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INTEGRATED APPROACH TO DUE DATE ASSIGNMENT, JOB SEQUENCING AND MAGV DISPATCHING PROBLEMS

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Abstract
To ensure timely deliveries, it is essential to determine appropriate due dates and accurately estimate the flow time of orders. This study aims to identify an optimal policy for assigning due dates to orders by considering material handling system dispatching and machine priority rules in a workshop operating within a flexible production system. A total of 4032 simulation models were developed in the study, addressing six different problem areas: due date assignment, job sequencing, task determination for Multi-load Automated Guided Vehicles (MAGVs), delivery point selection, pickup point selection, and load selection. These models were evaluated using five distinct performance criteria. The results indicate that the Constant Due Date (CON) rule is the most effective for assigning due dates. Compared to other rules, the CON rule demonstrates an average improvement of 0.054 % in the number of outputs, 1.81 % in flow time, 3.85 % in lateness, and 2.35 % in deviation time. However, for earliness, the Jobs in Queue (JIQ) rule outperform other rules by 11.58 %.
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Key Words: Due Date Assignment, Job Sequencing, Multi-Load AGV (MAGV), Priority Rules

1. INTRODUCTION

The AGV, developed in 1955, is a driverless, battery-powered material transportation vehicle controlled by an onboard computer. AGVs can be classified as single-load or MAGVs according to their load capacities. Single-load AGVs can have either an "Empty" or a "Full" state. There is a need for a decision-making mechanism for such AGV systems in order to select load pick points and solve load selection problems. The MAGV system, on the other hand, involves one of three states: "Empty", "Full" or "Partially Full", so a decision-making mechanism is necessary for determining tasks, selecting delivery points, and selecting pickup points and loads [1].

Researchers have been working to develop successful and efficient planning and scheduling of the production system [2]. The MAGV systems considered the problems of acquiring and selecting loads as one single problem by Ho et al. [3]. To select the load pickup point, the characteristics of the loads at the candidate points were also considered. Four stages are involved in their approach: preparation, clustering, evaluation, and execution. The load selection problem is one of the problems associated with AGV systems. This problem is studied using various heuristics [4]. The rule-based systems are frequently studied. Ho and Chien [1] describe four problems in MAGV systems, including the determination of the task, the determination of the delivery point, the determination of the pickup point, and the selection of the load. They developed some rules to these four problems. In a simulation study, they compared the solution rules for task determination and delivery point selection and found that the "Delivery Task First" (DTF) and "Shortest Distance" (SD) rules achieved the best results for task determination and delivery point selection, respectively. Among the different rules they discussed in a simulation study to determine the load pickup point for MAGVs, Ho and Liu [5] indicated that "Greatest Output Queue" (GOQ) performed best and it has been suggested that queue-based rules have better performance than time-based rules. Lee

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and Srisawat [6] investigated the effect of the heuristic solution rules used in the delivery point selection problem in MAGV systems on the production system. MAGV pickup point and load selection rules were examined by Ho and Liu [7]. As a result of the analyses, it was seen that the identical rule (ID), out of the six rules used to select the load, and the GOQ out of the twelve rules used to select the pickup point, gave the best results. Additionally, deadlock avoidance delivery methods were also studied for MAGV operating in a system with a high number of jobs available [8].

The problems of selection of delivery point and pickup point for MAGV systems were discussed by Azimi et al. [9]. For these two problems, the solution proposals in the literature were searched and listed as a cluster, fuzzy multi-criteria decision-making method and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method were used to choose the best combination from this cluster. A similar approach was employed by Azimi and Gardeshi [10] to solve the problem of picking and delivering points in MAGV systems using Simple Additive Weighting (SAW), TOPSIS, and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. Şahin [11] proposed a developmental scheduling approach for AGV and machine scheduling using a multi-agent system approach and compared it with online and offline scheduling methods. Fauadi et al. [12] proposed a new decision-making mechanism based on the multi-agent system for the task determination problem of MAGV systems. Erol et al. [13] developed a multi-agent-based system for simultaneous scheduling of machines and AGVs. In the research conducted by Kumar and Jayant [14], the distribution rule for the AGV system in an environment where workshop type production was carried out in the just-in-time production system was examined and a heuristic algorithm was proposed to balance the efficiency of the vehicle and the transfer time. Işık et al. [15] presented new approaches for task determination, delivery selection and load selection in MAGV systems.

In Yenigün's [16] study, a new approach was proposed to determine the delivery date for jobs in a workshop that manufactures doors and windows. In a mould manufacturing enterprise, Liu et al. [17] developed a multi-agent-based model to assign due dates. Zhao et al. [18], developed a dynamic programming algorithm and polynomial-time approximation scheme that minimise a cost function consisting of the number of delays and the cost of assigning the due date in a single machine production environment, determining the optimal due date and scheduling the production. In order to determine a suitable due date in a polyphase assembly line using the fixed due date rule as the delivery date assignment rule, Yaghoubi [19] formulated a finite state and continuous time Markov model by converting the queuing network into a stochastic network. Şahin [20] proposed an agent-based holonic control structure to address the delivery date assignment issue in flexible manufacturing. Using hybrid evolutionary strategies and hybrid simulated annealing algorithms, Demir et al. [21] investigated the integration of process planning and due date determination problems. Fakhrzad et al. [22] considered the parallel machine scheduling and delivery date determination problems as NP-hard and utilized genetic algorithms to seek solution. To predict delivery dates in a heterogeneous production environment, Dalalah et al. [23] used the Support Vector Machine classifier. Using Design Science Research methodology, Modesti et al. [24] developed a real-time due date prediction method based on artificial intelligence.

Different production environments require different priority rules [25, 26]. A dynamic approach to production scheduling is described in an environment with multiple machines on the shop floor [27-29]. In a production system where the due date is determined by the customer, Philipoom [30] examined the effect of pre-sequencing rules on meeting the due dates. Ayhan [31] compared and analysed machine priority rules in different job shop scheduling problems according to six performance criteria. Based on the penalty rates determined for early exit and delay of the works in a single machine production line, Jagan et al. [32] developed a net penalty equation.

This study focuses on determining the due date of incoming jobs in a workshop utilizing MAGV. In this context, rules and methods identified by researchers for setting due dates are examined. The key decision factors influencing system performance and job due dates include MAGV task determination, pickup, delivery point, and load selection from queues. The second focus of this study is to address these four problems comprehensively. The most used rules in the literature for solving these issues are reviewed. Additionally, the machine job prioritization problem was incorporated, and the most prevalent rules from literature are also considered in scope of the study. This study integrates all six interrelated problems (due date assignment, MAGV task determination, pickup point selection, delivery point selection, load selection, and machine job prioritization). The aim is to analyse the relationships among these problems and identify the most suitable solution set for discussed problems. The motivation for this study stems from the lack of research integrating these six problems, thereby contributing to the literature with a holistic approach. A simulation study was conducted to evaluate the performance of the compiled rules based on the data set used by Ho et al. [3]. After analysing the simulation data, the best solution set was proposed based on the statistical analysis.

2. MATERIAL AND METHODS

In order to obtain the data set of this study, a facility is composed to build different simulation models. The facility layout Ho et al. [3] used in their work was used. The facility layout is shown in Fig. 1. There are 15 points in the layout, and the first and 15th point represent the entrance and exit points, respectively. The other dots show workstations. Each time the AGV reaches a workstation; it first stops at the stop point and then picks up at the pickup point.

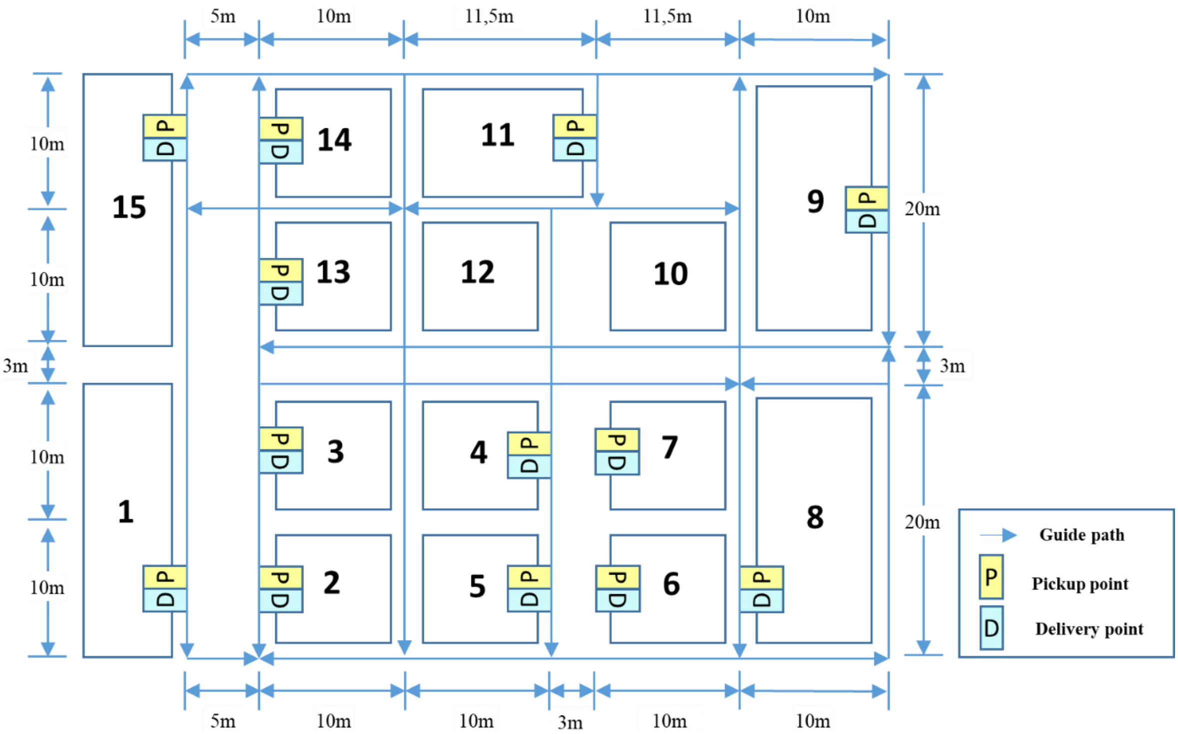

Figure 1: Facility layout [3].

There are 10 types of jobs in the system. Table I shows the frequency of these jobs, along with the order in which they are performed.

Table I: Job frequency and sequences [3].

Job	Frequency (%)	Sequence (Work Stations)
1	10	1-2-3-5-6-7-9-10-11-13-15
2	15	1-2-3-4-7-8-9-10-11-12-13-15
3	5	1-3-4-5-6-7-8-10-11-14-15
4	7	1-3-5-8-9-10-11-12-13-14-15
5	15	1-2-3-4-7-9-10-12-13-14-15
6	11	1-2-3-5-6-7-8-11-12-14-15
7	8	1-2-3-4-9-10-11-12-13-15
8	9	1-2-4-5-8-9-10-11-13-14-15
9	13	1-4-5-7-8-9-10-11-12-14-15
10	7	1-5-6-7-8-9-10-11-12-14-15

The study by Ho et al. [3] does not provide any information about machine processing times. Therefore, a random number was obtained for machine processing times based on a study by Ho and Chien [1] using a similar workshop setup. Using the method suggested by Gnanavelbabu et al. [33], randomness was applied. According to Gnanavelbabu et al. [33], the ratio of total transfer time/total processing time should be greater than 0.25 to see AGV's effect. The processing times fit the Normal (μ, σ) distribution, with μ and σ representing the mean and standard deviation for the processing time, respectively. In this experiment, random processing times were generated until the ratio of total transfer time to total processing time was greater than 0.25. Normally distributed datasets have negative values. For this reason, the probability of the generated processing times falling below zero has been calculated so that negative values will not adversely affect the operation. Eq. (1) calculates the probability of a normally distributed variable being less than a certain number. The processing times are given in Table II.

$$P(X < x) = P(Z < \frac{x - \mu}{\sigma}) \tag{1}$$

In Table II, the probability of the generated processing times being less than 0 according to Eq. (1) is calculated. In Table II, the mean, standard deviation and the probability of the generated numbers being less than 0 are given. Accordingly, all generated processing times are greater than 0. This result shows that the processing times are usable.

Table II: Machine processing times.

Machine	Processing times (min)		$P(X\leq0)$
	μ	Σ	
2	2	0.2	0
3	1.71	0.09	0
4	2	0.2	0
5	1.23	0.30	0
6	1.5	0.15	0
7	1	0.1	0
8	1	0.1	0
9	2	0.2	0
10	1.25	0.11	0
11	1.5	0.15	0
12	1.5	0.15	0
13	1	0.1	0
14	2	0.2	0

In this study, the number of finished jobs, flow, delay, early exit and deviation times were used as performance criteria. The equations for the calculation of the delay, early exit, deviation and flow times of the unit work are given in Eq. (2) (Trd_j), Eq. (3) (Erl_j), Eq. (4) (Sp_j) and Eq. (5) (Flt_j), respectively. Ts_j represents the finishing time of the j^{th} job, D_j represents the due date of the j^{th} job and A_j represents the entry time of the j^{th} job into the system.

$$Trd_j = max\,\{0, (Ts_j - D_j)\} \tag{2}$$

$$Erl_j = max\{0, \left(D_j - Ts_j\right)\} \tag{3}$$

$$Sp_j = \left|Ts_j - D_j\right| \tag{4}$$

$$Flt_j = Ts_j - A_j \tag{5}$$

The assumptions in this system are as follows:

- There are four MAGVs in the system, each of which can carry four loads.
- There are three vehicles fixed in the fleet.
- The AGV works on a station-centred principle.
- AGVs are called using the nearest vehicle (NV) rule.
- Each station has a loading, unloading and waiting area
- With an average arrival time of 5 minutes, the interarrival times between jobs in the system fit an exponential distribution.
- The speed of AGVs is fixed at 20 m/min.
- Each station has only one machine that can process one job at a time.
- The time required to load or unload is set at 30 seconds.

This study integrates all six interrelated problems (MAGV task determination, pickup point selection, delivery point selection, load selection, due date assignment, and machine priority rules). The rules used under these headings are explained below.

Task Determination Rules: DTF rule is mentioned by most researchers who deal with the MAGV systems. According to this rule, a partially occupied MAGV chooses the delivery task first, even if both pickup and delivery jobs are available. In the study by Ho and Chien [1], the best rule for the task determination problem of MAGV is the DTF rule. Işık et al. [15] proposed a new rule called NDTF, which gives better results compared to the DTF rule. In this study, DTF proposed by Ho and Chien [1] and NDTF rule proposed by Işık et al. [15] were used for the MAGV task determination problem. In order to define the NDTF rule, the DTF rule needs to be carefully examined. According to the DTF rule, an empty MAGV first selects the pickup task, the AGV goes to a waiting point and picks up the load. When there is a load, it chooses the next task as delivery. It goes to the point where the load needs to be unloaded and leaves the load. MAGV's next task is not affected by a load waiting for it. The NDTF rule permits MAGV to receive loads from its current location at this stage.

Delivery Point Selection Rules: In the second stage of the MAGV system, when there are several loads on the vehicle, many rules have been proposed by researchers to decide which load should be delivered first. Based on their study, Ho and Chien [1] found the three rules that gave the best results were, namely, the SD, the work with the smallest remaining processing time (SRPT), and the combined rule (CM). This study discusses these three rules and the EDD (Earliest Due Date) rule for the MAGV delivery point selection problem. This study seeks to examine the impact of the principle of determining the delivery date by considering the EDD rule. Every load on the MAGV is calculated according to its distance from the target station, and the load with the shortest distance will be distributed first. The remaining processing time of each load available on the MAGV is calculated and the job with the shortest time will be delivered first in SRPT. SRPT and SD rules are combined in the CM rule. During the selection process, the ratio of remaining operations/total number of operations is calculated for each load on the vehicle, and loads with a ratio less than or equal to 0.5 get priority (if more than one load has this priority, SRPT is applied to choose a load). If the calculated ratio for all loads is greater than 0.5, then the SD rule is applied. The delivery dates of the loads on the MAGV are compared, and the load that should be delivered as soon as possible is prioritized in the EDD rule.

Pickup Point Selection Rules: A MAGV system also faces the problem of choosing a pickup point. The study employs a "Station-Centred" methodology. To select the receiving point, the list of candidates includes the points referred to as that MAGV. In order to select the pickup point, the point with the highest workload in the output queue is selected from the points that call the MAGV in GOQ. A MAGV visits the pickup point containing the load whose waiting time is the longest according to the Longest Waiting Time at Pickup Point (LWPT) rule, in order to determine from which the load will be picked up. Among the points that request the MAGV, the point closest to the current location is selected for pickup in SD. A random pick occurs between two or more pickup points if their priority is the same.

Load Selection Rules: When there is more than one load waiting to be transported when a vehicle arrives at the pickup point, the priority policy should be defined for the loads. In addition to the First In First Out (FIFO)_ID_FIFO rule proposed by Işık et al. [15], the EDD rule is also discussed in this study. In accordance with the FIFO rule, the first load in the station's output queue must be received. Among the loads in the output queue of the station, the one with the closest due date shall be taken first according to the EDD rule. In F_ID_F, whenever choosing a load for a MAGV, priority is given to loads whose target stations are similar to those of the existing loads. To benefit from the FIFO rule, first, a load must be selected when the MAGV is empty, and then this rule is applied. According to the rule used when selecting AGV load, if two or more loads have the same priority, the load that enters the output queue first is selected.

Due Date Assignment Rules: As soon as a job logs into the system, the problem of assigning a due date for that job has been handled by many researchers and certain rules have been suggested. All processing times of a newly entered job are added together and multiplied by a fixed coefficient in the Total Work (TWK) rule. In the Number of Operations (NOP) rule, the number of operations of a job that has just entered the system is multiplied by a constant coefficient. The total processing time and number of operations of a job that has just entered the system are multiplied by certain coefficients and added in the Total Work with Number of Operations (TWK+NOP) rule. In JIQ, the total processing time of a job that has just entered the system and the total queue length of the stations where the job will go are multiplied by certain coefficients and added. The total processing time of a job that has just entered the system and the sum of the processing times of the jobs waiting at the stations where the job will go are multiplied by certain coefficients and added together in the Work In Queue (WIQ) rule. In CON, a fixed due date is determined for all jobs that enter the system. The Slack Time (SLK) rule uses to determine the due date for jobs entering the system. The due dates for entering jobs are determined in Total Work and Slack Time (PPW) rule.

Machine Priority Rules: In their study, Chiang and Fu [34] compared 18 solution rules for the machine priority sequencing problem. The five solution rules that gave the best results were selected after being applied to simulations and analysed statistically in their previous studies. The FIFO rule has also been added to this part of the study, which has been used by many researchers and has been found to produce better results. Additionally, since the study is about determining the delivery date, an examination of the EDD rule is included. The first load to enter the station's input queue is processed first in the FIFO rule. Among the jobs in the station's input queue, the job with the closest due date is processed first in the EDD rule. The Operation Due Date (*ODD*) value is calculated for the jobs in the input queue of the machine and the job with the smallest *ODD* value is selected. The total work-content of jobs in the queue of the next operation of job *i* is compared, and the job with the smallest total work content is selected in the Work in Next Queue (WINQ) rule. If operation *j* is the last operation for job *i*, then the total work content of job *i* is zero. The idle time (Slack Time, *SLACK*) is calculated for the jobs in the input queue of the machine, and the job with the smallest idle time is selected. In the Processing time, Waiting time, Operation time and Due Date (PQOD) rule, the *PQOD* value is calculated for the jobs in the input queue of the machine and the job with the smallest *PQOD* value is selected. In the Processing time, WINQ time and Slack time (PWS) rule, The *PWS* value is calculated for the jobs in the input queue of the station, and the job with the smallest *PWS* value is selected. According to the pre-machine sorting rules, if two or more jobs have the same priority value, the FIFO rule is applied to select a single job.

3. EXPERIMENTAL DESIGN

An experimental design is composed of different rules of the study as summarised in Table III. In the study, 8 due date assignment rules, 2 task determination rules, 4 delivery point selection rules, 3 pickup point selection rules, 3 load selection rules and 7 machine priority (job sequencing) rules were used and 4032 (8×2×4×3×3×7) combinations were obtained. A simulation study is conducted to measure the performance of the rules. The data and layout of the study by Ho et al. [3] were used as a reference for the parameters of the simulation. According to the research, a warm-up period of 2000 minutes and 20 replications are enough for a simulation length of 10000 minutes.

Table III: Rules in the experiments.

Problem	**Rules**			
Due date assignment (DD)	TWK	NOP	TWK+NOP	JIQ
	WIQ	CON	SLK	PPW
Task determination (TD)	DTF	NDTF		
Delivery point selection (DP)	SD	SRPT	CM	EDD
Pickup point selection (PP)	GOQ	LWPT	SD	
Load selection (LP)	FIFO	EDD	F_ID_F	
Machine priority (MP)	FIFO	EDD	ODD	WINQ
	SLACK	PQOD	PWS	

First, a normality test was conducted on the simulation data, and the results showed that the data were not normally distributed across all performance criteria. A variance analysis was performed after the normality test by considering each problem separately according to the performance criteria. These tests are intended to determine whether a statistically significant difference exists between the rules with respect to a performance criterion. Based on the results, it appears there is a difference between the rules for all four MAGV problems in terms of performance criteria. Regarding the due date assignment problem, all rules perform similarly in terms of the number of outputs and flow time, but there is a significant difference in terms of other criteria. On the machine priority problem, there is a difference between the rules in terms of early leave time and deviation time, but not in terms of other criteria.

According to the average performance criteria, Table IV shows the order of the rules used in the problems, from best to worst. *ANO*, *AFT*, *ALT*, *ATE*, and *ADT* are defined as Average number of outputs, Average flow time, Average latency, Average time to leave early, and Average deviation time, respectively. In Table IV, when the performance criteria used in the MAGV task assignment problem are examined, the NDTF rule outperformed the DTF rule by

2.74 % in terms of the number of outputs, which is an important indicator. It is seen that the SD rule outperformed the CM rule by a very small margin of 0.04 % for the number of outputs for the distribution point selection. It is seen that the GOQ rule outperformed the LWPT rule by a very small margin of 0.07 % for the number of outputs for the receiving point selection. The F_ID_F rule outperformed the EDD rule by 1.93 % and the FIFO rule by 2.06 % for the number of outputs for the load selection. In determining the delivery date, the CON rule has an advantage over the NOP rule by 0.02 %, the SLK rule by 0.02 %, the PPW rule by 0.03 %, the TWK+NOP rule by 0.05 %, the WIQ rule by 0.08 %, the JIQ rule by 0.08 % and the TWK rule by 0.10 % for the number of outputs. In determining the machine priority, the WINQ rule has an advantage over the FIFO rule by 0.04 %, the EDD rule by 0.06 %, the SLACK rule by 0.06 %, the PWS rule by 0.06 %, the PQOD rule by 0.07 % and the ODD rule by 0.08 %. It can be concluded that the best rule when determining the MAGV task is NDTF. MAGV delivery point selection is best solved by SD and worst by SRPT. For the selection of pickup points for MAGV, GQQ seemed to be the best rule while SD is considered to be the worst rule. The F_ID_F rule performed the best in the MAGV load selection problem, while the FIFO rule performed the worst. It is the CON rule that performs best in the due date assignment problem, while WIQ and JIQ are the worst. The machine priority problem can be summarized as WINQ is the best rule and ODD is the worst rule.

Table IV: Ranking the rules for performances.

Problem	**Rank**	***ANO*** (number)		***AFT*** (min)		***ALT*** (min)		***ATE*** (min)		***ADT*** (min)	
TD	1	NDTF	(1597.9)	NDTF	(203.2)	NDTF	(44.29)	DTF	(14.72)	NDTF	(1597.9)
	2	DTF	(1554.0)	DTF	(310.4)	DTF	(159.17)	NDTF	(7.57)	DTF	(1554.0)
DP	1	SD	(1598.1)	SD	(158.9)	SD	(14.70)	SD	(21.97)	SD	(1598.1)
	2	CM	(1597.5)	CM	(174.2)	CM	(24.33)	CM	(16.37)	CM	(1597.5)
	3	EDD	(1563.5)	EDD	(322.5)	EDD	(159.61)	EDD	(3.30)	EDD	(1563.5)
	4	SRPT	(1544.7)	SRPT	(371.5)	SRPT	(208.29)	SRPT	(2.94)	SRPT	(1544.7)
PP	1	GOQ	(1580.2)	GOQ	(223.8)	GOQ	(73.63)	GOQ	(16.00)	GOQ	(1580.2)
	2	LWPT	(1579.0)	LWPT	(252.4)	LWPT	(94.88)	LWPT	(8.73)	LWPT	(1579.0)
	3	SD	(1568.7)	SD	(294.1)	SD	(136.69)	SD	(8.70)	SD	(1568.7)
LP	1	F_ID_F	(1597.2)	F_ID_F	(181.8)	F_ID_F	(29.32)	F_ID_F	(13.86)	F_ID_F	(1597.2)
	2	EDD	(1566.3)	EDD	(291.5)	EDD	(135.09)	FIFO	(9.88)	EDD	(1566.3)
	3	FIFO	(1564.3)	FIFO	(297.0)	FIFO	(140.78)	EDD	(9.70)	FIFO	(1564.3)
DD	1	CON	(1576.7)	CON	(254.5)	CON	(99.23)	CON	(11.46)	CON	(1576.7)
	2	NOP	(1576.4)	NOP	(255.0)	NOP	(99.69)	NOP	(11.45)	NOP	(1576.4)
	3	SLK	(1576.4)	SLK	(255.1)	SLK	(99.80)	SLK	(11.45)	SLK	(1576.4)
	4	PPW	(1576.3)	PPW	(255.7)	PPW	(100.28)	PPW	(11.41)	PPW	(1576.3)
	5	TWK+	(1575.8)	TWK+	(256.7)	TWK+	(101.18)	TWK	(11.39)	TWK+	(1575.8)
	6	WIQ	(1575.4)	JIQ	(258.9)	TWK	(103.75)	TWK	(11.33)	TWK	(1575.4)
	7	JIQ	(1575.4)	WIQ	(259.1)	JIQ	(104.86)	WIQ	(10.34)	JIQ	(1575.4)
	8	TWK	(1575.2)	TWK	(259.2)	WIQ	(105.07)	JIQ	(10.31)	WIQ	(1575.2)
MP	1	WINQ	(1576.8)	WINQ	(253.7)	WINQ	(99.33)	WINQ	(11.84)	WINQ	(1576.8)
	2	FIFO	(1576.2)	FIFO	(256.5)	FIFO	(101.61)	FIFO	(11.35)	EDD	(1576.2)
	3	EDD	(1575.9)	EDD	(257.1)	EDD	(101.87)	EDD	(10.99)	FIFO	(1575.9)
	4	SLACK	(1575.9)	SLACK	(257.4)	SLACK	(102.13)	PWS	(10.97)	SLACK	(1575.9)
	5	PWS	(1575.8)	PWS	(257.4)	PWS	(102.21)	SLACK	(10.95)	PWS	(1575.8)
	6	PQOD	(1575.7)	PQOD	(257.5)	PQOD	(102.27)	PQOD	(10.95)	PQOD	(1575.7)
	7	ODD	(1575.5)	ODD	(257.9)	ODD	(102.71)	ODD	(10.95)	ODD	(1575.5)

To examine the interaction between the problems, a factor analysis of variance was conducted. A two-level and a three-level analysis are conducted. Using a two-level factorial variance analysis, each of the six performance criteria were analysed in pairs and the univariate test was applied to each performance criterion to determine whether there was any interaction between the groups. Table V shows the results of the univariate tests. With a *p*-value greater than 0.05, there is no significant interaction for each rule pair in Table V. The interaction between the two problems means that the coexistence of both problems has a significant effect on the system performance. The fact that the MAGV routing problems interact with each other indicates that the performance of this system is mostly dependent on these problems.

Table V: Statistical results of two-level factorial analysis of variance.

* *P*-value	***ANO*** (number)	***AFT*** (min)	***ALT*** (min)	***ATE*** (min)	***ADT*** (min)
DD * TD	0.184	0.000	0.000	0.000	0.000
DD * DP	0.086	0.000	0.000	0.000	0.000
DD * PP	1.000	0.940	0.960	0.000	0.946
DD * LS	0.373	0.000	0.000	0.001	0.000
DD * MP	1.000	1.000	1.000	1.000	1.000
TD * DP	0.000	0.000	0.000	0.000	0.000
TD * PP	0.000	0.000	0.000	0.000	0.000
TD * LS	0.000	0.000	0.000	0.000	0.000
TD * MP	0.451	0.037	0.012	0.000	0.003
DP * PP	0.000	0.000	0.000	0.000	0.000
DP * LS	0.000	0.000	0.000	0.000	0.000
DP * MP	0.999	0.053	0.038	0.440	0.026
PP * LS	0.000	0.000	0.000	0.000	0.000
PP * MP	1.000	1.000	1.000	0.000	1.000
LS * MP	0.998	0.909	0.909	0.000	0.839

Table VI: Statistical results of the three-level factorial analysis of variance.

* *P*-value	***ANO*** (number)	***AFT*** (min)	***ALT*** (min)	***ATE*** (min)	***ADT*** (min)
DD * TD * DP	0.074	0.000	0.000	0.000	0.000
DD * TD * PP	1.000	0.758	0.861	0.000	0.943
DD * TD * LS	0.290	0.000	0.000	0.175	0.000
DD * TD * MP	1.000	1.000	1.000	1.000	1.000
DD * DP * PP	1.000	0.792	0.781	0.871	0.740
DD * DP * LS	0.085	0.000	0.000	0.130	0.000
DD * DP * MP	1.000	1.000	1.000	1.000	1.000
DD * PP * LS	1.000	0.843	0.858	1.000	0.867
DD * PP * MP	1.000	1.000	1.000	1.000	1.000
DD * LS * MP	1.000	1.000	1.000	1.000	1.000
TD * DP * PP	0.000	0.000	0.000	0.000	0.000
TD * DP * LS	0.000	0.000	0.000	0.000	0.000
TD * DP * MP	0.999	0.047	0.043	0.997	0.041
TD * PP * MP	1.000	0.971	0.957	0.000	0.916
TD * PP * LS	0.000	0.000	0.000	0.000	0.000
TD * LS * MP	0.993	0.869	0.836	0.000	0.775
DP * PP * LS	0.000	0.000	0.000	0.000	0.000
DP * PP * MP	1.000	1.000	1.000	0.633	1.000
DP * LS * MP	1.000	0.999	0.998	0.162	0.994
PP * LS * MP	1.000	0.950	0.958	0.020	0.964

In the three-level factorial analysis of variance, each of the six problems was divided into three groups. To determine whether there is an interaction between the groups regarding performance, a univariate test was applied for each performance criterion. A summary of the results of the univariate tests can be found in Table VI. Interactions between rules affect the system. It cannot be said that the coexistence of rules that do not interact with each other has any effect on the system. Problems with MAGV routing are more likely to interact with one another. In other words, MAGV routing problems have a significant impact on the system.

4. CONCLUSION

In this study, six different production system problems are evaluated using simulation models. The six problems are investigated in an integrated manner as a contribution of this study by means of a simulation application. With the help of statistical data analysis methods, thousands of models were transformed into meaningful information.

Problems are ranked according to different performance criteria based on the rules used. Latency is often inversely proportional to early leave time. In the MAGV system, outputs and flow time are determined more by the four main problems than by the rules for assigning due dates. CON, NOP, SLK, and PPW rules have the best performance among due assignment rules. The NDTF rule performed better in the task assignment rules. In the delivery point selection problem, the SD rule provided the best results. The GOQ rule delivered the best results for selecting pickup points for MAGV. F_ID_F was the best rule for selecting MAGV loads. In the case of the machine priority problem, the WINQ rule was the most effective. There was no interaction between the due date and the machine priority rules. The interaction between the main problems of the MAGV system is more effective the system performance.

This study used an experimental data set. Using the dataset of a real workshop, a similar study could be conducted in the future. If waiting, delay, and early exit costs are considered in a real workshop, different conclusions may be obtained. The effect of different algorithms on the system can be examined by considering determining the parameters for the due date assignment rules in addition to the problems discussed in this study. Due date assignment was the focus of this study, so the rules determined as the best rules in the literature were applied to the other five problems. The integration of other existing rules that are not covered can be done in a more comprehensive manner.

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