Production and distribution scheduling optimisation in a three-stage integrated supply chain using genetic algorithm

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Abstract: This paper addresses an integrated P-D scheduling model arising in a three-stage supply chain, which involves three stages: a single vehicle after processing by different suppliers, manufacturers, distributors and consumers located in separate geographic regions. The contribution of this paper is to provide an integrated P-D scheduling under fixed departure times in supply chain with consideration of transportation fleet, integration of supplier-manufacturer. The mathematical model was proposed as a mixed integer programming and solved by CPLEX software in small-scale problems to validate the model. Given the complexity of the solution and NP-hard structure of the proposed problem, genetic algorithm was used to find quality solutions by MATLAB software. Finally, the results of research show that managers of the case study can deliver orders to customer in minimum time and cost. According to the results, the proposed algorithm (GA) has a desired level of quality in solving the P-D real problems.

Keywords: scheduling; supply chain; genetic algorithm; GA; optimisation; transportation.

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1 Introduction

Organisations of the 1960s and 1970s used to standardise and improve internal processes to increase their competitive power in order to provide better quality products with lower production costs. By diversification of customer expectations in the 1980s, organisations increasingly interested in enhancing flexibility of accepting new production lines and developing new products to satisfy customers requirements (Shahrezaee et al., 2012). Producers are under continuous pressure to improve their productivity by providing lower-cost goods and increased customer support (Ghadimi et al., 2020). The emergence of new technologies and the enormous change in global markets have forced various organisations to use supply chain management (SCM) theories to create and maintain their competitive position. One of the most important topics is SCM in industrial science with high product variation and small work orders volumes (Yilmaz, 2020). The information revolution and the emergence of new forms of corporate interconnection and increasing customer expectations for the cost of products and services, quality, delivery, technology and commitment cycle time due to increasing competition in global markets are among the factors that change the system (Rasi, 2018). The success of a firm in a turbulent and unpredictable environment of today's world will intensely depend on its ability to coordinate in a complex communication network among the supply chain partners (Lambert et al., 1990). A supply chain illustrates all the stages which add value to a product. The supply chain includes all the relationships between suppliers, manufacturers, distributors, and customers (Chang and Lee, 2004). In this way, materials are moved from upstream layers as suppliers, distributed to producers to deliver final products, and final products are delivered to consumers, retail markets, the last clients through transportation frameworks (Ma et al., 2016; Sarrafha et al., 2015). Production and distribution (P-D) arranging in prepare which decrease costs and increase the productivity of the related supply chain. Subsequently, interfacing competition and P-3D arranging can offer assistance considered supply chain increment market share and hence gain more benefit by drawing in more client orders (Rafiei et al., 2018). Within the supply chain background, competition between same levels of a chain is known as a level competition separated into "in-chain and chain-to-chain horizontal competition categories" (Mahmoodi and Eshghi, 2014). As an integrated approach for proper flow of materials and goods, information, and the ability to respond quickly to environmental conditions and determine the number of suppliers, as well as finding a method for the best relationship with the supply is one of the most important issues in the SCM. Improving overall customer value, reducing production and development costs, innovation, increasing flexibility, so product development is one of the many strategic given to companies by SCM (Dolgui et al., 2005). Production and transport scheduling are usually taken in an organisation in a sequential fashion, where production schedules are first set by the production department, and the transport schedules are then set by the logistics department, which does not result in the best scheduling decisions (Guo et al., 2017).

The purpose of this paper is to allocate jobs to suppliers and vehicles in such a way that the orders is delivered to the owners at the minimum time possible. The model addresses simultaneous minimisation of the orders time to complete in a supply chain. Since this problem is in among the NP-Hard problems, meta-heuristic algorithms and mathematical programming solving methods have utilised in order to solve the proposed model. For solving the mixed integer programming (MIP) model, we used GA algorithm by MATLAB software. This part aimed to determine the orders allocation to vehicle suppliers so that the orders delivery time would be optimised simultaneously in the transport sector. Based on the aforementioned contemplations, this article addresses the problem of production-distribution in a three stage integrated supply chain and time considerations. Exploring such a theoretically challenging and essentially significant issue problem, four contributions in this research are made as follows:

1. The paper is the first to work on a three stage integrated supply chain scheduling problem in which the minimisation the time to complete the order.
2. A novel integrated production scheduling and distribution model is presented under fixed departure times in an arborescent supply chain.
3. We show that the problem is NP-hard in the strong sense when the number of customers is arbitrary.
4. We will provide mathematical model with consideration of transportation fleet, integration of supplier-manufacturer, continuous time and random search (RS) technique.

The main question of this study is to how can be optimised P-D in a three stage integrated supply chain simultaneously in continuous time by mathematical programming model? The rest of the study is structured as follows: Section 2 briefly reviews the related literature of this paper. In Section 3, a single objective model is proposed for manufacturing, transportation and distribution allocation decisions integrated in a supply chain network. Using the multiplicity of supplying sites and combining this problem with the vehicle routing problem (VRP), the model will be minimised the orders make span to arrive at the main manufacturer, or the order owner site, and ultimately to the consumer. The model of this research including suppliers, transport fleet and site of production has been selected as the studied model. Section 4 describe the problem statement and provide preliminary analysis. The results and discussion for the problem have been mentioned in Section 5. The managerial implication will be provided in Section 6. Finally, conclusions and future studies work will also be presented in Section 7.

2 Background of integrated SCM

Due to intense competition between manufacturers, companies have to optimise their supply chain rather than improve their organisations to enhance their competitiveness in the market. The supply chain is made up a set of suppliers, manufacturers, and distributors, whose goal is to meet customer requirements. Chang and Lee (2004) investigated the timing of machinery in the supply chain. Their study simultaneously addressed machine scheduling and final product delivery and specifically, the situation where different amounts of storage space are needed during delivery. The mentioned problem includes production, transportation and delivering orders to customers. The objective function was to minimise the maximum orders completion times. Altiparmak et al. (2006) proposed a novel process based on genetic algorithm (GA) to find a set of Pareto optimal solutions for the multi-objective supply chain design problem in a plastic manufacturing plant in Turkey. Shaik and Floudas (2007) proposed an improved model for short-term scheduling of continuous processes, and investigated the modelling results in a mixed integer linear programming model. Li and Wormer (2008) investigated the supply chain configuration problem under resource constraints, and proposed a new model based on project scheduling with multiple resource constraints and in this way, The bridge between project scheduling and supply chain design, and solve the problem using the constraint planning (CP) approach which is among the optimisation methods in operation research. Sawik (2009) presented a MIP for scheduling the production of raw materials, supplying and producing raw materials in a customer-oriented supply chain, and two integrated hierarchal approaches were formulated by modelled using computational tests. Averbakh (2010) investigated the online scheduling in supply chain including a manufacturer and several customers with the goal of minimising the total weight of orders flow. Scholz-Reiter et al. (2010) studied the integration of production and transportation in a supply chain and presented a mathematical model for solving the problem. Their research proposed a framework for evaluating operational interfaces, tactics and strategies between transportation and production systems in the supply chain. Bhatnagar et al. (2011) provided transportation and scheduling programming in two types of air and sea transport. The most important contribution of this study was to analyse the benefits of planning and scheduling decisions coordination. Yeung et al. (2011) studied two-stage supply chain scheduling considering several shared delivery timeframe aiming to minimise transportation and inventory costs. They developed pseudo-polynomial dynamic algorithms, robust and related methods in the supply chain for achieving efficiency.

Osman and Demirli (2012) have examined the delivery scheduling and the economic-lot-quantities in three-stage and multi-product supply chain. They proposed a new model based on the double allocation problem for the problem, which determines a shared cycle of synchronisation of filling and evacuation of warehouses. This research utilises nonlinear mathematical model and hybrid algorithm including linearisation techniques, external approximation, and flexibility. Ullrich (2013) has addressed the integration of vehicle scheduling and routing considering timeframes. This research integrated distribution and production scheduling to minimise interferences. Selvarajah and Zhang (2014) investigated the supply chain scheduling in which, a manufacturer receives semi-finished materials from suppliers at different times and delivers finished goods to customers in batches. The research examined the producer supply chain scheduling problem to minimise maintenance and distribution costs, used a meta-heuristic hierarchical algorithm. Hao et al. (2015) studied the relationship between the suppliers and producers and investigated the production and transportation planning problem in these conditions. Hein and Almeder (2016) considered the P-D problem in the supply chain in two modes of ready to transport and just in time production. They examined the effect of different parameters on the amount of financial efficiency in their model, and developed an integrated model for production planning and procurement routing using clustering, heuristic, mathematical formulation and numerical tests. Amirtaheri et al. (2019) investigated a decentralised P-D supply chain consisting of one producer and one distributor. The producer decides about wholesale price, production interval, cost of advertising, and participation rate in the distributor's local advertising costs. Borumand and Beheshtinia (2018) proposed an integrated decision making approach for the integrated production and transportation scheduling problem in a two-stage supply chain. The functional objectives in their research include minimisation of delivery integration, product cost and maximisation of product quality that firstly, a mathematical model is provided and then, the problem was solved based on the combination of GA and VIKOR. Ganji et al. (2020) proposed MIP in a supply chain scheduling problem which the minimisation of fuel cost, carbon emission, customer dissatisfaction, and multiple time windows are considered simultaneously.

The review of literature in the research background indicates that many models and algorithms have been proposed for optimising production and transportation in the supply chain. This paper is focused to design the integration of P-D as a constructive and online relationship between the supplier's production and the transport system of companies in Emerson Group. The transportation system was used in this research is a shared transportation system which considering different capacities for vehicles. In this study, time factor is considered as one of the important factors in P-D scheduling in a three-stage supply chain and therefore researchers seek to minimise the delay period in the orders delivered to customers on time. On the other hand, as the mentioned above, the study of orders in different geographical points was also tried to address these orders in the shortest possible time considering the distance between suppliers, manufacturers and distributors. Given the frequency of optimisation algorithms, we tried to use the best and most appropriate algorithm to solve this problem. After reviewing the research background and the various algorithms, the GA was identified as the most appropriate solution for optimising this shared transportation system.

3 Problem definition and mathematical formulation

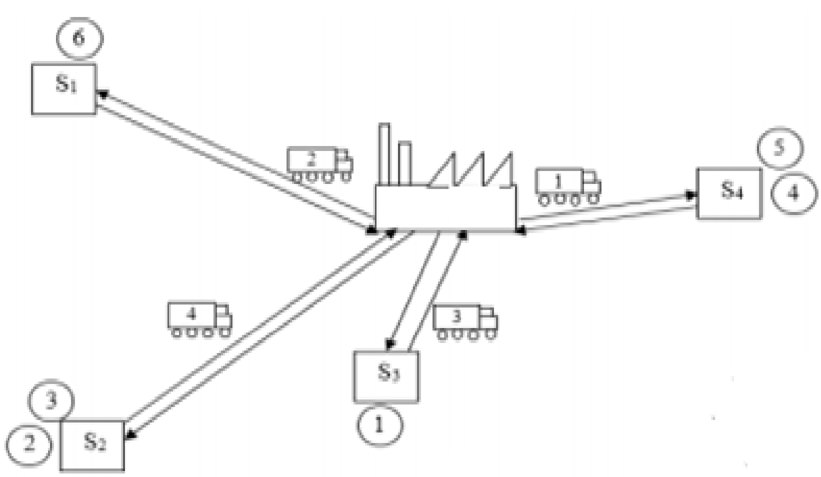
The problem of optimisation in a multistage supply chain environment with different orders is considered as a three-stage supply chain consisting of multi-orders, retailers (markets) and suppliers. The main objective of this paper is to minimise the time to complete the order i in stage j. In this research supply chain network model for different orders has been adopted from Beheshtinia and Akbari (2016). Therefore, in this problem considered items such as the rate of entry and exit to the chains and the impossibility of passing through each supplier more than once time and entering the vehicle in each transport from the factory to two or several suppliers. Further above each supplier has its own unique geographical position and a given distance to other suppliers and the main factory is in this problem. This paper aimed to investigate the production and transportation scheduling problem in a supply chain. The first stage includes suppliers, the transportation fleet of goods, and a manufacturer of finished products. The assumptions of the problem are as follows:

- There are n orders which should be carried by a transport fleet consisting of a single vehicle after processing by m different supplier that located in separate geographic regions.
- The final products should move towards the manufacturer.
- Some suppliers may have higher production speed than other suppliers because of possessing more equipment and machines and produce the materials required by the manufacturer more quickly, that this speed is based on (machine-hour) per (time).
- The vehicle in the transport fleet may also have different speeds, which is assumed constant throughout the entire route.

- The speed and capacity may be different for each vehicle. The carrying capacity of a vehicle is defined by the volume or weight of goods that can be carried by the vehicle at once.
- Officials are in different geographic coordinates.
- The distance between the suppliers can be ignored, and each one is at different distances from the manufacturer company.
- Each order occupies a different capacity of the vehicle.
- In this case, i.e., Emerson Group, the vehicle should be returned to carry the next shipment to the supplier and, as a result, the return time must also be considered in the scheduling.
- Every vehicle can carry orders of various suppliers in one shipment.
- The time to completion of each order is the time that the order is delivered to the manufacturer.

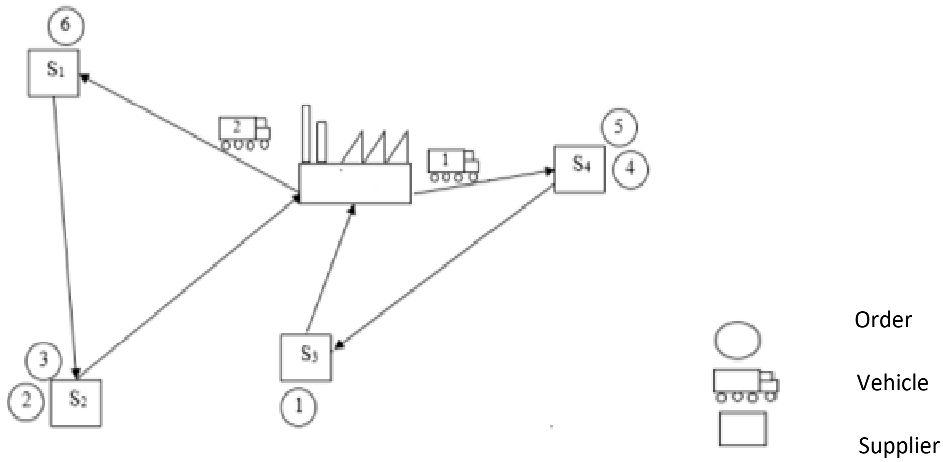
If orders arrive at the manufacturer before the lower bound of the time frame, then the time frame should wait until the lower bound of the time frame and the delay of each order is the difference between the time of completion of an order and the upper bound of its delivery. The objective is to minimise orders delay considering the constraints on assigning orders to suppliers, determining production sequences from suppliers, assigning orders to vehicles, and determining the transport priority of orders by vehicles. Figure 1 is an illustration of the problem studied in this research, there are six orders and four suppliers, so that order 6 is assigned to the supplier 1, orders 2 and 3 are assigned to the supplier 2, order 1 is assigned to supplier 3, and orders 4 and 5 are assigned to supplier 4. In Figure 1(a), suppliers independently send their orders to the manufacturer. Figure 1(b) illustrates a situation in which suppliers use a shared transport fleet to send their orders to the manufacturer. The type of supplier cooperation in using the shared transport fleet is VRP type.

Figure 1 A framework of the research



(a)

Figure 1 A framework of the research (continued)



(b)

3.1 Formulation P-D scheduling in a three stage integrated SC

This section formulates the P-D scheduling in a three stage integrated SC problem based on the model of Beheshtinia and Akbari (2016). The main objective is to minimise time of completion the order i in stage j in the supply chain. The indices, parameters and variables of the mathematical model of the problem are presented in this section.

Table 1 Indices and parameters

Indices	
w_i	Ordering index (w, i = 1, …, n)
s	Supplier index (s = 1, …, m)
k	Vehicle index (k = 1, …, l)
b	Shipment index (b = 1, …, n)
Parameters	
n	Number of orders
m	Number of suppliers
l	Number of vehicles
vol_i	Occupied capacity by order i
cap_k	The capacity of the k^{th} vehicle in terms of the number of orders
P_{is}	The i^{th} order processing time in the s^{th} provider
$tt_{ks}o$	Shipping time from supplier s to manufacturer by the k^{th} vehicle
$tt_{ks}s_o$	Shipping time from manufacturer to supplier s by the vehicle k
$tt_{kss'}$	Shipping time from supplier s to supplier s by vehicle k
Q	A very large number

Table 1 Indices and parameters

Decision variables	
c_{ij}	The time to complete the order i in stage j, j = 1, 2
c'_i	The order i loading time order on one of the vehicles for transport
av_{kbi}	When the vehicle k is ready to transport the order i in the b^{th} mission
Fin_{kb}	When the vehicle k is ready to deliver all orders assigned to the b^{th} shipment
$Ready_{kb}$	When the vehicle k is ready to carry out the b^{th} mission
X_{si}	If the order is given to the s^{th} supplier is equal 1, and 0 otherwise
Y_{iw}	If the order i placed before the order w is 1, and 0, otherwise
	It is equal to one, otherwise it is zero
Y_{kib}	If the order i is assigned in the b^{th} transport to the vehicle k is equal 1, and 0, otherwise
$Visit_{kibs}$	If the k vehicle loads i^{th} order in its b shipment from the provider s is 1 and 0, otherwise
r_{0s}^{kb}	If the k^{th} vehicle goes from factory to the supplier s in its b^{th} mission is equal 1 and 0, otherwise
$r_{0ss'}^{kb}$	If the k^{th} vehicle goes from the supplier s to the supplier s for the t^{th} time in its b^{th} mission is equal 1 and 0, otherwise
r_{s0}^{kb}	If the k^{th} vehicle goes from the supplier s to the manufacturer in its b^{th} mission is equal 1 and 0, otherwise
C_i	The delay of the i^{th} order

The mathematical model for the P-D scheduling problem is formulated as follows:

$$\text{Min}Z = \sum_{i=1}^{n} C_i$$

S.t.:

$$\sum_{s=1}^{m} x_{si} = 1 \quad \forall i \tag{1}$$

$$\sum_{k=1}^{l} \sum_{b=1}^{n} z_{kib} = 1; \quad \forall i \tag{2}$$

$$\sum_{i=1}^{n} vol_i \times z_{kib} \le Cap_k; \quad \forall k \forall b \tag{3}$$

$$c_{i1} \ge p_{is} - Q(1 - x_{si}); \quad \forall i \forall s \tag{4}$$

$$\begin{matrix} c_{1i} + Q*(2 + y_{iw} - x_{si} - x_{sw}) \ge c_{1w} + p_{is} \\ c_{1w} + Q*(3 - y_{iw} - x_{si} - x_{sw}) \ge c_{1w} + p_{ws} \end{matrix}; \quad \forall i, w \forall s \tag{5}$$

$$y_{iw} = 0; \quad \forall i, w \tag{6}$$

$$r_{0s}^{kb} + \sum_{s'=1}^{m} r_{s',s}^{kb} = r_{s0}^{kb} + \sum_{s'=1}^{m} r_{s,s'}^{kb}; \quad \forall k \forall b \forall s \tag{7}$$

$$r_{s0}^{kb} + \sum_{s'=1}^{m} r_{s,s'}^{kb} \leq 1 \tag{8}$$

$$r_{s,s}^{kb} = 0 \tag{9}$$

$$\sum_{s=1}^{m} r_{0s}^{kb} \leq 1; \quad \forall k \forall b \forall s \tag{10}$$

$$\sum_{s=1}^{m} r_{0s}^{kb} \leq \sum_{i=1}^{n} z_{kib}; \quad \forall k \forall b \forall s \tag{11}$$

$$\begin{aligned} &Visit_{kibs} \leq 0.5(z_{kib} + x_{si}) \\ &Visit_{kibs} \leq z_{kib} + x_{si} - 1 \end{aligned}; \quad \forall k \forall b \forall i \forall s \tag{12}$$

$$r_{0s}^{kb} \leq \sum_{i=1}^{n} Visit_{kibs}$$

$$r_{s0}^{kb} \leq Visit_{kibs}; \quad \forall k \forall b \forall s \tag{13}$$

$$\begin{aligned} &r_{0s}^{kb} + \sum_{s'=1}^{m} r_{s',s}^{kb} \geq 1 / Q * \\ &\sum_{i=1}^{n} Visit_{kibs} \end{aligned} ; \quad \forall k \forall b \forall i \forall s \tag{14}$$

$$\sum_{s=1}^{m} r_{0s}^{kb} \geq \frac{1}{Q} \sum_{i=1}^{n} Z_{kib} \tag{15}$$

$$\sum_{s=1}^{m} r_{0s}^{kb} \geq \frac{1}{Q} \sum_{i=1}^{n} Z_{kib}; \quad \forall k \forall b$$

$$\sum_{i=1}^{n} z_{ki(b+1)} \leq Q * \sum_{i=1}^{n} z_{kib}; \quad \forall k \forall b \forall i \tag{16}$$

$$c_i' \geq av_{kbi} - Q * (1 - z_{kib}); \quad \forall k \forall b \forall i \forall s \tag{17}$$

$$c_i' \geq c_{1i} \tag{18}$$

$$\begin{aligned} &av_{kbi} \geq c_w' + tt_{ks's} - Q * \\ &\left(5 + y_{iw}' - z_{kib} - z_{kwb} - x_{ws'} - x_{si} - r_{s',s}^{kb}\right) \end{aligned} \tag{19}$$

$$av_{kbw} \geq c'_i + tt_{kss'} - Q * \left(6 - y'_{iw} - z_{kib} - z_{kwb} - x_{ws'} - x_{si} - r^{kb}_{s,s'}\right); \quad \forall w \forall i \forall k \forall s \forall s' \forall b$$

$$y'_{iw} = 1 - y'_{iw}; \quad \forall w \forall i \tag{20}$$

$$fin_{kb} \geq left_{kbs} + tt_{ks0} - Q * \left(1 - r^{kb}_{s0}\right); \quad \forall k \forall b \forall s \tag{21}$$

$$ready_{k(b+1)} \geq fin_{kb}; \quad \forall k \forall b \tag{22}$$

$$left_{kbs} \geq c'_i - Q * \left(2 - z_{kib} - x_{si}\right); \quad \forall k \forall b \forall i \forall s \tag{23}$$

$$left_{kbs} \geq left_{kbs'} + tt_{ks's} - Q * \left(1 - \sum_{t=1}^{n} r^{kb}_{s',s}\right); \quad \forall w \forall i \forall k \forall s \forall b \tag{24}$$

$$r^{kb}_{s,s'} \geq z_{kib} + z_{kwb} + x_{si} + x_{ws'} + y_{iw} - 4; \quad \forall w \forall i \forall k \forall s \forall s' \forall b \tag{25}$$

$$c_{2i} \geq fin_{kb} - Q\left(1 - z_{kib}\right); \quad \forall k \forall b \forall i \tag{26}$$

Equation (1) indicates that each order should only be assigned to a single supplier. Equation (2) shows that each order should only be assigned to a vehicle and to one shipment. Relation (3) ensures that the total amount of occupied space should not exceed the capacity of that vehicle by the orders assigned to a vehicle in each shipment. Relation (4) consider the time of completion of each order at the suppliers stage, given the time of preparation of orders. Relation (5) states that each supplier cannot process more than one order at any time. Relation (6) deletes some of the redundant variables. Relation (7) guarantees that the number of entrants to the suppliers must be equal to the number of exits. Relation (8) ensures that the k^{th} machine does not pass of each supplier more than once for shipment b. Relation (9) eliminates some of the variables in the problem. Relation (10) states that the k^{th} vehicle cannot go direct from the factory to two or more suppliers in its b^{th} shipment. Relation (11) states that the k^{th} machine can only leave the origin when it is supposed to carry an order to carry the b^{th} shipments. Relation (12) determines whether the k^{th} vehicle load order i from the supplier S in its b^{th} shipment. This can be done with the help of the definition an auxiliary variable called $Visit_{kibs}$. Also, Relation (13) indicates that the vehicle k in its b shipment can only be entered directly from the factory to a supplier or from a supplier to the factory when it is supposed to load the order from that supplier. Constraint set (14) ensures that suppliers that should be visited based on the variable $Visit_{kibs}$ by the K^{th} vehicle on its b shipment can be accessed through one of the possible routes. Relation (15) indicates that if the k^{th} vehicle is assigned to b^{th} shipment, this vehicle must be exit from the factory on its b^{th} mission and must be entered from a supplier to the factory. Relation set (16) ensures that if the b^{th} shipment is not assigned to a k^{th} vehicle, then no order can be assigned to $b + 1^{\text{th}}$ shipment. Relation (17) creates a relationship between the loading time of each order and the time it is ready for the vehicle to be transported from the supplier. Relation (18) creates relationship between the loading times of each order with the completion time in the first stage. Relation (19) relates the access time of the k^{th} vehicle in the b^{th} shipment for loading each order to the time of loading of other orders. Relation (20) determines the relationship of the priority of carrying orders with each other. Relation (21) relates the time of completion of the b^{th} mission of the k^{th} vehicle and when this vehicle exits from the supplier s on its b^{th} mission, the relationship is established. Relation (22) relates the time to complete the b^{th} mission of the k^{th} vehicle and the start date of the $b + 1^{th}$ mission. Relation (23) related the time when the vehicle k exit from the supplier s in the b^{th} mission to loading time of the orders belong to that shipment. Relation (24) considers the departure times of the k^{th} vehicle with their b^{th} shipment from different suppliers relative to each other. Relation (25) determines the need for a route between two suppliers by the k^{th} vehicle on its b^{th} mission. Relation (26) considers the relationship between the time of delivery of the order i to the manufacturer and the time to complete the mission of the vehicle that carries it.

4 Case study

4.1 Overview

The case company is a global pipe manufacturer based in Iran called Emerson Group. The pipe is made from steel metal, plastic raw material and so on. The production is mostly based on injection moulds and, usually, prototypes are made before the mass production. The manufacturing of the pipe takes place in several cities around Iran. The production line of the first pipe line with the new design was reached in 1987. The unique characteristics of this product in the design of the body and the pipe system made it one of the most widely sold pipe. According to market needs, were 18 feet and 20 feet tall and reached the production stage. It is worth mentioning that 18 feet of years were the best-selling product of its kind in Iran, with pipe 20 feet still in the field. The average production of the pipe is around 500.000 per annum. The Emerson Company was chosen due to:

1 the access to data allowed by the headquarters in Iran

2 the difficulty of the global supply chain configuration

3 growing internal emphasis on production and transportation scheduling

4 the importance of time ordering and delivering between manufacture and suppliers in this company.

The case study problem has several parameters which have been examined seven parameters according to the experts of Emerson Company in order to generate problems. These parameters include the number of orders, number of suppliers, number of vehicles, order processing time, distances, order volume and machine capacity. According to Table 2, different levels such as low, moderate, and high are considered for each of the described parameters. All parameters follow a uniform distribution except for the number of orders. Generally, 3 * 3 * 3 * 2 * 2 * 1 * 1, namely 108 problems are generated. A large number of problems were created, in order to make comparisons, which were implemented by both GAs and RSs. The computational results of the algorithms were examined in the following. This section investigates the applicability of the proposed models in practice. The results were obtained by MATLAB 2019b and GAMS 22.9 using CPLEX solver on a laptop with an Intel Core i5 processor with 2.5 GHz of CPU and 4.0 GB of RAM. The notation used is shown in Table 2.

Table 2 The studied parameters and levels

Parameter	*Low*	*Medium*	*High*
Number of orders	10	50	100
Number of suppliers	U[1, 5]	U[5, 10]	U[10, 15]
Number of vehicles	U[1, 5]	U[5, 10]	U[10, 15]
Order processing time	U[1, 20]	-	U[20, 30]
Distances	U[1, 20]	-	U[20, 30]
Order volume	-	U[1, 5]	-
Vehicle capacity	-	U[5, 20]	-

4.2 The GA

The P-D is a NP-hard problem, as the classical problem of vehicle routing has been proven as NP-hard. Given the fact that the research problem is NP-hard, then it is not possible to use precise methods to solve the problem in a reasonable time and the heuristic or meta-heuristic methods should be used to solve the problem. The GA has been shown to be able to solve several NP-hard achieving near optimal solutions. The GA is also proposed to solve the problem. This algorithm has good quality due to the batch structure and applying operators, that the quality of the proposed algorithm is analysed in the following. The variables to be determined are identified to implement the research problem. Then these variables should be properly coded and displayed in the form of a chromosome. According to objective function, a fitness function for the chromosomes is defined and an arbitrary initial population is randomly selected. Next, the fitness rate is calculated for each chromosome of the initial population.

In this study, each chromosome is composed of two series of randomly-generated real numbers, and is generated through the process of combining chromosomes or offspring chromosomes. The first string is related to the suppliers and the second is related to the vehicle. The column number represents the order number and the integral part of each number in the first and second row indicates the supplier and vehicle number that the order corresponding to it is assigned to the gene. Decimal numbers are also the priority of the production (shipment) of each order.

Table 3 The problem chromosomal structure

	Order 1	*Order 2*	*Order 3*	*Order 4*	*Order 5*	*Order 6*
Suppliers	0.56	1.48	0.23	0.98	1.69	2.04
Vehicles	1.75	0.5	0.68	0.99	1.63	1.15

The initial population size is determined by the pop size parameter. A random chromosome is selected from the current population and is produced by the mutation operation of a new parameter. The proposed operator used in this algorithm is called simulation operator function. Using this selection operator, a number of members of the population are selected and moved to the next generation. The proposed algorithm operator, a chromosome called effective chromosome and an impressible chromosome are selected. In fact, in each iteration one solution affects the other and cause change in solution. In the proposed GA, according to the fitness function, the solutions are arranged at the end of each iteration and finally, transferred to the later population. The stop criterion for the algorithm is such that if the best value of the fitness function of the chromosome is not improved in several generations, the algorithm will be finished. The number of these repetitions is determined by the termination parameter. After studying several studies, it was experimentally found that the size of the initial population of 200, cross over rates of 0.5 and the mutation rate of 0.5 leads to fairly solutions at a reasonable time.

5 Results and discussion

We compared the GA solution quality to RS, which is separately developed, to evaluate the GA quality. The results are presented in Table 4.

In Table 4, the average answers and the times of each of the algorithms, the number of times the superiority of the GA algorithm compared to other algorithm (NBRO) and the number of times the GA algorithm provided worse solution compared to the other algorithm (NWO) is calculated. In one of 108 generated problems, the GA algorithm's answer is not equal to the other algorithm's answer. Table 4 illustrated the superiority of the GA in comparison with the RS in terms of the average answers and the NBRO. By reviewing the results, it is observed that by increasing the number of orders, the average answers and the times for both algorithms is decreased. Also, the average answers and times for the two algorithms are reduced by increasing the number of suppliers. The average answers and the times of the two algorithms are decreased by increasing the number of vehicles. Also, with the increase in the processing time of orders in suppliers, the average answers of both algorithms increases. The average answers of the two algorithms increases with increasing distances.

According to the results, the average of the GA solutions outperforms the average RS response, and this difference is increased by increasing the number of orders. This excellence can also be recognised based on NBRO and NWO indicators. A number of small scale problems were solved by CPLEX software to validate the mathematical model accuracy and the quality of the proposed algorithm. The validity of the proposed meta-heuristic method is comprehensively in this section. To this end, a number of evaluation criteria and experimental problems were established at different medium and large-scales in the previous section, and then the output of GA was evaluated in comparison with the RS. The efficiency metrics implemented in the previous section are used to correctly test the algorithms and the results are described in Table 4. To calculate the effect of conducting local search, the results that algorithms obtained are compared, first in the absence of local search and then in its presence.

According to the results, the proposed algorithm has a desired effectiveness than planning carried out by the industry. According to the research literature, GA has a high chance of providing high-quality solutions in P-D scheduling problems; therefore, it is expected that acceptable solutions are produced in the studied problem. After applying and examining the desired algorithm and its quality analysis it was found that the proposed attitude has a desirable quality in finding the solution for the problem and also on the case study of Emerson group.

Table 4 Results and comparisons of algorithms (RS&GA)

Parameter	*Level*	*Parameter amount*	*Algorithm average answers*		*Algorithm average times*		*NBRO*	*NEO*	*NWO*
			RS	*GA*	*RS*	*GA*			
Number of orders	Low	10	850.1111	793.4722	5.9732	12.0481	35	1	0
	Medium	50	19,324.53	17,519.78	28.6931	56.1973	35	0	1
	High	100	74,416.58	65,425.42	75.0044	165.357	34	0	2
Number of suppliers	Low	U[1, 5]	34,620.2	28,831.42	36.2537	102.568	35	1	0
	Medium	U[5, 10]	20,170.3	17,878.36	32.0092	67.8642	36	0	0
	High	U[10, 15]	39,800.8	37,028.9	41.4077	63.1695	33	0	3
Number of vehicles	Low	U[1, 5]	28,158.6	25,191.92	36.988	74.0722	34	0	3
	Medium	U[5, 10]	35,359.2	31,433.06	36.0933	79.7267	36	0	0
	High	U[10, 15]	31,073.4	27,113.7	36.5894	79.8031	34	1	1
Order processing time	Low	U[1, 5]	27,402.7	24,689.15	36.2049	73.8674	52	0	2
	Medium	U[5, 10]	35,658.1	31,136.6	36.9088	81.867211	52	1	1
	High	U[10, 15]	32,112.7	27,931	36.8255	78.946	53	0	1
Distances between suppliers	Low	U[1, 5]	35,658.1	31,136.6	36.9088	81.867211	52	1	1
	Medium	U[5, 10]	32,112.7	27,931	36.8255	78.946	53	0	1
	High	U[10, 15]	30,948.1	27,894.8	36.2883	76.7886	51	1	2
All of problems			31,350.41	27,912.89	36.5568	77.8673	104	1	3

Table 5 Raw materials required for the production in the case study of Emerson Group

Type no.	*Name*	*Manufacturing centre*
1	Epoxy resin	12
2	Phenolic resin	6
3	Titanium dioxide	9
4	Amyl acetate	3
5	Mono ethylene glycol	0
6	Methyl ethyl ketone	3
7	Isopropyl alcohol	1
8	Methyl isobutyl ketone	0
9	Butyl acetate	2
10	Polyamide hardener	0
11	Toluene	3

Table 6 Comparison of the proposed algorithm results and the forecasted plan by the factory

CPLEX		*GA*	
Tardiness	*Total cost*	*Tardiness*	*Total cost*
73.11	16,008.15	67.43	14,386.7

6 Managerial implication

This section suggests some observation that managers should remember when reviewing the study's findings. The proposed structure provides managers with a MIP model which can be applied in the context of an integrated supply chain by applying modifications. According to findings of this paper, due to suppliers are located at different geographical points, managers should meet customers' demands at the deadline and send orders at the lowest possible time. This eventually leads to a reduction in corporate costs, and on the other hand it will bring customers satisfaction compared to competitors. Therefore, Management should pay attention to the distance between suppliers, producers and consumers as an effective factor in reducing their costs. This will eventually lead to a reduction in production costs and the delivery of orders in the shortest possible time.

Another major problem affecting the productivity of the suppliers is the overall degree of growth being contrasted in Emerson Company in Table 6. The findings show that the model is capable of enhancing competitive manufacturing at the P-D scheduling in a three stage integrated supply chain may provide more valuable managerial insights.

7 Conclusions and future work

This paper presents a mathematical model developed to determine the P-D scheduling problem in a three stage integrated supply chain. This supply chain includes suppliers, transport fleet of goods to final product Emerson Company. An actual-life modelling of order time within the period is presented. The main objective function is to minimise the amount order delays. At first, a MIP model was developed for the problem. The GA is used to solve the problem. A RS algorithm was developed for the problem to evaluate the GA algorithm. According to the results, the GA algorithm outperformed the other approaches. Unlike previous research, i.e., the paper of Beheshtinia and Akbari (2016), in this study, researchers considered cases like, the real case study in Emerson Group, and time and cost considering the assumptions of research in complex situations. On the other hand, in this study several suppliers and vehicles and one plant were studied at different geographical points. In order to analyse the quality of the proposed algorithm, the data related to a manufacture are gathered and finally, the results obtained from the proposed algorithm as well as the studied company were analysed. According to the results, the proposed GA provide better results for the number of orders, suppliers, vehicles, order processing time and distance between suppliers than other methods and, on the other hand, the objective function value reduces by increasing the number of repetitions, which indicates the correct performance of the proposed algorithm. A special creation, crossover and mutation operators are developed and used; to ensure the feasibility of the offspring generations. Results showed that the GA solves the problem and converges faster than the GA to the best reached solution. In large-scale problems, the GA proved to be achieving a slightly better solution compared with that found for small scale ones, but at the cost of processing time. According to Table 6 is case of 11 types of raw material, the tardiness and total cost of GA (67.43; 14,386.7) is better than CPLEX (73.11; 16,008.15). Therefore, if the cost and time reduction are the important then the use of the GA will be beneficial. The meta-heuristic algorithms GA and RS were compared in computational experiments in order to test and validate the MIP model, while a variety of performance were used to determine the solutions.

Other meta-heuristic algorithms such as the tabu search (TS) and honey bee algorithms can be utilised as a basis for future research. Also, adding other objective functions such as minimising the maximum distance between two objects can be another subject for future research. The availability time of production machines depending the amount of function and the rest time for a certain amount of production, the loading and unloading time as definite, indefinite or dependent, the time to material preparation for production on the machine as deterministic and stochastic or dependent, the uncertainty at the time of transportation and processing, uncertainty in demand, examining the impact of integrity or non-integrity, as well as the effect of shared or dedicated transportation fleet on reducing the delay of production in several plants and finally, the effects of other costs, are among the issues that can be considered in the objective function of future studies.

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