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A dynamic in-plant milk-run system via agent-based modelling

Etmen tabanlı modelleme yöntemi ile tesis içi dinamik bir milk-run sistemi

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Abstract

Traditional vehicle routing problems aim to find a solution to minimize the total route cost under certain conditions. However, real-life problems consider different dynamic situations. One of the most common one is dynamic demand. To cope with the dynamism and management of its effects, such as unstable routes and route times, dynamic inventory turnovers are significant issues in in-plant transportation activities. The dynamic demand increases the dynamic movements within the facility. In this study, a milk-run model was developed to solve in-plant transportation problems under dynamic demand. The model was developed with an agent-based approach, which is an effective method in modeling complex and dynamic systems. The behavior of the model was analyzed with various scenarios through a sample case. As a result of the analysis, the efficiency of the model was shown. Based on the scenarios, considering performance measures such as average occupancy rate, average distance travelled, and average waiting time, a high number of trains with low train capacity suitable for the size of the system is recommended.

Keywords: Milk-Run System, Agent-Based Modelling, In-Plant, Dynamic Systems.

Öz

Geleneksel araç rotalama problemleri, belirli koşullar altında toplam rota maliyetini en aza indirecek bir çözüm bulmayı amaçlamaktadır. Ancak gerçek hayattaki problemler farklı dinamik durumları dikkate almaktadır. Bunlardan en yaygın olanı talebin dinamik olmasıdır. Dinamizmin ve değişken rotalar ve rota süreleri, dinamik envanter devirleri gibi dinamizmin etkilerinin yönetimi ile başa çıkabilmek tesis içi taşıma faaliyetlerinde önemli bir konu olmaktadır. Dinamik talep, tesis içindeki hareketlerin değişkenliğini artırmaktadır. Bu çalışmada dinamik talep altında tesis içi taşımacılık problemlerini çözmek için bir milk-run modeli geliştirilmiştir. Model, karmaşık ve dinamik sistemlerin modellenmesinde etkili bir yöntem olan etmen tabanlı yaklaşımla geliştirilmiştir. Modelin davranışı örnek bir durum üzerinden çeşitli senaryolarla analiz edilmiş ve modelin etkinliği ortaya koyulmuştur. Senaryolara dayalı olarak, ortalama doluluk oranı, ortalama mesafe ve ortalama bekleme süresi performans ölçütleri dikkate alındığında, sistemin büyüklüğüne uygun düşük tren kapasitesine sahip yüksek sayıda tren önerilmektedir.

Anahtar kelimeler: Milk-Run Sistemi, Etmen Tabanlı Modelleme, Tesis içi, Dinamik Sistemler.

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1 Introduction

The milk-run system concept is inspired by the milk distribution industry in United States. In this idea, while the number of distributors is limited, the number of customers is relatively high. In addition, milk distribution is done by cyclical tours. Distributors have two duties. These are, distributing full milk bottles and collecting empty bottles in a limited time [1]. Materials are distributed in standard routes within predetermined time intervals in the traditional milk-run systems. During the tour; the empty wagons are filled with materials in a central area (warehouse or supermarket) then the materials are distributed, the empty baskets are collected back from the stations, and the transport vehicles return to the starting area. In the distribution process, more than one basket or pallet is transported at the same time using train logic instead of a single-vehicle. Sadjadi et al. [1] mentioned that the milk-run system increases the logistics performance in assembly stations or other production areas. According to the authors, as a result of the implementation of the milk-run system, the effectiveness of the vehicles increases, the number of inventories decreases, the rate of inventories, and maintenance costs decrease, and there will be improvements in timely distribution. Domingo et al. [2] reported that by applying the milk-run system, the number of inventories could be reduced by 50%. Hanson and Finnsgard [3] showed that when milk-run train logic is used instead of forklifts, the area needed for inventories decreased by 67%, non-value-added works decreased by 20%, and distribution time decreased by 52%.

In the milk-run system, many interrelated decision problems should be solved for planning and controlling in-plant transportation activities. These problems are classified as follows according to Emde and Boysen [4];

- Layout problem; it includes problems such as determining the location of supermarkets and the placement of materials in supermarkets.
- Routing problem; it includes determining the number of trains and deciding on which route the trains use.
- Scheduling problem; this problem aims to find the most appropriate delivery times for the trains. Each train has a tour time. The tour times affect the number of tours. Tour times include both loading and unloading times at the stations.
- Loading problem; the purpose of this problem is to determine which type of material is transported in which quantities by the relevant train each cycle. Within the scope of this problem, it is aimed to minimize the amount of inventory in the stations, but

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the stations are not allowed to run out of inventory. Each train has a limited capacity.

In the literature there are various studies considering in plant milk run systems. In some of them authors developed mathematical models, heuristic, and metaheuristic algorithms to obtain optimal solutions to the problem [1], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14]. Besides optimization model simulation is one of most studied approaches in plant milk run studies in the literature especially in complex problems. Choi and Lee [15] did extensive dynamic planning by dealing with routing, scheduling, and loading problems together. In the scenario, the mixed-model assembly line was fed from a single warehouse. The feeding state of the assembly line was handled in two different ways; statically and dynamically. The amount of material consumption was fixed in the assembly line in the static condition, and the consumption amount was estimated dynamically in the dynamic state. The study aimed to minimize deviations in delivery time. The traditional vehicle routing method was used to solve the problem, and the study was simulated with real data. Faccio et al. [16] developed an integrated approach for the automotive industry, where the transportation between the mixed-model assembly line and the supermarket was carried out by trains. The problem was divided into short term and long term. Transportation problems that occurred while transporting materials with the trains were considered in the short term and analyzed by developing different dynamic simulation models. The optimization of the number of the Kanban was analyzed statically in the long term. Bae, Evans, and Summers [17] studied the effect of using a milk-run system in in-plant transportation with three simulation models. In the first scenario, a supermarket layout was determined horizontally, and in the second scenario the layout was analyzed with the vertical layout. In the study, the most suitable routes of supermarkets were compared. In the last scenario, the inventory demands of the stations were analyzed. Korytkowski and Karkoszka [18] proposed discrete-event simulation models for a milk-run system that feeds a traditional assembly line from a warehouse. The authors assumed that the milk-run system was already established in the production area and the routes and periods were already determined. The study aimed to analyze the inventory adequacy in stations, the usage of train operators, and assembly-line efficiency in various scenarios. Emde and Gendreau [19] discussed scheduling and loading problems for the train feeding the mixed-model assembly line. Guner et al. [20] analyzed the milk-run routing problem dynamically. Firstly, dynamic route plans were developed for the facilities and then simulated. In the second stage, the routes were determined by the stochastic time window dynamic programming method. In the last stage, a method with a time window was defined to increase the time-based performance of the milk-run delivery. Fedorko et al. [21] proposed a simulation model to identify critical failure points in a given delivery process based on the milk-run system. The model was developed in the Tecnomatix Plant Simulation program. According to the results obtained, a suitable solution was determined that would enable the whole process to operate more efficiently and reliably.

According to the literature of in-plant milk-run routing problems, it can be said that while routing problems are given wide coverage, there are few studies seeking solutions to the milk-run system in a dynamic environment, which especially consider the routing, scheduling, and loading processes simultaneously. However, in real life, the problem mostly has to be solved under various dynamics. Therefore, it is important to consider these dynamics to obtain effective solutions. The main contributions of this study are listed as follows: (i) to develop an in-plant milk-run system via agent based modelling focusing dynamic demand arrivals considering routing, scheduling, and loading problems simultaneously (ii) to develop a decision support system to the managers handling dynamic routes and periods for milk-run trains efficiently (iii) to eliminate required assumptions of analytic methods for solving the in-plant milk-run problem. In the developed model, production is done according to the dynamic demand. Therefore, the dynamism in the production amount also affects the amount of material to be transported and the route times [21]. Analytical methods are often not suffient to handle these dynamisms. Even if they are sufficient to resolve the system it may be necessary to restructure the all operations in the system according to every dynamic change. This is generally not applicable. In this study, the dynamic system based on this cyclical expedition is modeled using agent-based modelling approach and the effectiveness of the model is investigated with various scenarios. The proposed approach has a structure that constantly monitors dynamic changes and offers effective solutions to the managers. Agent based modeling is a promising approach for dynamic in-plant milk-run problems, since the nature of the problem is complex, dynamic, and large-scale. To the best of the authors knowledge, there are a few agent based studies in the literature on milk run systems. Kluska and Pawlewski [22] describes methodology of milk-run system design and implementation for intralogictic systems. They built a hybrid model combination of the discrete event and agent based simulation. The study provides methodology in general and the future work was planned as development of the tools used and implementation of the approach. Aragão et al. [23] evaluated different collobration strategies for dynamic vehicle routing in milk-run, where vehicles are assigned to picking up components and parts from Original Equipment Manufacturer suppliers. In the approach agents detect the unexpected traffic congestions, and then decide about the transference of tasks to other vehicles. The paper evaluates two strategies: the number of auxiliary vehicles, and the negotiation of tasks between vehicles. In the application regular vehicles assigned to picking up tasks, plus auxiliary vehicles, the excess of tasks allocate to regular vehicles is transfer to them if necesssary.

In the next section of the paper, the concept of the agent-based modelling is described. In section 3, the developed model is explained in detail and the analyses are given in section 4. In the last section conclusions and future works are presented.

2 Agent-based Modelling

The milk-run vehicle routing problem discussed in this study was solved by using an agent-based modeling approach, which is a successful method for modeling and analyzing dynamic and complex systems. In literature, in various kinds of routing problems, agent-based models are used and effective results are obtained [24], [25], [26], [27], [28], [29],[30],[31].

An agent is an active object capable of perceiving, reasoning, and acting. It is assumed that agents have the knowledge and that they have the mechanisms to use it. Another assumption is that they can communicate. This communication takes place in the form of receiving and sending messages. Agents communicate to improve their own goals or the goals of the system they are in. Some protocols and mechanisms are used to coordinate agents. One of these mechanisms is the auction mechanism, which is used, especially in systems with a high

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number of agents. The auction mechanism, which has been successfully used in many computer science applications, provides a relatively easy-to-analyze solution environment for the researcher in problem-solving. In the auction mechanism, there is usually an agreement between; one leading the auction and the one that offered the bid. The auction is held when the auction owner wants to sell a product at the highest price while the participants want to buy it at the lowest possible price. In agent-based modeling, it is possible to obtain effective solutions for the system addressed by using this mechanism [32]. The auction mechanism is used in the agent-based model developed in this study. The details of the model are explained below.

3 Agent-based Modelling for the Dynamic In-plant Milk-run Problem

A production environment based on dynamic demand causes changes in inventory requirements and in-plant distribution amounts and routes. Therefore, the traditional periodic milk-run routing is not sufficient in these kinds of environments. This study aimed to find an efficient solution to this dynamic planning problem using agent-based modelling. In the developed model, a manager agent provides the coordination between the station agents and train agents.

Behaviors of the station, train, and manager agents are defined and various duties are assigned to the agents. Within the model, the mechanisms are developed to reduce the waiting times of the stations, to increase the occupancy rate, and determine the departure times of the trains appropriately. Then, the effectiveness of the mechanisms is analyzed and discussed with various experimental scenarios. The model was developed in Anylogic™.

Assumptions of the model, the agents and their mechanisms are explained in detail in the following.

3.1 Assumptions of the model

The model was developed by considering the following assumptions;

- There is a sufficient inventory area for raw materials at the stations.
- The raw material consumption and production rates of the stations are equal.
- Each train only stops at the stations assigned and then returns to the warehouse.
- There are no route conflicts.
- The loading time of the materials in the warehouse on trains is not considered.

3.2 Agents in the model

Statecharts defining the agent's behaviors and features of the agents are as follows.

3.2.1 Station agent

If there is a demand in the system, each station agent produces according to its production time. When the raw material amount reaches the reorder point, it informs the manager agent of the inventory requirement. If there is not any raw material, the station agent stops production.

Figure 1 shows the statechart of the station agent. The agent has two states, such as "noDemand" and "production". When the amount of demand in the system is greater than zero, the agent goes to the "production" state and begins producing according to its production time. During the production, the current raw material amount and the demand value decreases and the production amount increases. When the inventory is equal to the reorder point, the required quantity and times are calculated by the station. Then, the manager agent is informed.

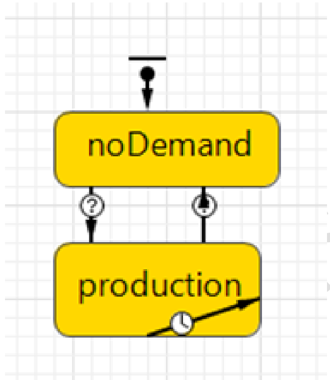

Figure 1. The statechart of the station agent.

3.2.2 Manager agent

The manager agent coordinates the other agents. Duties of the manager agent;

- Calling for bids
- Evaluating bids
- Assigning trains to the stations
- Informing the related agents of the auction results

Figure 2 shows the statechart of the manager agent. If there is a message received from any station and if there is at least one train waiting in the warehouse, the agent goes to the "callBid" state. In the "callBid" state, the agent sends a message to the train agents for preparing a bid. When all trains in the warehouse send a bid, then it goes to the "auction" state. In the "auction" state, the bids are evaluated and the relevant station is assigned to the selected train. The agent informs the results of the evaluation to the train agent and goes to the "available" state.

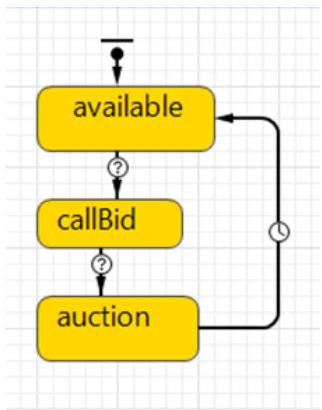

Figure 2. The statechart of the manager agent.

3.2.3 Train agent

The train agent is responsible for supplying the raw material requirements of the stations. The train distributes the materials to the stations that were assigned with the manager agent's decision. The duties of the train agent;

- Preparing and sending bids to the manager agent

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- Deciding to distribution time
- Distributing raw materials to the assigned stations

Figure 3 shows the statechart of the train agent. The "inTheWarehouse" state is the initial state for the train agent. The train that finishes the distribution process returns to the warehouse and waits there. When the manager agent is in the state of "callBid", it calls the train agent to prepare a bid, and the train agent goes to the "prepareBid" state. The prepared bid is sent to the manager instantly while in the "sendBid" state. The train agent periodically checks its departure time. If a train agent decides to depart, it becomes "onTheRoad" state. In the state, the agent informs the manager agent about its departure and starts distribution. After the distribution is over, it becomes the "inTheWarehouse" state. The train agent informs the manager agent about its availability.

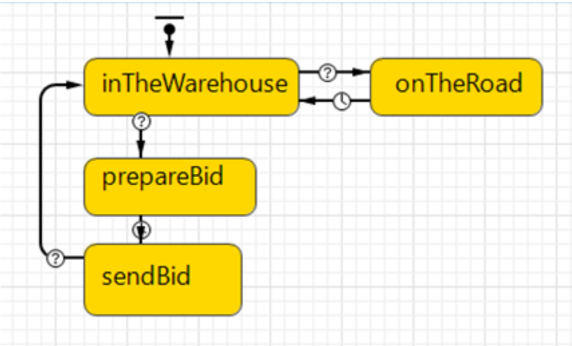

Figure 3. The statechart of the train agent.

3.3 Protocol of the model

The model protocol is explained in Figure 4. According to the protocol; the station agent goes to the "production" state for production when there is demand in the system. In the state, each station, also calculates the required inventory amount and time by the inventory control mechanism. Then, these calculated data are transmitted to the manager agent. The manager agent goes to the "callBid" state when it gets the data. In this state, it calls the train agents to the auction. The train agent goes to "prepareBid" state by this call. Each available train prepares a bid to satisfy the required inventory for the relevant station. The train agent that prepares the bid goes to the "sendBid" state and notifies the manager agent about the bid. The manager agent, which receives the bids from all the trains in the warehouse, goes to the "auction" state. Bids are evaluated according to the bid evaluation and decision-making mechanism, and the relevant station is assigned to the train determined by the manager. The trains decide to depart according to the departure decision mechanism. The train, which departs and completes the distribution process, returns to the warehouse and then waits for new calls from the manager agent.

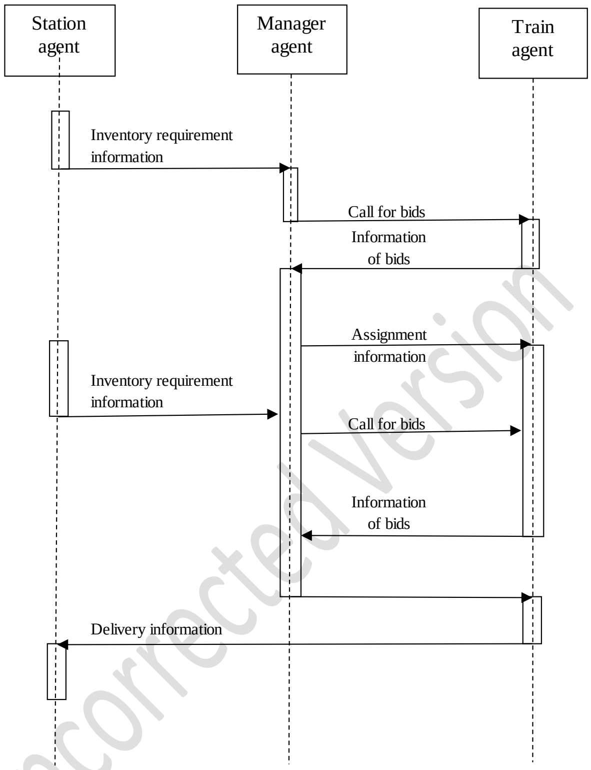

Figure 4. Protocol of the model.

3.4 Mechanisms in the model

It is aimed to reduce the waiting time for the station agent with the inventory control mechanism. In addition, the station agent determines the inventory requirement by this mechanism and, it informs the manager for the requirements. While the train agent prepares an offer for the relevant station with the bid preparation mechanism and informs the manager, the manager, who receives the bids, assigns the station to the relevant train with the bid evaluation mechanism. The train agent controls the departure status via departure mechanism which considers the occupancy rate and the on-time delivery status. The proposed approach concerns several mechanisms in order to gather an efficient dynamic milk-run system.

The details of the mechanisms are described in the following sections. The parameters and variables used in the mechanisms are given below.

Index i is used for the train agent, and index j is used for the station agent in the formulas.

3.4.1 Parameters

D_j: The amount of demand that the j^{th} station should meet
V_j: Production time of one product at the j^{th} station (minutes)
A_j: Reorder point of raw material of the j^{th} station
L_j: Inventory capacity of raw material of the j^{th} station
$Xcoordst_j$: X coordinate of the j^{th} station
$Ycoordst_j$: Y coordinate of the j^{th} station
$Xcoordtr_i$: X coordinate of the i^{th} train
$Ycoordtr_i$: Y coordinate of the i^{th} train
k: Train speed
f: The time for a train to leave a full wagon at the station and pick up an empty wagon from the station

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3.4.2 Variables

P_j: Production quantity of the *j^th^* station
S_j: Raw material inventory amount of the *j^th^* station
M_j: Demand of raw material amount of the *j^th^* station
H_j: The lead time of M_j of the *j^th^* station in order not to run out of inventory

T_{ij}: The time to leave raw materials at the j^th^ station by the i^th^ train
d_{ij}: Distance between *j^th^* station and i^th^ train
B_i: Bid value prepared by the *i^th^* train
C_i: Remaining raw material capacity of the *i^th^* train
n_i = Number of stations assigned to the *i^th^* train

3.4.3 Inventory control mechanism

The station agent has an internal transition when it is in the "production" state as seen in Figure 1. The transition is triggered by production time.

When the transition is triggered, the following steps are performed;

If (S_j > 0)

Calculate

$S_j = S_j - 1$

$D_j = D_j - 1$

$Pj = Pj - 1$

If ($S_j = A_j$)

Calculate

$M_j = L_j - A_j$

$H_j = A_j * V_j$

Request raw material from manager agent

Inform M_j and H_j values to the manager agent

3.4.4 Bid preparation mechanism

If the following conditions are met, the manager agent goes to the “callBid” state from the “available” state. Then it asks for a bid from each train agent.

- If there is at least one station requested for raw material
- If there is at least one train in the warehouse

When the i^th^ train agent gets the call, then it goes to "prepareBid" state and calculates a bid value considering the following steps for the jth station auctioned by the manager. Then, each train in the warehouse informs the manager.

Step 1: If $C_i \geq M_j$, go to step 2. Otherwise do not send bid to the manager.

Step 2: If one station is assigned to the train, calculate d_{ij} by Equation 1 considering rectilinear distance measure and T_{ij} by Equation 2. If more than one stations are assigned to the train, T_{ij} is calculated by taking these stations into account. Stations are arranged from near to far to the supermarket, and calculations are made considering rectilinear measurements between the points. For example, if the 5^th^ station is already assigned to the 2nd train and if a bid is calculated for the 7^th^ station, T_{25} is calculated, then the distance between 5^th^ station and 7th station is calculated (let’s call this measured distance ss) T_{27} will be $T_{25} + ss/k + f$.

Step 3: If $H_j - T_{ij} < 0$, this means that the j^th^ station will be late if it is assigned to the i^th^ train. This check is also done for all stations assigned to the relevant train before. If there is no late station, send T_{ij} as the bid value.

$$d_{ij} = \left|Xcoordtr_i - Xcoordst_j\right| + \left|Ycoordtr_i - Ycoordst_j\right| \quad (3)$$

$$T_{ij} = d_{ij}/k + f \quad (4)$$

3.4.5 Departure mechanism

With this mechanism, each train in the warehouse does a capacity and lateness check every minute. This checks whether the remaining capacity values are equal to zero. If the remaining capacity is zero, the relevant train performs the distribution process and returns to the warehouse. After the capacity check, the train does the lateness check, which is explained in section 3.4.4, considering the all stations assigned to itself. If there is any late station, the train starts distribution regardless of the remaining capacity.

3.4.6 Bid evaluation and decision making

If all trains in the warehouse send bids, the manager agent goes to the "auction" state and evaluates the bids as follows;

Step 1: If there is no bid, assign the station to a train with sufficient capacity. If at least one train is sent a bid, sort the bids from biggest to smallest then go to step 2.

Step 2: Assign the station to the train which has sent the biggest bid value and inform the train.

After the auction, the remaining capacity of the train, which the station is assigned, is updated.

An illustrative example that can clarify the role of the auction mechanism in the proposed approach is given in the following. Considering the case, while the system is running, let us look at the system some intervals of time in order the see the steps of the algorithm. In this example scenario the levels of factors in Table 2 is considered as 2, 125, 250, 50, 0.5 respectively.

The situation after the inventory level of the 8^th^ station is 50 is as follows: 3^rd^ station, 6^th^ station, 9^th^ station, and 10^th^ station has requested raw material, and the inventory levels of them 46, 41 42, 42. The stations are assigned to 2^nd^ train. Both 1^st^ train and 2^nd^ train are in the warehouse.

8^th^ station requested raw material from the manager agent and informs the requested amount and time informations as 100 and 100 respectively. Manager agent asks for a bid from each train.

Both 1^st^ train and 2^nd^ train send bid to the manager, bid values are 1.68, 4.321 respectively.

Manager agent assigns the 8^th^ station to 2^nd^ train since it has sent the biggest bid value.

The advantages of auction mechanisms make them a powerful tool for several problems concern resource allocation, especially in complex or competitive systems. Their ability to fairness (all participants have an equal opportunity to compete), easy decision making, dynamic adaptability (resources can be allocated in real time based changing conditions efficiently), competition (all participants offer their best possible price) make them promising in real life dynamic problems.

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3.5 Scenario assumptions

The effectiveness of the developed model was tested on a hypothetical system. In this milk-run system, there are 10 stations that work independently of each other and identical trains that distribute raw materials to the stations.

The assumptions of the model are as follows;

- Demands come to each station according to exponential distribution.
- Train speeds are constant and the value is 5 kilometers/hour. Since the model base time unit is the minute, the train speed is taken as 83.33 meters/minute.
- f is taken as 0.6 minutes.
- The coordination of the warehouses (50,0) (meter, meter).

Location coordination and production times of the stations are as in Table 1.

Table 1. Location coordination and production time of each station.

Stations	Coordination of the station (X, Y) (meter, meter)	Production time of the station (minute/piece)
1	(50, 10)	2
2	(50, 15)	3
3	(50, 20)	1
4	(50, 25)	5
5	(50, 30)	2
6	(50, 35)	2
7	(50, 40)	4
8	(50, 45)	2
9	(50, 50)	1
10	(50, 55)	2

4 Experimental Design

The feasibility and efficiency of the proposed approach are demonstrated with several scenarios. Scenarios are determined according to a full factorial experimental design and the results are analyzed. Five two-level factors are considered in the experimental design. Each experiment was run for five times for 7200 minutes (5 days * 24 hours * 60 minutes). The average values of results of the experiments were used in the analysis.

The factors and their levels are given in Table 2. The demand of each station is exponentially distributed and the rate parameter of the distribution is given in Table 2.

Tablo 2. Factors and their levels.

Factors	Levels
Number of trains	2; 3
Inventory of raw material (unit)	125; 150
Train capacity (unit)	250; 400
Reorder point (unit)	25; 50
The distribution parameter of the demand	0,5; 1

As a result of the experiments, the occupancy rate (%) of a train, the average occupancy rate (%) for the trains, the average number of tours, and the average distance traveled per tour are determined using Equation 5, Equation 6, Equation 7, and Equation 8, respectively. For the stations, the average waiting time is considered as the performance criteria and calculated using Equation 9.

$$\textit{Occupancy rate} = \textit{The total transported amount} \div (\textit{Train capacity} \times \textit{total number of tours}) \quad (5)$$

The occupancy rates for each train are summed to set the total occupancy rate value and the average occupancy rate is determined, as in Equation 6.

$$\textit{Average occupancy rate} = (\textit{Total occupancy rate} / \textit{Number of trains}) * 100 \quad (6)$$

$$\textit{Average number of tour} = \textit{Total number of tours of trains} / \textit{Number of trains} \quad (7)$$

$$\textit{Average distance traveled per tour} = \textit{Total distance traveled by trains} / \textit{Total number of tours} \quad (8)$$

$$\textit{Average waiting time} = \textit{Total waiting time of stations} / \textit{Number of stations} \quad (9)$$

The effect of the change in the factors on the average occupancy rate is examined by considering the main effect plot in Figure 5. The analysis shows that the change in demand, inventory capacity, and reorder point does not have a significant effect on the average occupancy rate. The p-value of the effects 0.712, 0.738 and 0.056 respectively. Since the p-values>=0.05, the factors have no statistically significant effect. The p-values of the effects of number of trains and train capacity are 0. The plot shows that the change in demand and inventory capacity does not have a significant effect on the average occupancy rate. In the figures, low level values of factors are shown with (-1) and high-level values with (+1). Here, the statistically significant effect belongs to the train capacity and the number of trains. The interaction plot in Figure 6 shows that when the train capacity is low, the change in the number of trains has little effect on the occupancy rate. According to the main effect plot, when the train capacity is 250, the occupancy rate is 81.43%. Having a capacity of 400 reduced the average occupancy rate to 69.47%.

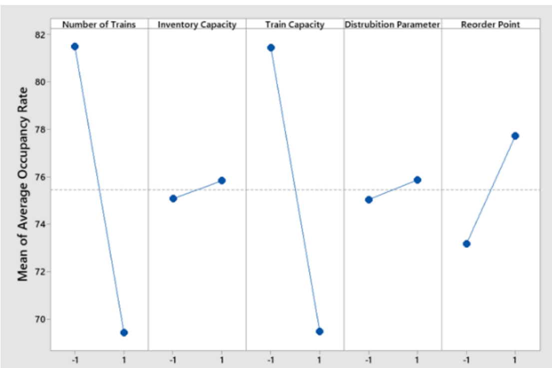

Figure 5. Main effect plot of the average occupancy rate (%).

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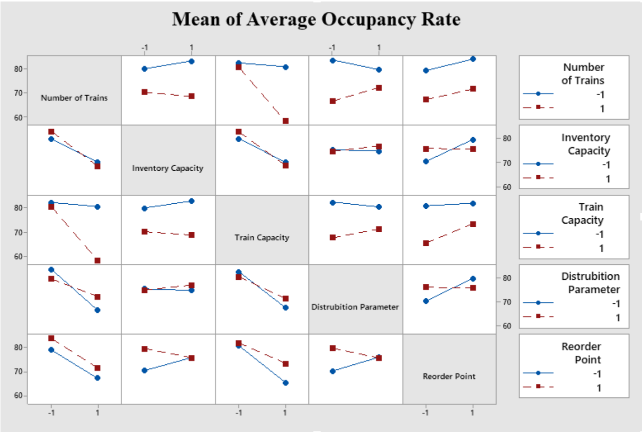

Figure 6. Interaction plot of the average occupancy rate (%).

Figure 7 shows that the most effective factor on the average distance traveled per tour is the reorder point. Train capacity and inventory capacity are also effective factors. The p-values of these factors are 0. The average distance traveled by trains decreases when the reorder point is 25 units, the train capacity is 250 units, and the inventory capacity is 150 units. The interaction plot in Figure 8 supports this.

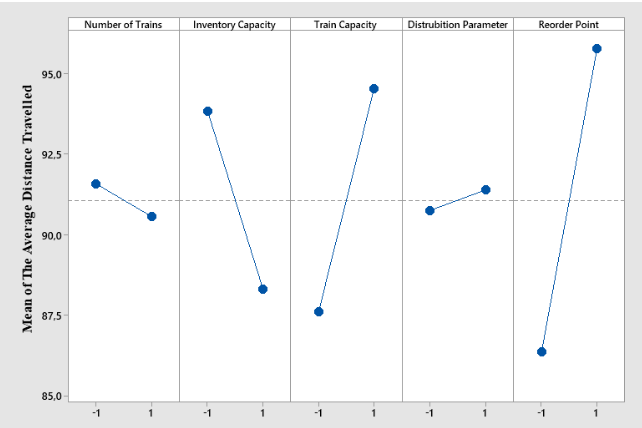

Figure 7. Interaction plot of the average distance travelled.

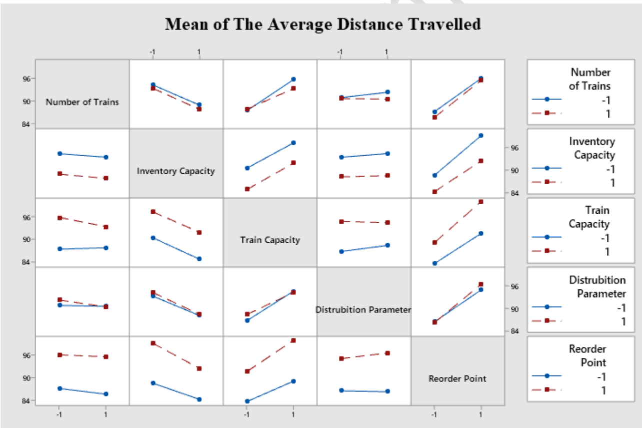

Figure 8. Interaction plot of the average distance travelled.

As shown in Figure 9, number of trains, train capacity, the distribution parameter of demand, and reorder point values affect the number of tours statistically significantly. Since the p-values of the effect 0, 0, 0, and 0.003 respectively. As expected, the average number of tours increases when the demand parameter is high, and the average number of tours decreases when the demand parameter is low. Figure 10 shows that the number of tours decreases significantly when the train capacity is 400 and the number of trains in the model is assumed to be 3.

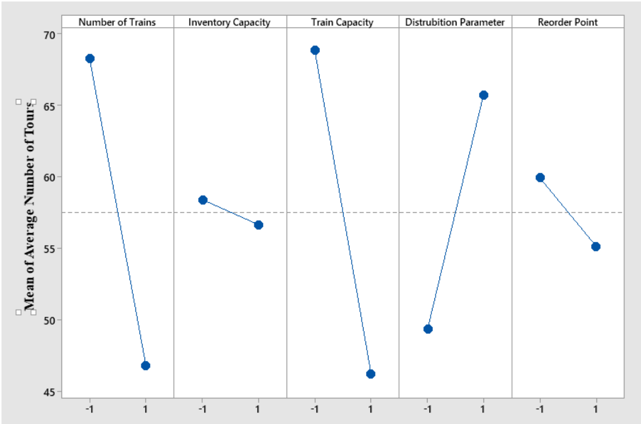

Figure 9. Interaction plot of the average number of tours.

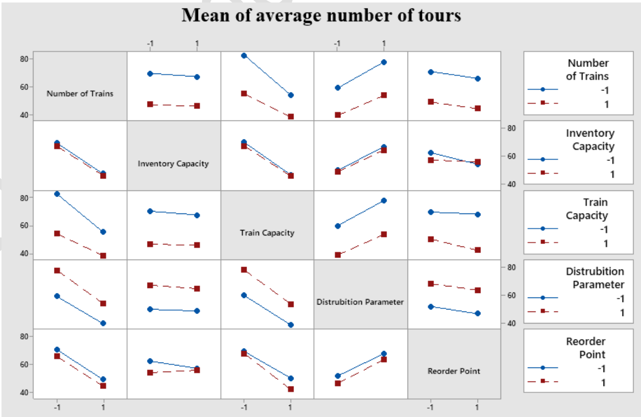

Figure 10. Interaction plot of the average number of tours.

The test results in terms of average waiting time are shown in Figure 11, and the information about the first five experiments with the highest and lowest average waiting times is given in Table 3. The results show that when the distribution parameter is high, the waiting time is likely to be high. We can also say that the high inventory capacity relieves the production system, considering the waiting time.

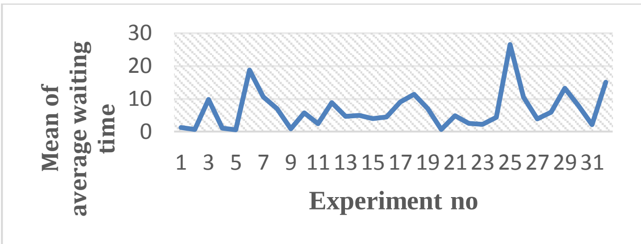

Figure 11. Changing of the waiting time chart.

Table 3. Highest and lowest values for waiting time (minutes).

Experiment no	Lowest value	Highest value	Number of trains	Inventory capacity	Train capacity	Distribution parameter	Reorder point
5	0.6		2	150	250	0.5	25
2	0.7		2	150	400	0.5	50
20	0.7		3	150	250	0.5	25
9	0.9		3	150	400	0.5	50
4	1.1		2	150	400	0.5	25
18		11.4	2	150	400	1	25
29		13.2	3	150	250	1	50
32		15.1	2	125	250	1	50
6		18.78	2	125	250	1	25
25		26.5	2	150	250	1	50

Considering the test results, generally, we can say that the effect of the factors in the performance criteria function as expected. In fact, this is an indication that the proposed approach effectively manages the dynamic milk-run system. Furthermore, determination of levels of the factors is simple and efficient via experimental design. According to performance measures such as average occupancy rate, average distance travelled, and average waiting time, a high number of trains with low train capacity suitable for the size of the system is appropriate. Managers can consider the number of trains, inventory of raw material, train capacity, and reorder point as 3, 150, 250, and 25 respectively both in case of low demand and in case of high demand. In the case of high demand, especially if the number of tours is desired to be low, train capacity can be taken as 400.

Once the parameters are determined, the system will make its own milk-run flow decisions during its operation under dynamic demand. Thus, the proposed approach is a promising decision support method for managers. In many cases of the real milk-run problem, dynamism should be considered to obtain effective results. But with traditional methods. It is often not possible to solve the problem for every dynamic change because it is too costly. With this approach, effective decisions can be made in the running system without disturbing the complete system.

5 Conclusions

In this study, in-plant transportation activities in a dynamic environment are discussed. In the proposed approach, the milk-run system is modelled using agent-based modelling, which is an effective method for dynamic systems.

In-plant transportation, route planning, scheduling and loading are major problems. Especially in discrete manufacturing systems, production rates and frequency of demand vary in real cases. Due to these variations, it is not possible for trains to always follow the same routes. This study aimed to provide a promising model that could handle this variability. In the model, stations and trains are considered agents. To operate the system more effectively, a departure mechanism for train agents and an inventory control mechanism for station agents were developed. The manager's decision process was structured by the auction mechanism. The behavior of the developed model was analyzed using scenarios created from an example. Considering the results of the scenarios, the number of trains, capacities of trains, the inventory capacity of the stations, the reorder point, and the distribution parameter of the demand are analyzed.

The goal is to reduce the waiting time for the raw material of the stations while increasing the occupancy rate of the trains through the departure and auction mechanism. In addition, the inventory control mechanism aims to reduce the waiting time for the raw material in the stations. The presence of a decision-making agent in the model strengthens the communication between agents. The scenario analyses show that the proposed model can effectively deal with dynamic demand.

The in-plant milk run system is particularly effective in many sectors; automotive industry, packaging industry, food industry, consumer goods manufacturing industry, textile industry etc. However, if these industries concern dynamism in their operations, the traditional milk run approach is not sufficient for managing in-plant transportation activities. Since it requires frequent, reliable, and well coordinated transportation. For both these industries having stable transportation but studying under dynamism and other sectors which do not meet the requirements of using milk run method to take the advantages of milk run approaches, there is a need for an approach which monitors dynamic changes and ensures the effective implementation of the milk run methodology under these dynamic conditions. The proposed approach is aimed at addressing the gap in this area. Today's technology enables to monitor the data in systems instantaneously considering different tools such as RFID systems and enables the use of these data in various industries. The proposed approach provides to use these data on managerial states of the milk run system efficiently.

Other types of dynamics, such as dynamic situations in the manufacturing operations and trains, can be considered for future work. For example, the proposed method can be developed by considering dynamic situations such as station failures, inability to supply raw materials, train breakdowns, etc. Modeling and solving these dynamics with the proposed method is much more effective compared to traditional methods. Since most of the traditional methods presents a new solution in every dynamic change and every new solution affects the entire system. But, it is often not possible to restructure the operations in all the processes. Managers can make dynamic decisions with the proposed approach, which consider the dynamics and offers effective solutions without disturbing the whole system. Furthermore, different agent control and bid determination mechanisms can be used to find a more efficient approach. Also by removing each assumption considered in the model, a more realistic approach can be obtained. Although the model is created with the specified assumptions, it will be much easier to remove these assumptions with the proposed method if necessary. The

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existence of individual characteristics, behaviors, and communication abilities of the agents enables this situation. The proposed approach can be applied to a real-world problem.

6 Author contribution statement

In the present study, Author 1 took part in the literature review, methodology, modelling, performing the analyses, writing the original draft. Author 2 contributed to the methodology, modelling, writing-review editing, supervision.

7 Ethics committee approval and conflict of interest statement

There is no need for any permission from ethics committee for the article prepared.

The authors report no conflict of interest.

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