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An Integrated Multi-Stage Supply Chain Model under Continuous Production and JIT Delivery

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Abstract

This paper deals with a continuous production based two-stage supply chain system of a manufacturing facility that operates under a *just-in-time* (JIT) environment. The facility consists of raw material suppliers, manufacturer, and retailers who are involved with their respective inventories. This research considers that the production of finished goods in one cycle starts immediately after the production or uptime of the previous cycle to minimize the downtime of the facility and thus makes the process continuous. Considering this scenario, inventory models are formulated as integer non-linear programming problems for raw material and finished goods. Two algorithms are developed to solve the model and to estimate the optimum number of orders and shipments, and the optimum production quantity and minimum total system cost for both decentralized and centralized supply chain systems. The solutions are confirmed through numerical examples and illustrated the effectiveness of the method with sensitivity analyses.

Key words: *Supply Chain System*, *Continuous Production, JIT Delivery*.

1. Introduction

Production and supply chain management play an important role on the current economy. The fluctuating demand of various products and increasing expectations influence the social economy as well as the business enterprises in focusing their attention on the appropriate control of their supply chain. The continuous development of business environment has made it necessary to improve the knowledge and techniques of supply chain management. Supply chain philosophy enables an individual business organization to achieve superior productivity and minimizes its system cost by satisfying the service level requirements.

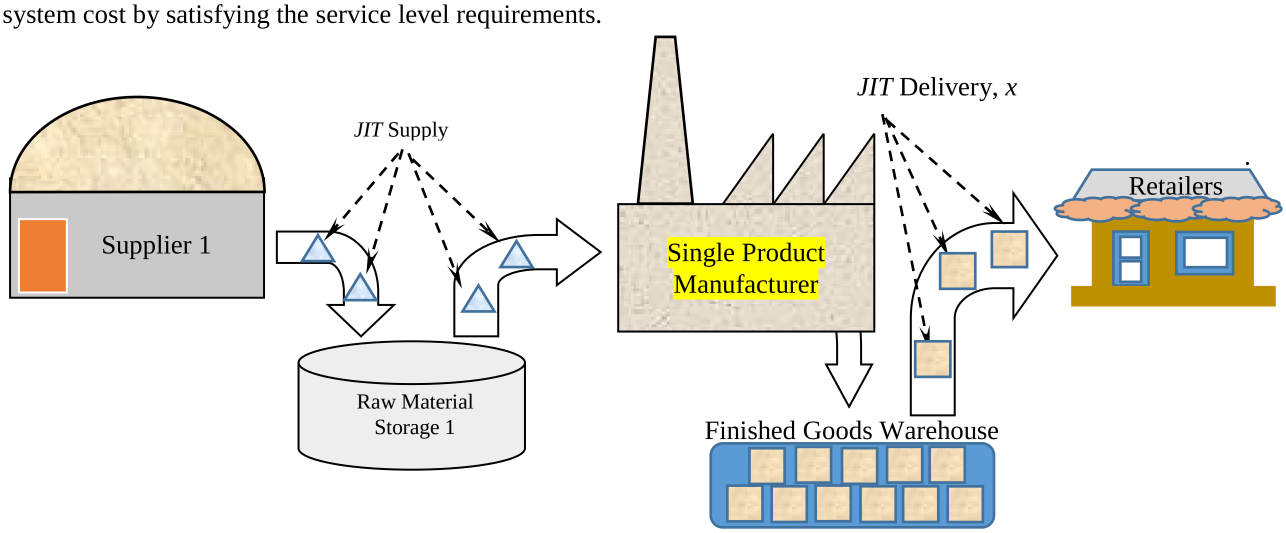

Fig. 1 A typical supplier-manufacturer-buyer supply chain model

A typical supply chain system contains raw materials supplier, manufacturer of finished products and customers. The raw materials are procured from the suppliers and stored in inventory storage area at production centers. The finished goods are manufactured in the production centers and stored in warehouses, which, in turn, are shipped to the buyers or retailers. To improve productivity and reduce manufacturing costs, the just-in-time (JIT) technology has often been adopted by many production systems. In supply chain system with just-in-time (JIT) mechanism, the finished product output rate is controlled by the demands of the customers. Fig. 1 represents the supply chain system with just-in-time (JIT)mechanism.

1.1 Literature Review

Recent interest in supply chain management centers on the coordination among various members of a supply chain, comprising of manufacturers, distributors, wholesalers and retailers. Sharing information among members of the supply chain is one important mechanism for good coordination in a supply chain. These information flows have a direct impact on the production scheduling, inventory control and delivery plans in a supply chain. In just-in-time (JIT) driven systems, the supplier and producer have to coordinate their raw material supply and finished goods production according to the buyers' demands to maintain minimum inventory. In reality, the manufacturer ends up carrying large inventories in distribution centers or warehouses and delivers limited shipments requested by retailers. Sarker and Parija (1994) analyzed the stated problem with a single-buyer and single-supplier system with JIT delivery. Hill (1995) complied a viewpoint on Sarker and Parija's (1994) work considering integer number of shipments for average finished goods stock. Later, Sarker and Parija (1996) extended their research in optimal multiple ordering policies from a single supplier for single product manufacturing batch to minimize the total cost of production. Nori and Sarker (1996) developed a multi-product production system with a single-facility scheduling scheme considering two situations: (1) fixed setup cost, and (2) variable setup cost under a JIT delivery policy. Later Parija and Sarker (1999) studied a multi-retailer system by introducing the problem of determining the production start time, the cycle length and raw material order frequency for an infinite planning horizon.

Goyal (1995) and Aderohunmu *et al*. (1995) proposed models for joint supplier-buyer policy considering only the finished goods related costs in a JIT manufacturing environment. Grout (1997) developed a mathematical model to analyze the configuration of on-time delivery incentives in a contract between a buyer and a single supplier of raw materials when early shipments are prohibited. Sarker and Khan (1999) proposed an ordering policy for raw materials to meet the requirements of a production facility that must deliver finished goods according to customers' demand at a fixed point of time with quality certification of the products. Khan and Sarker (2002) developed another model for a manufacturing system that estimates production batch sizes for a JIT delivery system and incorporated a JIT raw material supply system. Zhou *et al*., (2004) presented a general time-varying demand inventory lot-sizing model with waiting-time-dependent backlogging and a lot-size-dependent replenishment cost. They derived the model's cost function for a "shortages followed by inventory" replenishment policy. Wang and Sarker (2005) studied the assembly-type supply chain system (ATSCS) controlled by kanban mechanism with JIT delivery policy. They developed a heuristic which divides the ATSCS into several small size problems, and then conquers them individually. Wang and Sarker (2006) extended the previous model to a multi-stage supply chain system considering a JIT delivery policy. In 2006, Sarker and Diponegoro studied an exact analytical method to obtain an optimal policy for a more general class of problem with multiple suppliers, non-identical buyers, finite production rate and finite planning horizon. Kim *et al*. (2008) examined the relationship benefits of buyer-supplier over lot-for-lot with single setup single delivery systems. Also, they suggested two policies so that the supplier can satisfy customers' demand with single setup multiple delivery, multiple setup multiple delivery. Diponegoro and Sarker (2006) developed an ordering policy for raw materials and determined an economic batch size for a product in a manufacturing system that supplies finished products to customers for a finite planning horizon. They considered the JIT delivery policy with lost sale problem due to shortage.

Diponegoro and Sarker (2007) studied operational policies for a lean supply chain system considering single supplier and single buyer with fixed delivery size, and time dependent delivery quantity with trend demand. Diponegoro and Sarker (2007) solved the problem by a closed-form heuristic, which provided near optimal solutions and tight lower bounds. Banerjee *et al*. (2007) established a mathematical model of a supply chain structure consists of a single manufacturer with multiple retailers and suppliers. Rau and OuYang (2008) presented a new integrated production–inventory policy under a finite planning horizon and a linear trend in demand by assuming that the supplier makes a single product and supplies it to a buyer with a non-periodic and just-in-time (JIT) replenishment policy. Mungan *et al*. (2010) studied an integrated JIT based inventory model for high-tech industries under continuous price decrease over finite planning horizon. Chen and Sarker (2010) proposed a multi-supplier optimal model to decide the batch size of supplier's production, and delivery frequencies of different buyers to the manufacturer using shared transportation costs. Hoque (2011) developed a generalized single-supplier multi-buyer supply chain model by synchronizing supply chains with equal-sized or unequal-sized lots.

Yu and Dong (2014) studied of a production lot sizing problem consisting of customers, one retailer, and one manufacturer with random demand. The authors assumed that the retailer replenishes inventory as well as the manufacturer starts production cycle when the manufacturer's inventory falls to or below zero. Chen and Sarker (2014) considered a manufacturing system with JIT procurement and supply where they developed an integrated optimal model of inventory lot-sizing vehicle routing of multi-supplier single-manufacturer with milk-run JIT delivery. During the inventory model development, the authors considered that the production cycle starts after the inventory falls down to zero. Eduardo Cardenas-Barron *et al.* (2014) proposed an alternative heuristic algorithm for a multi-product Economic Production Quantity (EPQ) vendor–buyer integrated model with Just in Time (JIT) philosophy, a budget constraint, and similar inventory situation as above. Omar and Sarker (2015) considered a just-in-time (JIT) manufacturing system to synchronize JIT purchasing and selling in small lot size as a means of minimizing the total supply chain cost. The authors proposed an optimal policy where the shipment intervals as well as the lot sizes are varied. Torkabadi and Mayorga (2017) considered on the implementation of Just-In-Time (JIT) in a multi-stage, and multi-product supply chain with Kanban, ConWIP, and a hybrid PCP. Considering the uncertainty, the authors evaluated performances of policies via a Fuzzy AHP method. Wang and Ye (2018) studied the Just in time (JIT) and Economic order quantity (EOQ) models with carbon emissions in a two-echelon supply chain with single manufacturer and *n* retailers. In their model, they proposed that the manufacturer and retailers could adopt either a JIT mode or an EOQ mode in which every retailer could decide its own optimal lot size.

Kim and Shin (2019) proposed that the third-party logistics service provider would determine the optimal order quantity, considering defective items under the VMI and JIT conditions. They designed a mathematical decision-making problem based on the EPQ /EOQ with defective items, which provides the optimal order quantity for TPL service providers under VMI and JIT. Leuveano *et al.* (2019) dealt with the problem of transportation and quality within a Just-in-Time (JIT) inventory replenishment system including an integrated vendor-buyer lot-sizing model by considering transportation and quality improvements into a JIT environment. Nobil *et al*. (2020) developed a multiproduct economic production quantity inventory model for a vendor–buyer system in which several products are manufactured on a single machine and vendor delivers the products to customer in small batches. The aim of this study was to determine the optimal cycle length and the number of delivered batches for each product so that the total inventory cost is minimized. Chinello *et* al. (2020) proposed a practical framework for identifying the main drivers of inventory optimization, using simulation modeling on a) a multi-echelon supply chain model. Recently, Biswas and Sarker (2020) proposed a JIT based inventory model for multiple product production and delivery from a single facility lot sizing model.

In this research, a single stage production facility is considered that purchases raw materials from multiple suppliers and processes them to deliver in a fixed quantity of finished products to multiple retailers (or customers) at a fixed-interval of time. In previous research [Fig. 2], it is observed that the production cycle of a manufacturing facility continues up to certain period of time (uptime) to produce the required inventory to satisfy the demand of that cycle. The next production cycle begins after all the inventory shipped to the customer leaving no or zero inventory at the warehouse. This research focused on this issue and considers that the uptime or production of a cycle starts immediately after the uptime of the previous cycle and the setup time [Fig. 3]. Therefore, the system does not remain idle until the finished goods inventory falls to zero like Fig. 2. This research also considers that the raw materials are replenished instantaneously to the manufacturing system to meet the JIT operation. This research deals with decentralized supply chain manufacturing system composed of production with multiple suppliers and multiple supplier operating under JIT delivery (fixed deliveries at fixed intervals). Though, some researchers used random demand in their model, but in this research deterministic modes are considered to avoid additional complexity.

During the model development, all of the previous researchers considered that the system remains idle until the shipments are made. Fig. 2 shows the production with just-in-time (JIT) delivery.

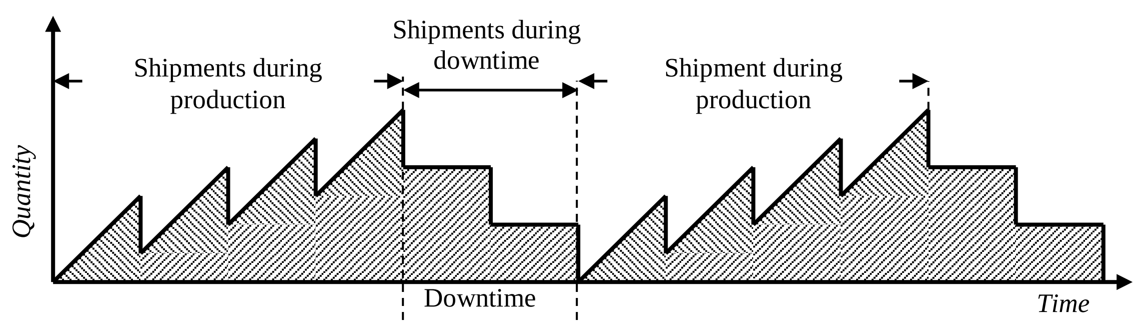

Fig. 2 Inventory models with just-in-time (JIT) delivery with downtime

In fact, large production industries (refineries, paper mills, sugar mills, etc.) do not let their production system be idle, because it incurs a high cost to shut down and restart their equipment. Also, some industries (such as automotive assembly plants, etc.) follow the production schedules of eight, twelve, and sixteen hours. Moreover, the manufacturing industries have multiple suppliers of raw materials and multiple buyers for finished products. The production of these industries can be categorized into semi-continuous production where the subsequent production cycle (uptime) starts just after completion of prior production uptime. Also, these industries carry the inventories from one cycle to the other and may deliver the finished goods combing with the new produced finished goods. During production, the manufacturer also delivers the finished goods to multiple buyers following the JIT delivery method to lower finished goods handling cost. Previous researchers ignored these types of models due to complexity of the problem.

The current research is based on the facts encountered in supply chain systems of different manufacturing systems, such as computer/electronics industries, sheet-metal industries, refineries, and paper industries. For example, to manufacture filing cabinet, metal sheets and L-angles are obtained from steel industries. The delivery of the finished cabinets depends on the downstream market demand. Similarly, computer and automobile industries procure various items and maintain supply chain both upstream and downstream to sustain uniform flow of products. Also, the manufacturing industries tires to utilize their system by producing more finished products, and they do not stop production until the inventory falls to zero. This is an important issue which researchers ignored while forming their model. The problem for this research is established by researching the shortcomings of the previous researchers. First, the researchers did not consider the minimization of downtime of the production systems, but Sarker and Khan (1999) proposed a model that happened to be minimizing inactive time of the production facility. In their model they did not consider the delivery during the production or up time. Therefore, this case is considered in the present research.

2. Problem Description

This part of the paper deals with the supply chain system considering just-in-time (JIT) technique and considers a continuous manufacturing system, which has minimum downtime between successive production cycles. In a supply chain system, when the production quantity exactly matches the demand of a cycle time, it is called *perfect matching*. Therefore, the perfect matching is the situation when there are no finished goods remaining after the shipments are completed to the customers at the end of a production cycle. To find an economic order quantity (*EOQ*) for the raw materials, and an economic manufacturing quantity (*EMQ*) for the production facility with *prefect matching*, the following costs are considered: raw material ordering cost, raw material inventory cost, manufacturing setup cost, and finished goods inventory carrying cost. In this section, an expression for the generalized cost function is developed that may be used to determine an optimal batch quantity for the production run with reduced downtime.

2.1 Notation

To develop the model for determining the interactions between raw materials and finished goods demand, following definitions and notation are used:

D_f : Demand for finished goods, units/year.
D_r : Demand for raw materials, units/year.
f : Conversion factor of the raw materials; $f = D_f / D_r = Q_f / Qr$.
h_f : Holding cost of finished goods, \$/units/year.
h_r : Holding cost of raw materials, \$/units/year.
I_f : Total finished goods inventory, units.
$\overline{I_T}$: Average finished goods inventory, units.
I_r : Total raw materials inventory, units.
$\overline{I_r}$: Average raw materials inventory, units.
I_{ps} : Total finished goods inventory with downtime, units.
$\overline{I_s}$: Average finished goods inventory with downtime, units/year.
A_r : Ordering cost of raw material, \$/order.
A_f : Manufacturing setup cost, \$/batch.
L : Time between successive shipments of finished goods, years, $L = k/D_f$.
m : Number of orders for raw materials; $n \geq m \geq 1$.
n : Number of *full* shipments of finished goods per cycle time.
P : Production rate, units/year.
Q_f : Quantity of finished goods manufactures per setup, units/batch.
Q_r : Quantity of raw materials required for each batch; $Q_r = Q_f / f$.

T_P : Production time (uptime), years; $T_1 = Q_f / P = nk/P$.
T_D : Pure consumption time, years (downtime);
T : Total cycle time, years; $T = nL$.
T_S : Setup time, years; $T_s < L$.
ETC_f : Total cost of finished goods, \$.
ETC_r : Total cost of raw materials, \$.
$ETC(m, n)$: Total cost function, \$/year.
$ETC_s(m, n)$: Total cost function with downtime, \$/year.
$\overline{I}_s$: Average finished goods inventory for with downtime, units/year.
k : Fixed quantity of finished goods per shipment at a fixed interval of time, units/shipment; $k = Q_f/n = LD_f$.

2.2 Assumptions

To develop the mathematical model and to simplify the solution methodology, some assumptions considered are as follows:

1. Production rate is constant and finite.
2. Production rate is greater than the demand rate, $P > D_f$.
3. Production facility considers as just-in-time (JIT) delivery and supply of finished products and raw materials, respectively.
4. Production facility operates under the condition, where succeeding production cycles start immediately after the production period of preceding cycles.
5. There is only one manufacturer and one raw material supplier.
6. Only one type of product is produced in each cycle.
7. Finished goods delivery is in a fixed quantity at a regular interval.

2.3 Average Inventory and Total Cost Function

In this part of the research, the production rate, P is assumed to be greater than the demand rate, D_f, so that there should be an inventory build-up during production. Fig. 3 shows the inventory build-up due to processing of finished goods from raw material, where top part of the Fig. 3 represents the inventory of the raw material supply, and the lower part represents the on-hand finished goods inventory in the warehouse.

For the finished product production, it is assumed that, the production of cycle 1 starts (at a finite rate of P) T_s time units after the end of the uptime of the previous cycle (i.e., at time A) and the first delivery of $k/2$ units for cycle 1 is made at L time units after the previous delivery. Since, the cycles overlap (uptime of succeeding cycle with downtime of preceding cycle), at the same time (every L time units) $k/2$ units are delivered both from the downtime of previous cycle and uptime of following cycle. Therefore, at fixed time period L, total k units are being delivered which satisfies customers' demand. As the produced item during L-T_s time units is exactly $k/2$ amount for cycle 1, so there is no inventory after the delivery made at the end of L time units. After L time units, production starts again and for every L time units, shipments of $k/2$ units from each cycle are made. During L time period, Y amount of finished goods are produced and after shipping $k/2$ units, the remaining items are $Y - k/2 \geq 0$. Thus, the finished goods inventory build-up forms a saw-tooth pattern during the production uptime T_P. Clearly, $Q_f = PT_P$ units are produced in a cycle. After the end of the production, shipments of $k/2$ units at every L time units are made to the customers during the downtime, T_D, which is followed by the new cycle.

During the down time of a cycle, finished goods are not produced for that cycle, and the on-hand inventory depletes at regular intervals (every L time units) from the end point of the production period to the end of cycle. Thus, the later part of the inventory cycle (T_D period) forms a staircase pattern (under curve GH'). The finished products are delivered in n shipments (where $n \geq 1$) of $k/2$ equal quantities at each T time period. Since, the uptime of all cycles and the downtime of their previous cycles coincide, the total delivery, in L time period, becomes $2(k/2) = k$ amount.

The pattern of raw material inventory is shown in Fig. 3(a) where Q_r is the raw materials required and these Q_r units are ordered in m instantaneous replenishments of Q_r/m units. It is assumed that each unit of finished goods produced requires f units of raw material, so that $Q_r = fQ_r$. Again, in this research the raw materials are ordered and converted to finished goods during the production time or uptime, T_P. Thus, the time weighted inventory of raw material held in a cycle is given by

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$$\bar{I}_r = \left(\frac{Q_r T_P}{2m}\right) = \left(\frac{nk}{2mf}\right)\left(\frac{nk}{P}\right) = \frac{n^2k^2}{2mfP}. \quad (1)$$

where $Q_r = Q_f / f = nk / f, T = nk / D_f$ and $T_P = nk / P$.

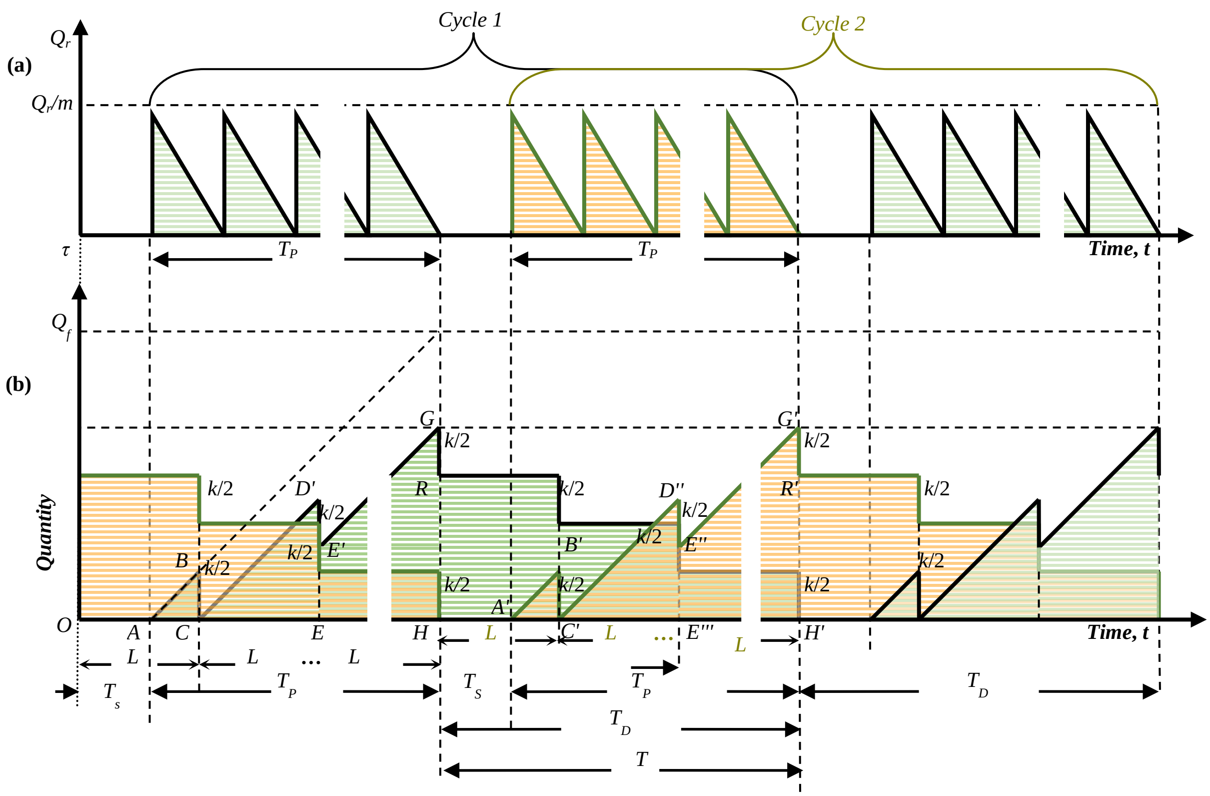

Fig. 3 Supply chain inventory of (a) raw materials; (b) finished goods

Hence, the total cost for the raw material can be expressed as

$$ETC_r(m) = \frac{D_r}{Q_r / m} A_r + \bar{I}_r h_r = \frac{mD_f}{nk} A_r + \frac{n^2k^2h_r}{2mfP}. \quad (2)$$

where $Q_f / Q_r = D_f / D_r = f$.

As shown in Fig. 3(b), the production of cycle 2 begins at point A', which is setup time, T_s, after the end of *production period* (uptime) of cycle 1. Hence, the machines or the production cycle will not remain idle till the end of the shipments of the finished products after previous cycle. That is why, the overlapping parts Area HGH' and Area $A'B'C'D''E''G'H'$ are combined inventories during T time period denoted by Area $HGG'H'$. The delivery follows the just-in-time (JIT) system and so does the raw material supply. Fig. 3(b) shows that the on-hand inventory does not increase after production stops at the end of T_P in cycle 1. The quantity produced in T_P time units should meet the customer's demand for period T such that $Q_f = nk$, where n is the number of full shipments to customers per cycle and is assumed to be an integer for an infinite planning horizon. The raw materials for production are ordered during the time T_P time period. If I_T, I_P, and I_D are denoted as total finished product inventory, inventory produced at time T_P and inventory shipped at time T_D, respectively, then the total finished product inventory during T time period can be written as

$$I_T = I_P - I_D. \quad (3)$$

Also, from Fig. 3, it is found that the total cycle time T is

$$T = T_P + T_s = T_D = nk / D_f, \quad (4)$$

where $L = k / D_f$.

Now, from Fig. 3(b), I_P and I_D can be calculated as

$$I_P = \frac{nk}{2}T_P + \frac{nk}{2}T \text{ , and} \tag{5}$$

$$I_D = \frac{n(n-1)k^2}{2D_f}. \tag{6}$$

Therefore, using Eq. (3), Eq. (5), and Eq. (6), the total finished product inventory is found to be

$$I_T = \frac{n^2k^2}{2D_f} + nk\left(\frac{k}{2D_f} - \frac{T_s}{2}\right). \tag{7}$$

Therefore, the average finished product inventory of the entire cycle can be found as

$$\bar{I}_T = \frac{1}{T}\left[\frac{n^2k^2}{2D_f} + nk\left(\frac{x}{2D_f} - \frac{T_s}{2}\right)\right] = \frac{D_f}{nk}\left[\frac{n^2k^2}{2D_f} + nk\left(\frac{k}{2D_f} - \frac{T_s}{2}\right)\right] = \frac{nk}{2} + D_f\left(\frac{k}{2D_f} - \frac{T_s}{2}\right). \tag{8}$$

Hence, the total cost function for the finished goods inventory can be written as

$$ETC_f(n) = \frac{D_f}{Q_f}A_f + \bar{I}_F h_f = \frac{D_f}{nk}A_f + \frac{h_f}{2}\left[nk + D_f\left(\frac{k}{D_f} - T_s\right)\right]. \tag{9}$$

Therefore, the total cost function for both raw material and finished product inventories for this problem can be written as

$$ETC(m,n) = ETC_r + ETC_f = \frac{n^2k^2h_r}{2mfP} + \frac{mD_fA_r}{nk} + \frac{D_f}{nk}A_f + \frac{h_f}{2}\left[nk + D_f\left(\frac{k}{D_f} - T_s\right)\right]. \tag{10}$$

Upon simplification which yields

$$ETC(m,n) = \frac{n^2}{m}\left(\frac{k^2h_r}{2fP}\right) + \frac{m}{n}\left(\frac{D_fA_r}{k}\right) + \frac{1}{n}\left(\frac{D_fA_f}{k}\right) + \frac{nkh_f}{2} + \frac{D_fh_f}{2}\left(\frac{k}{D_f} - T_s\right). \tag{11}$$

2.4 Problem Formulation

The total cost function for this part of research is a non-linear integer programming problem with has integer variables *m* and *n*. The problem can be expressed as a minimization problem as follows:

***Problem*:** Find *m* and *n* to

Minimize:

$$ETC(m,n) = \frac{n^2}{m}\left(\frac{k^2h_r}{2fP}\right) + \frac{m}{n}\left(\frac{D_fA_r}{k}\right) + \frac{1}{n}\left(\frac{D_fA_f}{k}\right) + \frac{nkh_f}{2} + \frac{D_fh_f}{2}\left(\frac{k}{D_f} - T_s\right) \tag{12}$$

Subject to:

$$n \geq m \geq 1 \tag{13}$$

m and n are integer. (14)

Next section describes the solution methodology, numerical examples and special case of the proposed problem.

3. Solution Method of the Proposed Problem

3.1 Proof of Convexity

The total cost function developed for the problem is a nonlinear integer programming (NLIP) problem. Since *ETC* is a function of (*m*, *n*), it is sufficient to show that *ETC*(*m*, *n*) is convex for *m*, *n* ≥1. All the parameter used in this model are non-negative, i.e., $P, D_f, A_r, A_f, h_r, h_f, k, f \geq 0$ and $m, n \geq 1$. Hence, it is required to prove that the principal minors of the Hessian matrix of Eq. (11) are positive. The Hessian of TC_{PM} can be found by partial differentiation with respect to *m* and *n* as follows:

$$H(m,n) = \begin{bmatrix} \square & \square \\ \square & \square \end{bmatrix}, \tag{15}$$

where $\square = \dfrac{\partial^2 ETC}{\partial n^2} = \dfrac{k^2 h_r}{mfP} + \dfrac{2D_r}{n^3 k}(mA_r + A_f)$, $\square = \dfrac{\partial^2 ETC}{\partial m \partial n} = -\left(\dfrac{D_f A_r}{n^2 k} + \dfrac{nk^2 h_r}{m^2 fP}\right)$, and $\square = \dfrac{\partial^2 ETC}{\partial m^2} = \dfrac{n^2 k^2 h_r}{m^3 fP}$

From Eq. (15), the first principal minors of Hessian $H(m,n)$ is found as

$$H_1(m,n) = \square = \frac{k^2 h_r}{mfP} + \frac{2D_f}{n^3 k}(mA_r + A_f). \tag{16}$$

Hence, $H_1(m,n) \geq 0$ as all parameters are positive. Using Eq. (15) the second principal minor for the objective function can be found as

$$H_2(m,n) = \square\square - \square^2 = \frac{2kD_f A_f h_r}{m^3 nfP} - \frac{D_f^2 A_r^2}{n^4 k^2}. \tag{17}$$

Therefore, from Eq. (17) it can be confirmed that $H_2(m,n) \geq 0$ if and only if

$$\frac{A_f h_r k^3}{fPD_f A_r^2}\left(\frac{n}{m}\right)^3 \geq \frac{1}{2}, \tag{18}$$

which confirms that the total cost function is a quasi-convex function.

3.2 Solution Method

Considering the problem described above, it is found that this problem can be not be solved using the traditional minimization techniques as *n and m* are depended on each other. Therefore, it can be solved using the incremental or enumeration method used by Giri and Sharma (2015) and Sarker and Parija (1994). Using the decentralized decision-making policy, the cost of the supply chain can be divided into two parts i.e., (a) raw material supply and inventory cost [presented in Eq. (2)], and (b) finished product setup and inventory cost [presented in Eq. (9)]. These costs can be minimized separately to find the local optimal for both decision variables *m* and *n*. In this decentralized decision-making policy, the number of shipments (*n*) to the retailers influences the manufacturer's demand for the number of raw materials supply (*m*) from the supplier. Therefore, the optimal value of n^* can be determined by the enumeration technique to satisfy the following condition generated as

$$ETC_f(n^* - 1) \geq ETC_f(n^*) \leq ETC_f(n^* + 1). \tag{19}$$

Using Eq. (9) with n^*-1, n^*, and n^*+1, Eq. (19) can be written as

$$\frac{D_f}{(n^*-1)k}A_f + \frac{h_f}{2}\left[(n^*-1)k + D_f\left(\frac{k}{D_f} - T_s\right)\right] \geq \frac{D_f}{n^* k}A_f + \frac{h_f}{2}\left[n^* k + D_f\left(\frac{k}{D_f} - T_s\right)\right]$$
$$\leq \frac{D_f}{(n^*+1)k}A_f + \frac{h_f}{2}\left[(n^*+1)k + D_f\left(\frac{k}{D_f} - T_s\right)\right]. \tag{20}$$

Upon simplification and taking the positive roots, the boundary condition of n^* can be evaluated as

$$\left\lfloor \frac{1}{2}\sqrt{1 + \frac{8D_f A_f}{h_f k^2}} - 1 \right\rfloor \leq n^* \leq \left\lfloor \frac{1}{2}\sqrt{1 + \frac{8D_f A_f}{h_f k^2}} + 1 \right\rfloor \tag{21}$$

which will generate two values as n_1^*, and n_2^*. Now using the following argument, the n^* can be found as

$$n^* = \arg\min \{ETC_f(n_1^*), ETC_f(n_2^*)\} \tag{22}$$

Similarly, for integer shipments of raw material supply, m^* can be achieved using the following condition

$$ETC_r(m^* - 1) \geq ETC_r(m^*) \leq ETC_r(m^* + 1). \tag{23}$$

Using Eq. (2), Eq. (22), and Eq. (23), it can be found that

$$\frac{(m^*-1)D_f}{n^* k}A_r + \frac{n^{*2}k^2 h_r}{2(m^*-1)fP} \geq \frac{m^* D_f}{n^* k}A_r + \frac{n^{*2}k^2 h_r}{2m^* fP} \leq \frac{(m^*+1)D_f}{n^* k}A_r + \frac{n^{*2}k^2 h_r}{2(m^*+1)fP}. \tag{24}$$

Hence, the boundary conditions of m^* can be found as follows:

$$\left\lfloor \frac{1}{2}\sqrt{\frac{1+4h_r n^{*3}k^3}{2\,fPD_f A_r}} - 1 \right\rfloor \le m^* \le \left\lfloor \frac{1}{2}\sqrt{\frac{1+4h_r n^{*3}k^3}{2\,fPD_f A_r}} + 1 \right\rfloor \quad \text{and} \qquad (25)$$

generates two values as well as Eq. (21) with m_1^*, and m_2^*, which can be eliminated by

$$m^* = \arg\min\{ETC_r(m_1^*), ETC_r(m_2^*)\}. \qquad (26)$$

Finally, using Eq. (21), Eq. (22), Eq. (25), Eq. (26), Eq. (2) and Eq. (9) the following algorithm is developed to solve the decentralized supply chain problem.

Algorithm1: Determining Number of Orders and Shipments for Decentralized Operation

Step 1: Set the values of $P, D_f, A_r, A_f, h_r, h_f, k,$ and f as the initial values.

Step 2: Solve n^* using Equations (21) and (22)

Step 3: Solve m^* using Equations (25) and (26)

Step 4: Find the optimal solution of $ETC(m^*, n^*)$ by satisfying the following relations provided in Eq. (12), Eq. (13), Eq. (14), Eq. (19) and Eq. (23).

Also, the algorithm for centralized supply chain optimization for the proposed problem is presented as follows:

Algorithm2: Determining Optimum Number of Orders and Shipments for Centralized Operation

Step 1: Set the values of $P, D_f, A_r, A_f, h_r, h_f, k,$ and f and $j = 0$ as the initial iteration

Step 2: Set $m^*_{j=0} = m^*$ and $n^*_{j=0} = n^*$ and n^* from *Algorithm 1* as starting basic solution and solve for $ETC_{j=0}(m^*, n^*)$ using Eq. (12)

Step 3: Set $n^*_{j=j+1} = n^*_j + 1$, and compute $ETC_{j=j+1}(m^*, n^*)$,

if $ETC_{j=j+1}(m^*, n^*) = ETC_{j=j}(m^*, n^*)$ or $ETC_{j=j+1}(m^*, n^*) > ETC_{j=j}(m^*, n^*)$

go to Step 5,

if $ETC_{j=j+1}(m^*, n^*) < ETC_{j=j}(m^*, n^*)$

else go to Step 3

Step 4: Set $m^*_{j=0+1} = m^*_0 + 1$, and compute $ETC_{j=j+1}(m^*, n^*)$,

if $ETC_{j=j+1}(m^*, n^*) = ETC_{j=j}(m^*, n^*)$ or $ETC_{j=j+1}(m^*, n^*) > ETC_{j=j}(m^*, n^*)$

go to Step 5,

if $ETC_{j=j+1}(m^*, n^*) < ETC_{j=j}(m^*, n^*)$

else go to Step 4

Step 5: Stop, optimum solution achieved $ETC_{j=j}(m^{opt}, n^{opt})$.

Next section evaluates the results using numerical values and the algorithm presented above.

3.3 Computational Results

In this section, the numerical tests are presented using the solution procedures for the perfect matching supply chain system and six sets of data, which have been chosen from different hypothetical scenarios. The sets of *examples* presented in Table 1. The optimal results for all six problems are computed as Example 1 and are presented in Table 2. A sample computation is presented using data set of Problem 1 from Table 1 and the solution technique discussed in Section 3.2.

Table 1: Data set for numerical computation for perfect matching problem

Parameters	***Example 1***	***Example 2***	***Example 3***	***Example 4***	***Example 5***	***Example 6***
P (units/year)	3,600	3,600	6,000	7,000	8,000	11,000
D_f (units/year)	2,400	2,400	3,000	5,200	5,200	7,200
A_r ($/order)	150	100	150	200	200	300
A_f ($/setup)	50	100	60	70	200	250
h_r ($/unit/year)	1	10	3.5	4	4	10.5
h_f ($/unit/year)	2	10	5	15	25	45
f	2	3	3	2.5	3	4
k(units/shipment)	100	100	150	200	300	350
T_s (years)	0.001	0.002	0.002	0.003	0.005	0.006

Using Algorithm 1 and Algorithm 2 the optimum decentralized and centralized results for all six problems are presented in Table 2 and Table 3, respectively for the decentralized and centralized supply chain systems.

Table 2: Results using *Algorithm 1* and given data set for decentralized supply chain

Parameters	***Problem 1***	***Problem 2***	***Problem 3***	***Problem 4***	***Problem 5***	***Problem 6***
m^*	1	1	1	1	1	1
n^*	4	2	2	2	1	1
Q^*	400	200	300	400	300	350
$ETC_f\,(n^*)$	$797.60	$2,676.00	$1,710	$5,293.00	$10,641.67	$21,870.15
$ETC_f\,(m^*)$	$911.11	$1,218.52	$1,513.13	$2,618.29	$3,474.17	$4,286.03
$ETC^*(m^*, n^*)$	$1,708,17	$3,894.52	$3,223.13	$7,911.29	$14,115.83	$26,106.90

Table 3: Results using *Algorithm 2* and given data set for centralized supply chain

Parameters	***Problem 1***	***Problem 2***	***Problem 3***	***Problem 4***	***Problem 5***	***Problem 6***
m^*	1	1	1	1	1	1
n^*	7	3	3	2	1	1
Q^*	700	300	450	400	300	350
$ETC_f\,(n^*)$	$548.31	$841.67	$1,029.53	$5,012.05	$10,641.67	$21,870.15
$ETC_f\,(m^*)$	$969.03	$2,776.00	$1885.00	$3,054.86	$3,474.17	$4,286.03
$ETC^*(m^*, n^*)$	$1,517.34	$3,617.67	$2,914.53	$7,911.29	$14,115.83	$26,106.90

After comparing Table 2 and Table 3 results, it can be concluded that when delivery quantity increases, both algorithms generate the same results. This phenomenon can be observed in sensitivity analysis section.

3.3 Special Case

If there is no overlapping in between the cycles, which means during the downtime no production or uptime takes place, then the inventory diagram in Fig. 3 becomes similar to Giri and Sharma (2015) [also, Mungan *et al.* (2010), Chen and Sarker (2010), Diponegoro and Sarker, (2002, 2006, 2007); Sarker and Diponegoro (2006, 2009); Sarker and Parija, (1994, 1996)] model shown in Fig. 4. In this case the cycle time, *T*, becomes $T = T_s + T_P + T_D = nL$ and there is downtime during the pure shipment or downtime and each cycle delivers *k* units of finished goods every *L* time units. Therefore, the finished goods inventory, I_P, from Eq. (5) will convert to I_{PS} when

$$T_s \rightarrow T_s + T_D = T_s + T_s + T_P = 2T_s + nk/P. \quad (27)$$

Applying Eq. (27) in Eq. (5) it can be found that

$$I_s = \frac{n^2k^2}{2D_f} + nk\left\{\frac{k}{2D_f} - \frac{1}{2}\left(2T_s + \frac{nk}{P}\right)\right\} = \frac{n^2k^2}{2D_f}\left(1 - \frac{D_f}{P}\right) + nk\left(\frac{k}{2D_f} - T_s\right) \quad (28)$$

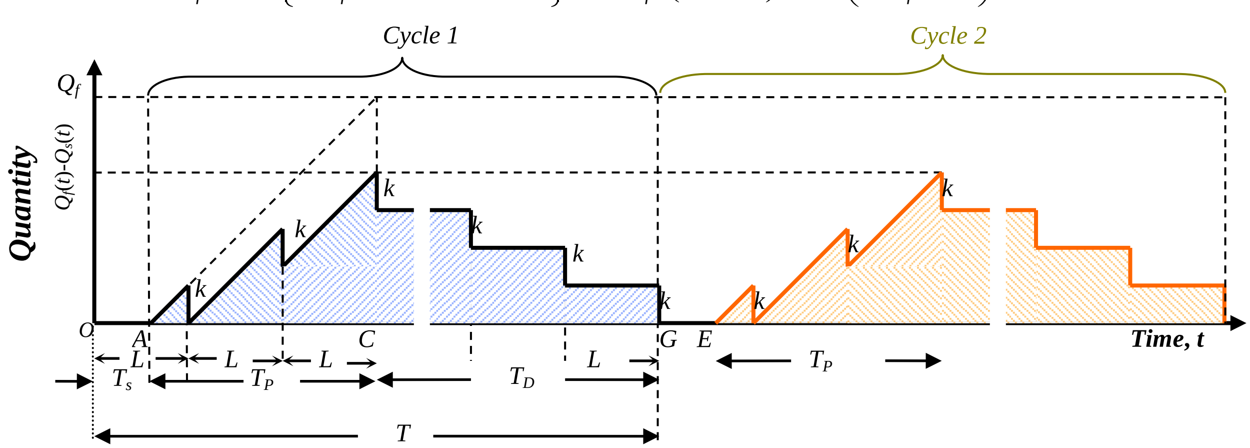

Fig. 4 Finished products inventory with downtime, respectively.

and the average inventory becomes

$$\overline{I}_s = \left[\frac{nk}{2}\left(1-\frac{D_f}{P}\right) + D_f\left(\frac{k}{2D_f} - T_s\right)\right]. \quad (29)$$

Therefore, the total cost function given in Eq. (9) converts to

$$ETC(n) = \frac{A_f D_f}{nk} + h_f\left[\frac{nk}{2}\left(1-\frac{D_f}{P}\right) + D_f\left(\frac{k}{2D_f} - T_s\right)\right], \quad (30)$$

which is similar to Giri and Sharma (2015) [also, Mungan *et al.* (2010), Chen and Sarker (2010), Diponegoro and Sarker, (2002, 2006, 2007); Sarker and Diponegoro (2006, 2009); Sarker and Parija, (1994, 1996)] cost function model for infinite planning horizon.

Let Giri and Sharma (2015) [also, Mungan *et al.* (2010), Chen and Sarker (2010), Diponegoro and Sarker, (2002, 2006, 2007); Sarker and Diponegoro (2006, 2009); Sarker and Parija, (1994, 1996)] model be "Deferred Production" (as there is a long downtime after the production stops at end of time period T_P), and the model described in this paper for is "Accelerated production". The operation schedule presented in Fig. 3 and Fig. 4 provide the number of shipments to the retailers are 3 and 6, respectively. Applying the parametric values given in Table 1, and using cycle time, $T = nL = 3k/D_f$, the values of T, quantity produced, Q during T and downtime, T_s in accelerated production for all six problems are computed and presented in Table 4. Similarly, for deferred production, the cycle time can be computed as $T = 6k/D_f$ and using the parametric values, the computed values of T, quantity produced, Q during T and downtime, T_D also presented for Deferred production in Table 4. Finally, it can be observed that, in accelerated system produces, more finished products result than the deferred production for supply chain system.

Table 4: Inventory produced in accelerated and deferred production

Problems	Accelerated			Deferred			Accelerated	Deferred
	Cycle time (years)	Quantity produced (units)	Downtime (years)	Cycle time (years)	Quantity produced (units)	Downtime (years)	Quantity Produced (units/year)	Quantity Produced (units/year)
1	0.125	24.85	0.001	0.250	36.90	0.124	198.80	147.60
2	0.125	24.70	0.002	0.250	36.30	0.123	197.60	145.20
3	0.150	44.55	0.002	0.300	88.20	0.148	297.00	294.00
4	0.115	45.25	0.003	0.231	55.08	0.113	392.17	238.68
5	0.173	101.60	0.005	0.346	151.96	0.168	587.02	439.00
6	0.146	98.93	0.006	0.292	144.24	0.140	678.38	494.54

4. Sensitivity analysis

This part of the research presents the sensitivity analyses of the total cost functions of the supply chain systems which have been discussed in previous sections. These analyses are performed based on the static values involved in the cost function. They are shipment quantity, raw material conversion factor, ratios of ordering and setup costs, and ratios of raw material and finished goods holding costs.

4.1 Effect of Shipment Size (k) on Total Cost Functions

In a just-in-time (JIT) delivery-based production system, the shipment size is an important factor. The total cost functions revolve around the shipment size, k. Also, k determines the on-hand inventory and its carrying costs. Therefore, it is necessary to perform a sensitivity analysis base on the variation of shipment size, k. To perform this analysis, it is necessary to evaluate the differentiations with respect to k of the Eq. (11) as follows:

$$\frac{dETC(m^*, n^*)}{dk} = \frac{n^{*2}kh_r}{m^* fP} - \frac{D_f}{n^* k^2}(m^* A_r + A_f) + \frac{1}{2}h_f(n^*+1) \quad (31)$$

Applying the parametric values for all the *Examples* from Table 1 in Eq. (31) and varying the values of k from 1 to 800 units/shipment, the graphical presentations are shown in Fig. 5. From Fig. 5, it can be observed that the total cost functions increase when k value varies from 1 to 300 units/shipment, after that the total costs become saturated in straight lines, which are almost parallel to *x-axis*. This is because whatever quantities are produced, are being shipped to the customers. Therefore, there is no inventory holding costs for finished products.

4.2 Effect of Raw Material Conversion Factor (*f*) on Total Cost Functions

Another important parameter here is raw material conversion factor, *f*, which is a determination factor of ordering required raw materials. In this section, the sensitivity analysis is performed for the system with respect to *f*. Differentiating Eq. (11) with respect to *f* it can be found that

$$\frac{dETC(m^*,n^*)}{df} = -\frac{1}{2}\frac{n^{*2}k^2h_r}{m^* f^2 P}. \quad (32)$$

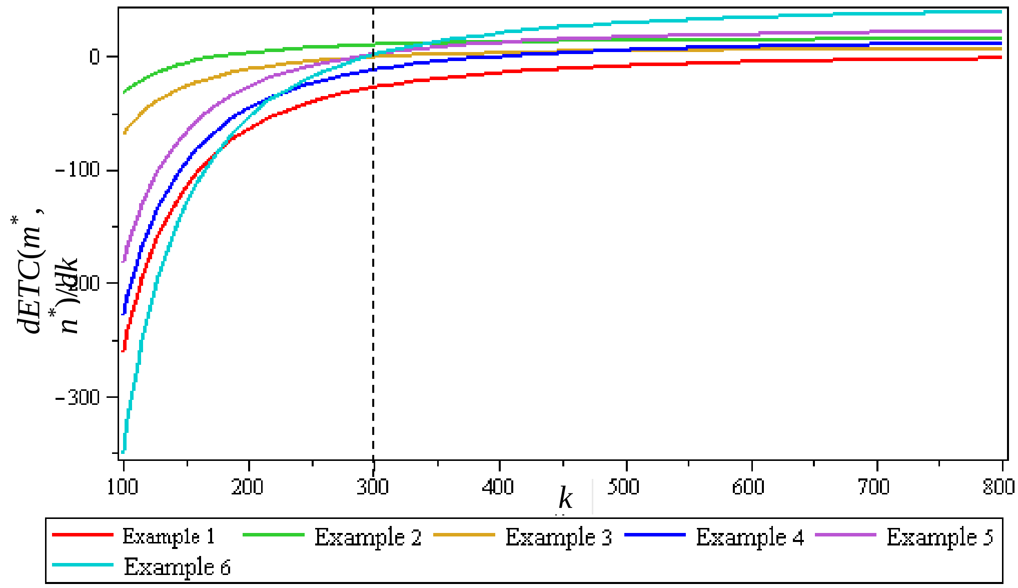

Fig. 5 Effect of shipment size *k* on the total system costs

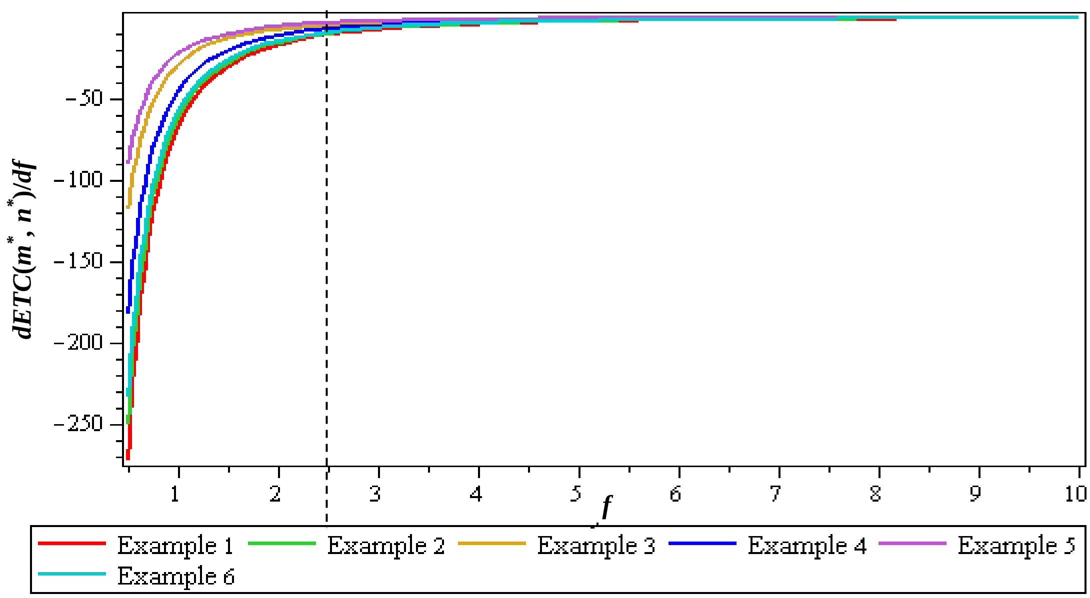

Fig. 6 Effect of conversion factor *f* on the total system costs

Applying the parametric values (from Table 1) in Eq. (32) and varying the values of f from 1 to 10, the illustration is shown in Fig. 6. Fig. 6 shows that the change in total costs for all problems increases with the increase of f when f varies from 1 to 2.5, as the quantity of raw material ordering increases.

4.3 Effect of Ordering (A_r) and Setup Costs (A_f) on Total Cost Functions

Raw material ordering (A_r) and setup (A_f) costs have significant impact on the total cost functions. According to the formation of the total cost functions of the system [Eq. (11)], it can be observed that the ordering (A_r), and setup (A_r) costs are a linear operator for the cost functions. Therefore, the total cost will increase with the increase of both the A_r and A_f.

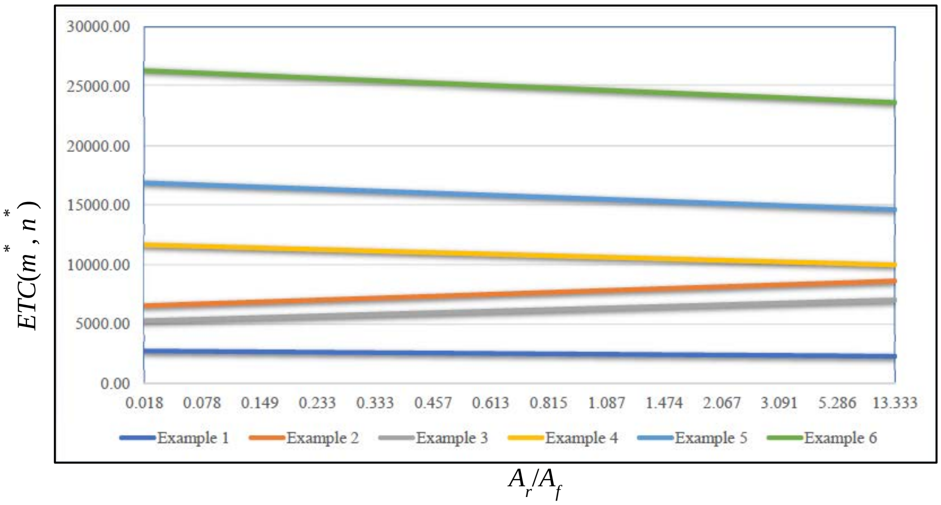

Fig. 7 Effect of A_r/A_f on total system costs

Table 5: Effect of A_r/A_f on the total costs

Ratio of A_r/A_f	*Example 1*	*Example 2*	*Example 3*	*Example 4*	*Example 5*	*Example 6*
0.018	2751.63	6556.83	5299.77	11681.29	16889.17	26312.62
0.078	2717.34	6716.83	5433.10	11551.29	16715.83	26106.90
0.149	2683.06	6876.83	5566.43	11421.29	16542.50	25901.19
0.233	2648.77	7036.83	5699.77	11291.29	16369.17	25695.47
0.333	2614.48	7196.83	5833.10	11161.29	16195.83	25489.76
0.457	2580.20	7356.83	5966.43	11031.29	16022.50	25284.05
0.613	2545.91	7516.83	6099.77	10901.29	15849.17	25078.33
0.815	2511.63	7676.83	6233.10	10771.29	15675.83	24872.62
1.087	2477.34	7836.83	6366.43	10641.29	15502.50	24666.90
1.474	2443.06	7996.83	6499.77	10511.29	15329.17	24461.19
2.067	2408.77	8156.83	6633.10	10381.29	15155.83	24255.47
3.091	2374.48	8316.83	6766.43	10251.29	14982.50	24049.76
5.286	2340.20	8476.83	6899.77	10121.29	14809.17	23844.05
13.333	2305.91	8636.83	7033.10	9991.29	14635.83	23638.33

Conversely, the ratio of A_r/A_f also plays an important role on the system cost. Therefore, a sensitivity analysis has been performed by increasing the ratio of A_r/A_f from 0.02 to 13, and the variation of the total cost function has been observed. The detailed results are presented in Table 5 and a graphical representation is shown in Fig. 7. According to the Fig. 7 and Table 5, it can be observed that total cost of the system decreases with the increase of ordering and setup cost ratio in linear fashion except for Example 2 and Example 3.

4.4 Effect of Raw Material (h_r) and Finished Goods (h_f) Carrying Costs

In the total cost function of a two-echelon inventory system, the raw material (h_r) and finished goods (h_f) carrying costs, play an important role. So, it is essential to find the impact in the total cost function, with variations in both the raw material (h_r) and finished goods (h_f) holding costs. The total costs decrease with the increase of the ratios of h_r/h_f as the total cost functions are linearly dependent upon h_r and h_f.

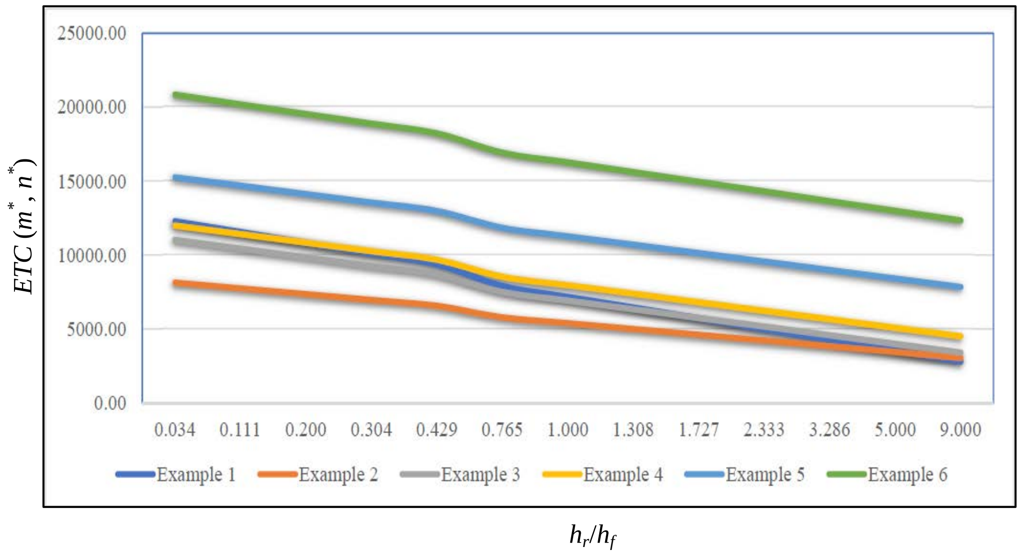

Fig. 8 Effect of h_r/h_f on the total system costs

Table 6: Effect of h_r/h_f on the total costs

Ratio of h_r/h_f	***Example 1***	***Example 2***	***Example 3***	***Example 4***	***Example 5***	***Example 6***
0.034	12284.94	8132.48	11017.22	11988.37	15258.21	20839.28
0.111	11555.4	7741.45	10431.66	11413.11	14687.96	20185.26
0.200	10825.85	7350.42	9846.09	10837.86	14117.71	19531.25
0.304	10096.31	6959.38	9260.53	10262.6	13547.46	18877.23
0.429	9366.764	6568.35	8674.97	9687.343	12977.21	18223.21
0.765	7907.675	5786.28	7503.84	8536.829	11836.71	16915.18
1.000	7178.131	5395.25	6918.28	7961.571	11266.46	16261.17
1.308	6448.587	5004.22	6332.72	7386.314	10696.21	15607.15
1.727	5719.042	4613.18	5747.16	6811.057	10125.96	14953.13
2.333	4989.498	4222.15	5161.59	6235.8	9555.71	14299.12
3.286	4259.953	3831.12	4576.03	5660.543	8985.46	13645.10
5.000	3530.409	3440.08	3990.47	5085.286	8415.21	12991.09
9.000	2800.864	3049.05	3404.91	4510.029	7844.96	12337.07

Conversely, the ratio of raw material (h_r) and finished goods (h_f) carrying costs have different effects on the total cost $ETC(m^*, n^*)$. Therefore, varying the ratio of h_r/h_f from 0.03 to 9.0, and using the parametric values (from Table 1) in Eq. (11), the effects system total cost, $ETC(m^*, n^*)$ is presented in Fig. 8. Also, details computational results are presented in Table 6. From both Fig. 8 and Table 6 it is observed that the total cost functions decrease with the increase of the ratio of h_r/h_f.

5. Conclusion

The primary objective of this research was to determine the operational policy for a two-stage continuous production-based supply chain system (the production of a cycle starts immediately after the end of its preceding cycle), and to minimize both the inventory and system cost. This study presents an operations policy of a supply chain system with just-in-time (JIT) deliveries. A set of problems are categorized as a serial system with a fixed quantity and a fixed delivery interval in a perfect matching condition, where the finished goods produced are the same as the finished goods delivered to the customers. For the research, the optimum number of orders, optimum batch sizes, and optimum number of shipments were evaluated to minimize the total system cost. The operation policies prescribe the number of orders and the ordered quantities of raw materials from suppliers, production quantities, and number of shipments to the customers for an infinite planning horizon.

In this research, the perfect matching problem is formed as non-linear integer (NILP) non-convex function, and the problems with rotation cycle is formed as non-convex mixed integer non-linear programming (MINLP) problem. The solution techniques were proposed using integer approximations, and divide and conquer rules. Based on these solution processes, this research used various numerical analysis based on numerical data found in previous research. Moreover, the total cost for the accelerated production (current research) is higher than the cost for the deferred production (found in literature), because the current research produced more finished products as the facility has less downtime or down time.

The proposed models will allow the decision makers to quickly respond to the changes in demand and setup parameters by adjusting the cost parameters and the planning horizon. System performances such as work-in-process, inventory costs, and system cost can be reduced down to a significant level by implementing the prescribed policies and their solution techniques. Specific applications can be found in supply chains for refinery, paper mills, microchips, electronic industries, and retail industries. Prospective research issues such as time varying demand, variable production capacity, transportation cost, etc. can be pursued further concerning the supply chain system addressed in this research.

6. References

[1] R. Aderohunmu, A. Mobolurin, and N. Bryson, "Joint vendor-buyer policy in JIT manufacturing," *Journal of Operational research Society*, Vol. 46, No. 3, 1995, pp. 375-38.

[2] A. Banerjee, S-L. Kim, and J. Burton, "Supply chain coordination through effective multi-stage inventory linkages in a JIT environment," *International Journal of Production Economics*, Vol. 108 No. 1-2, 2007, pp. 271-280.

[3] P. Biswas, and B. R. Sarker, "Operational Planning of Supply Chains in a Production and Distribution Center with Just-in-time Delivery," *Journal of Industrial Engineering and Management*, Vol. 13, No. 2, 2020, pp.73-89, Online ISSN: 2013-0953 – Print ISSN: 2013-8423, https://doi.org/10.3926/jiem.3046.

[4] Z. X. Chen, and B. R. Sarker, "Multi-vendor integrated procurement-production system under shared transportation and just-in-time delivery system," *Journal of the Operational Research Society*, Vol. 61, No. 11, 2010, pp. 1654 –1666.

[5] Z. X. Chen, and B. R. Sarker, "An integrated optimal inventory lot-sizing and vehicle-routing model for a multisupplier single-assembler system with JIT delivery," *International Journal of Production Research*, Vol. 52, No. 17, 2014, pp. 5086-5114.

[6] E. Chinello, Z. Nadja, L. Herbert-Hansen, and W. Khalid, "Assessment of the impact of inventory optimization drivers in a multi-echelon supply chain: Case of a toy manufacturer," *Computers & Industrial Engineering*, Vol. 141, No. March, 2020, pp. 106232.

[7] A. Diponegoro, and B. R. Sarker, "Finite horizon planning for a production system with permitted shortage and fixed-interval deliveries," *Computers & Operations Research*, Vol. 33, No. 8, 2006, pp. 2387-2404.

[8] A. Diponegoro, and B. R. Sarker, "Operations policy for a supply chain system with fixed interval delivery and linear demand," *Journal of the Operational Research Society*, Vol. 58, No. 7, 2007, pp. 901-910.

[9] L. Eduardo Cardenas-Barron, G. Trevino-Garza, G. A. Widyadana, and H-M. Wee, "A constrained multi-products EPQ inventory model with discrete delivery order and lot size," *Applied Mathematics and Computation*, Vol. 230, 2014, pp. 359–370
[10] G. Fandel, and J. Trockel, "Investment and lot size planning in a supply chain: coordinating a just-in-time-delivery with a Harris- or a Wagner/Whitin-solution," *Journal of Business Economics*, Vol. 86, 2016, pp. 173–195.
[11] B.C. Giri, and S. Sharma, "Optimizing a closed-loop supply chain with manufacturing defects and quality dependent return rate," *Journal of Manufacturing Systems*, Vol. 35, 2015, pp. 92–111.
[12] D. Y. Golhar, and B. R. Sarker, "Economic manufacturing quantity in a just in time delivery system," *International Journal of Production Research*, Vol. 30, No. 5, 1992, pp. 961-972.
[13] S. K. Goyal, "An Optimal Method for a Deterministic Joint Replenishment Inventory Policy in Discrete Time," *Journal of the Operational Research Society*, Vol. 46, No. 11, 1995, pp. 1404.
[14] J. R. Grout, "A model of incentive contracts for just-in-time delivery," *European Journal of Operational Research*, Vol. 96, No. 1, 1997, pp. 139-147.
[15] R. Handfield, D. Don Warsing, and X. Wu, "(Q,r) Inventory policies in a fuzzy uncertain supply chain environment," *European Journal of Operational Research*, Vol. 197, No. 2, 2009, pp. 609-619.
[16] R. M. Hill, "Viewpoints on: an optimal batch size for a production system operating under a fixed-quantity, periodic delivery policy," *Journal of Operational Research Society*, Vol. 46, No. 2, 1995, pp. 271-273.
[17] M. A. Hoque, "An alternative optimal solution technique for a single-vendor single-buyer integrated production inventory model," *International Journal of Production Economics*, Vol. 131, No. 1, 2011, pp. 463–472.
[18] Jonrinaldi and D. Z. Zhang, "An integrated production and inventory model for a whole manufacturing supply chain involving reverse logistics with finite horizon period," *Omega-The International Journal of Management Science*, Vol. 41, No. 3, 2013, pp. 598–620.
[19] L. R. Khan, and R. A. Sarker, "An optimal Batch size for a JIT manufacturing system," *Computers and Industrial Engineering*, Vol. 42, No. 2-4, 2002, pp. 127-138.
[20] S. C. Kim, and K. S. Shin, "Negotiation Model for Optimal Replenishment Planning Considering Defects under the VMI and JIT Environment," *The Asian Journal of Shipping and Logistics*, Vol. 35, No. 3, 2019, pp. 147-153.
[21] S. L. Kim, A. Banerjee, and J. Burton, "Production and delivery policies for enhanced supply chain partnerships," *International Journal of Production Research*, Vol. 46, No. 22, 2008, pp. 6207–6229.
[22] R. A. C. Leuveano, M. N. A. Rahman, W. M. F. W. Mahmood, and C. Saleh, "Integrated Vendor-Buyer Lot-Sizing Model with Transportation and Quality Improvement Consideration under Just-in-Time Problem," *Mathematics*, Vol. 7, No. 944, 2019, pp. 1-25.
[23] A. Mardani, D. Kannan, R. E. Hooker, S. Ozkul, M. Alrasheedi, E. B. Tirkolaee, "Evaluation of green and sustainable supply chain management using structural equation modelling: A systematic review of the state of the art literature and recommendations for future research," *Journal of Cleaner Production*, Vol. 249, No. 10, 2020.
[24] N. M. Modak, S. Panda, and S. S. Sana, "Optimal just-in-time buffer inventory for preventive maintenance with imperfect quality items," *Tékhne*, Vol. 13 (2), 2015, pp.135-144.
[25] D. Mungan, J. Yu, and B. R. Sarker, "Manufacturing lot-sizing, procurement and delivery schedules over a finite planning horizon," *International Journal of Production Research*, Vol. 48, No. 12, 2010, pp. 3619-3636.
[26] A. H. Nobil, A. H. A. Sedigh, and L.E. Cárdenas-Barrón, "A multiproduct single machine economic production quantity (EPQ) inventory model with discrete delivery order, joint production policy and budget constraints" *Annals of Operations Research*, Vol. 286, 2020, pp. 265–301.
[27] V. S. Nori, and B. R. Sarker, "Cyclic scheduling for a multi-product, single-facility production system operating under a just-in-time delivery policy," *Journal of Operational Research Society*, Vol. 47, No. 7, 1996, pp. 930-93
[28] M. Omar, and R. A. Sarker, "An optimal policy for a just-in-time integrated manufacturing system for time-varying demand process," *Applied Mathematical Modelling*, Vol. 39, 2015, pp. 5327-5329.
[29] G. R. Parija, and B. R. Sarker, "Operations planning in a supply chain systems with fixed-interval deliveries of finished goods to multiple customers," *IIE Transactions*, Vol. 31, No. 11, 1999, pp. 1075-1082.
[30] H. Rau, and B. C. OuYang, "An optimal batch size for integrated production–inventory policy in a supply chain" *European Journal of Operational Research*, Vol. 185, No. 2, 2008, pp. 619-634.
[31] B. R. Sarker, and A. Diponegoro, "A finite horizon planning with fixed interval of deliveries and no shortage, *OPSEARCH*, Vol. 43, No. 4, 2006, pp. 404-424.

[32] B. R. Sarker, and A. Diponegoro, "Optimal production plans and shipment schedules in a supply-chain system with multiple suppliers and multiple buyers," *European Journal of Operational Research*, Vol. 194, No. 3, 2009, pp. 753–773.
[33] B. R. Sarker, and G. R. Parija, "An optimal batch size for a production system operating under a fixed-quantity, periodic delivery policy," *Journal of Operational Research Society*, Vol. 45, No. 8, 1994, pp. 891-900.
[34] B. R. Sarker, and G. R. Parija, "Optimal batch size and raw material ordering policy for a production system with a fixed-interval, lumpy demand delivery system," *European Journal of Operational Research*, Vol. 89, No. 3, 1996, pp. 593-608.
[35] R. A. Sarker, and L. R. Khan, "An optimal batch size for a production system operating under periodic delivery policy," *Computers and Industrial Engineering*, Vol. 37, No. 4, 1999, pp. 711-730.
[36] Tirkolaee, E. B., Mahmoodkhani, J., Bourani, M. R., and Tavakkoli-Moghaddam, R., 2019. A Self-Learning Particle Swarm Optimization for Robust Multi-Echelon Capacitated Location–Allocation–Inventory Problem. *Journal of Advanced Manufacturing Systems*, Vol. 18, No. 4, 677-694.
[37] Tirkolaee, E. B., Mardani, A., Dashtian, Z., Soltani, M., and Weber, G-W.,. A novel hybrid method using fuzzy decision making and multi-objective programming for sustainable-reliable supplier selection in two-echelon supply chain design. *Journal of Cleaner Production*, **250** (30 March), 2020.
[38] A. M. Torkabadi, and R. V. Mayorga, "Implementation of Just-In-Time Policies in Supply Chain Management," *International Journal of Economics and Management Systems*, Vol. 2, 2017, pp. 315-320.
[39] S. Wang, and B. R. Sarker, "An assembly-type supply chain system controlled by kanbans under a just-in-time delivery policy," *European Journal of Operational Research*, Vol. 162, No. 1, 2005, pp. 153-172.
[40] S. Wang, and B. R. Sarker, "Optimal models for a multi-stage supply chain system controlled by kanban under just-in-time philosophy," *European Journal of Operational Research*, Vol. 172, No. 1, 2006, pp. 179-200.
[41] S. Wang, and B. Ye, "A comparison between just-in-time and economic order quantity models with carbon emissionsm," *Journal of Cleaner Production*, Vol. 187, No. 20 June, 2018, pp. 662-671.
[42] A. J. Yu, and Y. Dong, "A numerical solution for a two-stage production and inventory system with random demand arrivals," *Computers & Operations Research*, Vol. 44, 2014, pp. 13-21.
[43] Y. W. Zhou, H. S. Lau, and S. L. Yang, "A finite horizon lot-sizing problem with time-varying deterministic demand and waiting-time-dependent partial backlogging," *International Journal of Production Economics*, Vol. 91, No. 2, 2004, pp. 109-119.

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