ time information to schedule jobs in a specific queue. Jobs with early release dates/ times are more favorable to be chosen for processing than jobs with later release dates. As a result, the schedule's average completion period (makespan) is reduced. This result is similar to the findings stated in previous researches where FIFO produced the best makespan [19,24]. The composite dispatching rule obtained the second-best result in minimizing the makespan objective. The explanation for this rule's strong success is that it decreases job completion variance from the due date.

Figure 7 shows that different dispatching rules affect the resulting mean tardiness. Even though DP3 is effective at reducing the makespan, it performs poorly in terms of reducing mean tardiness. This is due to FIFO's disregard for work due dates. The result is almost similar in terms of the DPs performance in minimizing mean tardiness [24]. However, although the DP4 performs better than FIFO in terms of reducing mean tardiness, it is not significantly better than the other DPs as the respective variables are not considered.

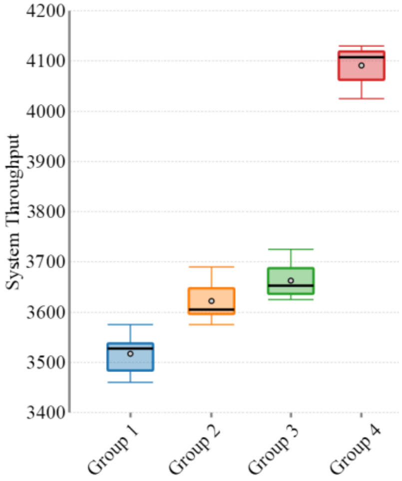

Figure 5: Results for system throughput

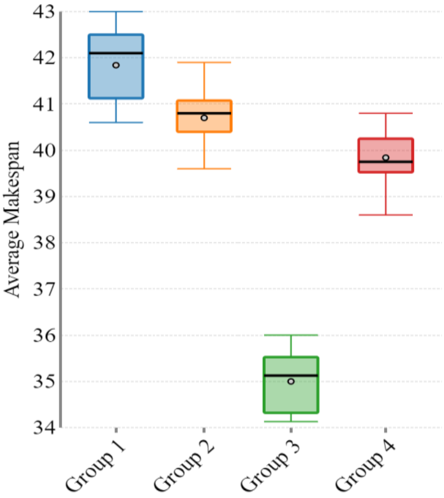

Figure 6: Results for average makespan

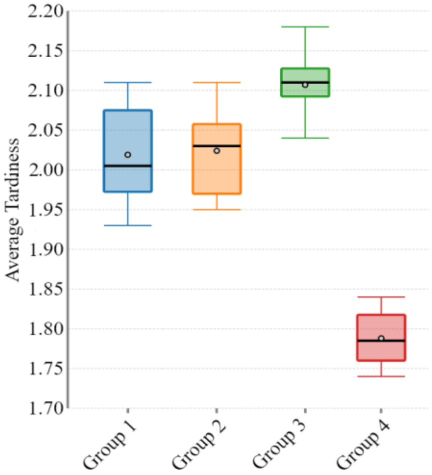

Figure 7: Results for average tardiness

4.0 CONCLUSION

Based on the result obtained, it can be concluded that the study has successfully provided insight into how the proposed approach could be used as a decision support tool in optimizing manufacturing systems. Based on the result, throughput has been increased by 17% and tardiness has been reduced by 14% thus achieving the research objective in optimizing the performance. This was done by modeling the maintenance activities using SD technique. Future studies may focus on the other dynamic variables to create a more realistic environment.

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