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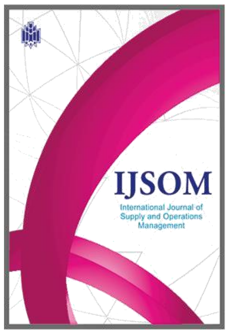

An Integrated Bi-Objective Supply Chain and Maintenance Problem in the Build-to-Order Environment

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Abstract

Nowadays, by increasing competition and customization, a build-to-order (BTO) system is given more consideration. Because of receiving the order at the beginning of assembling in BTO systems, the time of a failed machine causes a longer lead time. Thus, preventive maintenance (PM) can increase the availability of machines and is useful in this system. It is under the constant interval, in which the Weibull's graph is used to estimate a Weibull distribution for a failure rate function. This paper aims to maximize the total available time of machines, which is calculated based on the sum of the time of stopping the machines. In other words, the time of stopping the machines is maximized. This paper develops a new integrated bi-objective BTO supply chain problem, which maximizes the profit and minimizes the time of stopping the machines by PM. Maintenance is a new issue in BTO studies. Since the importance of on-time lead time in these systems, PM has beneficial results in these systems, which is very useful for senior managers. Outsourcing and pricing are the other issues considered in this paper. Furthermore, a robust optimization approach is applied to handle uncertainty. The new robust BTO supply chain model is performed in a wood industry to accredit this proposed model. At last, managerial insights are provided in such a way that using PM, outsourcing, pricing, and uncertainty in BTO systems is very useful and applicable.

Keywords*:* Preventive maintenance; build-to-order; robust optimization; supply chain.

1. Introduction

By increasing competition and reducing product lifecycles, it is very important to adopt environmental changes. Supply chain management (SCM) is one way to help organizations to be successful (Ehtesham Rasi et al., 2019). Many researchers have suggested that SCM integrates functions, distribution operations, and production to be a flexible company, and reduce the costs (Touil et al., 2019). The flow of information, materials, and finance is managed in SCM. Especially, managing finance flow is very important (Pant & Mahapatra, 2018). On the other hand, by increasing the customization, a build-to-order (BTO) supply chain is attracting more consideration. Timely delivery and high performance of production have high importance in customized systems (Laimazloumian et al., 2013). The failed devices and time to repair them make the lead time lengthy. Therefore, preventive maintenance (PM) can be beneficial in reducing the lead time in a BTO system. The literature has studied joint PM and production planning (PP) and lacked in the joint SC and PM. A few studies in the SC field are about spare parts maintenance, which lacks studying echelons in the SC. Also, maintenance has not been considered in the literature of BTO systems. To the best of our knowledge, we study the joint SC and PM in the BTO environment under uncertainty. This paper has two objectives, which maximize the profit and minimize the time of stopping the machines. Also, pricing and outsourcing are new issues in the maintenance literature considered in this model. Outsourcing is a novel issue in PM studies, which is beneficial for reducing the cost. Also, another contribution of the proposed model is to apply a robust optimization approach in formulating the integrated model with demand and cost fluctuations.

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2. The literature review

Integrated PM with PP and integrated PM with scheduling problems have been investigated in a few literature reviews. Sin and Chung (2019) studied PM in a scheduling problem, in which a single machine was scheduled under time-of-use pricing. Oscan and Simsir (2019) investigated a rail production line to formulate a replacement scheduling problem for 1349 parts replaced based on PM. Miyata et al. (2019) proposed an integrated PM and *m*-machine scheduling problem, which minimizes makespan.PM in their model is under the flexibility concept and diverse maintenance level. Alimian et al. (2019) proposed an integrated model, which studied corrective and preventive actions in PP. They used a robust optimization approach to consider demand fluctuations. Liu et al. (2020) studied maintenance to increase the availability of wind-power equipment. Kalinowski et al. (2020) considered maintenance in a rail infrastructure to be in a safe and reliable condition. Gu et al. (2020) investigated a control-limited maintenance policy in large manufacturing systems. Amiri et al. (2018) suggested a bi-objective PM model for energy hub scheduling, which PM was used for hub equipment to optimize the cost and reliability under demand uncertainty. Kang and Subramaniam (2018) studied integrated preventive and corrective maintenance and control of production in deteriorating a manufacturing system with a single machine. Also, they considered a maintenance level in their model. Rashidnejad et al. (2018) investigated PM in geographically distributed assets, which used the remaining useful life and prognostic information. Zhong et al. (2019) proposed fuzzy chance-constrained programming and studied wind firms in the offshore, which used PM for a wind turbine. Vieira et al. (2017) presented maintenance and production to increase the service level, enhancement of the utilization rate of the process, and reduction of the number of maintenance operations. Dellagi et al. (2017) considered an integrated maintenance and production model by studying the relation between production and failure rates. Statistical process control is another issue studied in their research. Rasay et al. (2018) addressed a production process, in which maintenance and statistical process control were considered simultaneously.

A few literature studies have addressed an SC and maintenance problem with a spare part SC. Gallab et al. (2017) addressed a liquefied petroleum gas (LPG) SC by investigating maintenance risk for the SC equipment. The decision related to purchase or produce spare parts was another issue considered in their study. Uddin and Sharif (2016) studied a maintenance SC of spare parts because the supply, inventory, and uncertain demand of spare parts have a high cost. Roy et al. (2018) provided comprehensively a review of studied sustainable SCM. Turki and Rezg (2017) considered E-maintenance in the SC Company so the online products have a warranty period to maintain. Conventional maintenance service and E-maintenance are two cases studied in their research. Oalumali Sirisena and Samarasekera (2018) investigated a location decision and maintenance SC problem for vessel spare parts. The location decision problem for a spare part distribution center was solved by the analytical hierarchy process and factor rating methods.

The BTO literature can be classified into conceptual problems. Flexibility, knowledge management and reduction strategies are the issues addressed in the conceptual models. Some mathematical models have considered uncertainty that one of them was studied by Lalmazloumian et al. (2013), who applied robust optimization with cost and demand uncertainties. Lin and Wang (2011) investigated a BTO supply chain with supplier and demand uncertainties. The L-shape algorithm was used for the scenario-based model. Lin and Wu (2013) formulated a BTO supply chain, with stochastic demand which was dependent on the price. Li and Chen (2011) studied customer segmentation and investigated two segments of customers. In another study, the customer utility was considered in a BTO supply chain so that the utility function was based on the quality and price. The bi-objective problem was solved by two meta-heuristics, namely NRGA and NSGA-II (Ebrahimi et al. 2018). Lim et al. (2017) investigated sales and operation planning in BTO systems, in which their multi-objective problem trades-off between customer satisfaction and costs. They applied their model in the automobile industry. Ebrahimi et al. (2019) studied BTO systems under uncertainty and proposed a multi-objective problem that minimizes the cost and lead time and maximizes the quality.

There are many studies in the maintenance field; however, some of them have been addressed the joint PM and PP. Also, a few of them were formulated a joint SC and PP. Most of them were investigated a spare part or maintenance SC. Therefore, the contribution of our study is to consider the joint SC and PM problem in a three-echelon SC. Furthermore, some elements are gained by outsourcing. On the other hand, this paper is a new integrated BTO supply chain and PM problem since the PM did not address in the BTO literature in the previous research. The receiving order is at the beginning of assembling the final product. Therefore, the failed machines cause longer lead time, and then PM will be beneficial for BTO systems.

3. Presented model

This section explains the mathematical model.

3.1. Robust optimization formulation

Handling uncertainty in the problem, there are three approaches, namely a fuzzy-based, distribution-based, and robust optimization. In this paper, the Mulvey's robust optimization approach (Laimazloumian, 2013) is used as a scenario-based approach. It searches to evaluate the trade-off between model robustness and solution robustness that are the measure of feasibility and optimality, respectively.

3.2 Model description

We have studied many literature reviews in maintenance and BTO supply chain, integrated some aspects (e.g., object and some limitations) of them, and then proposed an integrated model. This paper proposes a three-echelon SC model consisting of suppliers, manufacturer, and customer zones. Suppliers provide the raw materials or components to manufacturers, who fabricate components or assemble the modules (or fabricated components) to produce some types of products. In this paper, the profit of the SC as a whole is considered. The aims are to maximize the profit and availability of machines. Pricing is the subject investigated in this study. Also, outsourcing is a new issue in BTO systems investigated in this study. Some elements supplied by outsourcing in this problem to reduce the total cost. Because of receiving the order at the beginning of assembling, the time of the failed machine causes a more lengthy lead time. Thus, PM can reduce the time of stopping of machines and will be beneficial in these systems. Also, the total available time is calculated based on the sum of the time of the stopping of machines. We use PM in the constant interval to minimize the time of stopping of machines. A Weibull's graph is used to estimate a Weibull distribution for a failure rate function. The bi-objective proposed model maximizes the availability of machines or minimizes the stop time of machines and maximizes the profit. In this paper, there are two types of demands, namely the demand for elements producing in-home and the demand for the final products.

3.3. Model formulation

Indices

j	Final product
so	Suppliers of components
c	Customer
n	Components
r	Raw material
de	Machine
t	Period
su	Suppliers of raw materials
s	Scenario

Parameters

$D_{c,j,t,s}$	Demand of product j in period t for customer c under scenario s
$Dnq_{c,n,t,s}$	Demand of component n in period t for customer c under scenario s
$C_{j,t,s}$	Production cost in period t for product j under scenario s
$\mathrm{OCN}_{n,so,t,s}$	Purchasing cost from the supplier so for component n in period t under scenario s
$\mathrm{CN}_{n,t,s}$	Fabricating cost for component n in t period under scenario$s$
T_n	Fabricating time for component n
$OCR_{r,su,t,s}$	Purchasing cost from supplier su for raw material r in period t under scenario s
MR_r	Maximum inventory capacity for raw material r
MN_n	Maximum inventory capacity for component n
NQM_n	Maximum fabricating capacity for component n
QM	Maximum manufacturing/assembling capacity for product j
$STO_{t,s}$	Stop time of machines in period t under scenario s
$CC_{j,t}$	Price lower bound for product j in period t
$PM_{j,t}$	Upper bound of the price of product j in period t
$TF_{de,s}$	Repair time in machine de for corrective maintenance under scenario s
$TP_{de,s}$	Length of repair time for PM in machine de under scenario s
$\eta_{de,s}$	Weibull distribution parameter of machine de for the failure function rate under scenario s
$\beta_{de,s}$	Weibull distribution parameter of machine de for the failure function rate under scenario s
$\mu_{n,j}$	Amount of required component n in product j
$\gamma_{r,n}$	Amount of row material r required in component n
$\mu\mu_{r,j}$	Amount of required row material r in product j
τ	Price-sensitive coefficient in demand

Decision variables

$P_{c,j,t}$	Price of product j in period t for customer c
$Q_{j,t,s}$	Quantity of manufacturing product j in period t under scenario s
$\mathrm{ONQ}_{n,so,t,s}$	Quantity of selling component n from supplier so under scenario s in period t
$\mathrm{NQ}_{n,t,s}$	Quantity of fabricating component n under scenario s in period t
$ORQ_{r,su,t,s}$	Quantity of selling raw material r in period t from supplier su under scenario s
$IR_{r,t,s}$	Inventory of raw material r under scenario s in period t
$IN_{n,t,s}$	Inventory of component n under scenario s in period t
$H_{de,t,s}$	Failure function rate for machine de in period t under scenario s
$TTP_{de,t,s}$	Length of maintenance cycles for machine de under scenario s in period t
$DN_{n,t,s}$	Component n' demand in period t under scenario s
$DNQ_{c,n,t,s}$	Component n' demand for customer c in period t under scenario s
$DR_{r,t,s}$	Raw material r' demand in period t under scenario s

$$\text{Max } Z1_s = \sum_t \sum_j (\sum_c P_{c,j,t}.D_{c,j,t,s} - C_{j,t,s}.Q_{j,t,s}) - \sum_{\mathrm{n}} \left(\sum_{\mathrm{s}} (\mathrm{OCN}_{\mathrm{n,so,t,s}}.\mathrm{ONQ}_{\mathrm{n,so,t,s}} + \mathrm{CN}_{\mathrm{n,t,s}}.\mathrm{NQ}_{\mathrm{n,t,s}} \right) - \sum_r OCR_{r,s,t,s}.ORQ_{r,su,t,s} \quad (1)$$

$$\text{Min } Z2_s = \sum_{de} \frac{H_{de,t}.TF_{de,s} + TP_{de,s}}{TTP_{de,t} + TP_{de,s}} \quad (2)$$

s.t.

$$H_{de,t} = (\frac{TTP_{de,t}}{\eta_{de,t,s}})^{\beta_{de,t,s}} \quad (3)$$

$$p_{c,j,t} > CC_{j,t} \quad (4)$$

$$p_{c,j,t} < PM_{j,t} \quad (5)$$

$$Q_{j,t,s} = \sum_c D_{c,j,t,s} \quad (6)$$

$$DN_{n,t,s} = \sum_j Q_{j,t,s}.\mu_{n,j} \quad (7)$$

$$DR_{r,t,s} = \sum_n \gamma_{r,n}.DN_{n,t,s} + \sum_j Q_{j,t,s}.\mu\mu_{r,j} \quad (8)$$

$$IN_{n,t+1,s} = IN_{n,t,s} + ONQ_{n,t,s} - DN_{n,t,s} + NQ_{n,t,s} - DNQ_{n,t,s} \quad (9)$$

$$IR_{r,t+1,s} = IR_{r,t,s} + ORQ_{r,t,s} - DR_{r,t,s} \quad (10)$$

$$IN_{n,t,s} \leq MN_n \quad (11)$$

$$IR_{r,t,s} \leq MR_r \quad (12)$$

$$STO_{t,s} = \sum_{de} \frac{H_{de,t}.TF_{de,s} + TP_{de,s}}{TTP_{de,t} + TP_{de,s}} \quad (13)$$

$$T_n.NQ_{n,t,s} \leq T_n.NQM_n - STO_{t,s} \quad (14)$$

$$\sum_j Q_{j,t,s} \leq QM \quad (15)$$

$$P_{c,j,t}, D_{c,j,t,s}, Q_{j,t,s}, \mathrm{ONQ}_{\mathrm{n,so,t,s}}, \mathrm{NQ}_{\mathrm{n,t,s}}, ORQ_{r,s,t,s}, IR_{r,t,s}, IN_{n,t,s}, H_{de,t}, TTP_{de,t}, DN_{n,t,s}, DNQ_{c,n,t,s}, DR_{r,t,s} \geq 0 \quad (16)$$

The first objective function is related to increasing profit. The second objective function is related to minimize the stop time of machines, which may have preventive or corrective maintenance. Equation (3) is related to the function of the failure rate. Equations (4) and (5) are shown the lower and upper bounds of the price, respectively. The product's required quantity, which satisfies all customers, is shown in Equation (6). The demand for raw materials and component are illustrated in Equations (7) and (8), respectively. The inventory balance of raw materials and components are represented in Equations (9) and (10), respectively. Equations (11) and (12) shown the upper bound of inventory capacity of raw materials and components, respectively. Total stop time of machines is shown in Equation (13). Equations (14) and (15) are related to the maximum capacity of component fabrication and final product manufacturing/assembling.

The robust optimization is used to handle inevitable uncertainty in the real world. It is a scenario-based method, in which there are two types of variables contains a control variable (dependent on uncertain parameters) and design a variable (independent of uncertain parameters). This approach seeks to a trade-off between the model robustness and the solution robustness. The deterministic model based on the Mulvey's robust optimization method (Laimazloumian et al., 2013) is illustrated by:

$$\text{Max } ZM_1 = \sum_{s} pr_s . Z_{1_s} + \lambda_1 . \sum_{s} pr_s . \left(Z_{1_s} - \sum_{\acute{s}} pr_{\acute{s}} . Z_{1_{\acute{s}}} + 2.\theta 1_s \right) + omega . \sum_{s}\sum_{j}\sum_{k}\sum_{t} pr_s . (delta_{n,t,s}) \tag{17}$$

$$\text{Min } ZM_2 = \sum_{s} pr_s . Z_{2_s} + \lambda_2 . \sum_{s} pr_s . \left(Z_{2_s} - \sum_{\acute{s}} pr_{\acute{s}} . Z_{2_{\acute{s}}} + 2.\theta 2_s \right) \tag{18}$$

s.t.

$$H_{de,t} = (\frac{TTP_{de,t}}{\eta_{de,t,s}})^{\beta_{de,t,s}} \tag{19}$$

$$p_{c,j,t} > CC_{j,t} \tag{20}$$

$$p_{c,j,t} < PM_{j,t} \tag{21}$$

$$p_{c,n,t} > \mathrm{CN_{n,t}} \tag{22}$$

$$p_{c,n,t} < NPM \tag{23}$$

$$Q_{j,t,s} = \sum_{c} D_{c,j,t,s} \tag{24}$$

$$IN_{n,t+1,s} + delta_{n,t,s} = IN_{n,t,s} + ONQ_{n,t,s} - DN_{n,t,s} + NQ_{n,t,s} - DNQ_{n,t,s} \tag{25}$$

$$DN_{n,t,s} = \sum_{j} Q_{j,t,s} . \mu_{n,j} \tag{26}$$

$$DR_{r,t,s} = \sum_{n} \gamma_{r,n} . DN_{n,t,s} + \sum_{j} Q_{j,t,s} . \mu\mu_{r,j} \tag{27}$$

$$IR_{r,t+1,s} = IR_{r,t,s} + ORQ_{r,t,s} - DR_{r,t,s} \tag{28}$$

$$IR_{r,t,s} \leq MR_r \tag{29}$$

$$IN_{n,t,s} \leq MN_n \tag{30}$$

$$STO_{t,s} = \sum_{de} \frac{H_{de,t}.TF_{de,s} + TP_{de,s}}{TTP_{de,t} + TP_{de,s}} \tag{31}$$

$$T_n.NQ_{n,t,s} \leq T_n.NQM_n - STO_{t,s} \tag{32}$$

$$\sum_j Q_{j,t,s} \leq QM \tag{33}$$

$$Z_{1_s} - \sum_{\acute{s}} pr_{\acute{s}}.Z_{1_{\acute{s}}} + \theta 1_s > 0 \tag{34}$$

$$Z_{2_s} - \sum_{\acute{s}} pr_{\acute{s}}.Z_{2_{\acute{s}}} + \theta 2_s > 0 \tag{35}$$

The first term is related to the expected first objective function, the second term is related to measurement weighted first objective function variance, and the third term is the penalty function of infeasibility (Eq. 17). The first term is related to the expected second objective function, the second term is related to measure the weighted second objective function variance (Eq. 18). $delta_{n,t,s}$ in Eq. (25) measures the allowed infeasibility in the control constraint. The difference between the first objective and its expected mean as well as its deviation for contravention of the mean should be positive (Eqs. 34 and 35).

4. Case study and computational analysis

The proposed bi-objective model is transferred to a single objective function by the Lp-metric method (Farughi and Mostafayi, 2016)and utility function or total weighted method (Howang et al., 1980; Pishvaee et al., 2014). The data obtained from the North Wood Industry Company of Iran are used by examining the proposed model. A range of clipboard in different sizes is produced in this company. Also, the data with 12 periods are considered.

4.1. Case description

The north wood industry company has a BTO system. We consider a part of it involving one manufacturer, seven suppliers, and 10 customer zones. Each supplier can provide one raw material. Two chipboards coated and one MDF coated are final products. The manufacturer produces two components (two types of chipboards) and one of component (MDF) is outsourced. We apply a PM policy to reduction of the stop time of devices. Costs, demand, and time to repair are uncertain parameters basing on a scenario. Some data gathered by the company are shown in Tables 1 and 2.

Table 1. Supplier's cost of raw materials

Raw materials	**Supplier**						
	1	2	3	4	5	6	7
Glue			250		230		190
Paper		13000				13000	
Wood	1010			1010			

Table 2. Maximum capacity of raw materials

Raw materials	**Maximum capacity**
Wood (wood chips)	40000 ton
Glue	248 ton
Paper overlay	66 pallet

4.2. Computational analyses

Based on the historical record, it can be reasonable that future economic scenarios will be suitable for three possible scenarios (good, fair, and poor (s=1, 2, and 3)). Three scenarios with probabilities of 0.2, 0.5, and 0.3 are considered to examine the proposed model. The sum of all probabilities is equal to 1. The Lp-metric method (i.e., p=1 and p=2) and the total weighted method are used to solve the bi-objective robust model. Also, the presented robust model is solved by different values of w. The Conopt solver of GAMS software was applied, which computational results are shown in Tables 3 to 5.Table 3 shows the optimal amount of the final product in one period with the Lp-metric method (i.e., p=1 and γ=0.6).

Table 3. Optimal amount of the final product

Final product	**Scenario**		
	1	2	3
1	933.988	957.988	974.988
2	43588.841	43826.012	43809.012

Tables4 and 5 show the optimal quantity of modules (i.e., components) and the optimal amount of the outsourced components with the total weighted method for 12 periods, respectively. Components 2 and 3 are manufactured in the company; however, component 1 is outsourced. So, Table 4 involves Components 2 and 3. Table 5 shows the optimal raw materials in 12 periods by the total weighted method. Since there are costs of the raw materials of different suppliers, the optimal raw material is determined. So, all raw materials are not provided by each supplier. Because of the lower cost of supplier 7 for raw material 3 provided by supplier 7. Suppliers 1 and 2 provide raw material 2 having fairly the same cost in different scenarios; thus, raw material 2 is provided by suppliers 1 and 2. Since the costs of suppliers 3 and 4 are fairly the same, so they provide raw material 1. Thus, both of them provide the optimal raw material 1.

Table 4. Optimal quantity of components

Components	**Period**	**Scenario**		
		1	2	3
2	1	175	197	208
	2	133	165	175
	3	150	155	158
	4	134	147	152
	5	195	214	225
	6	168	186	195
	7	57	64	74
	8	143	152	159
	9	211	225	237
	10	273	286	292
	11	140	145	153
	12	140	153	162
3	1	16.6	18.707	18.770
	2	0.521	0.584	0.73
	3	14.59	16.58	18.77
	4	16.68	18.18	19.81
	5	2.086	2.774	3.441
	6	1.043	1.186	1.46
	7	17.72	19.18	20.64
	8	1.564	1.752	2.064
	9	0.417	0.584	0.73
	10	4.692	5.255	7.091
	11	1.564	1.94	2.086
	12	4.171	4.672	6.257

Table 5. Optimal amount of raw materials

Raw materials	Suppliers	Period	Scenario 1	Scenario 2	Scenario 3
1	3	1	1182588.116	1378206.78	14605996.78
		2	255413.284	581805.32	1703.92
		3	1682657.188	1851341.85	1804215.583
		4	1394558.26	1583604.85	854125.46
		5	1540632.84	1586725.92	
		6	1113157.72	1319318.39	
		7	477326.116	569088.71	
		8	1146581.46	1475158.31	790661.19
		9	4492644.83	4541284.57	3682166.65
		10	2075946.116	2150670.71	1230598.8
		11	538.824	1655793.89	1574398.39
		12	1013748.652	1096781.24	646424.66
	4	1	126340.66		
		2	254032.036		598613.39
		3	126340.66		62402.66
		4	126340.66	84044.07	854125.46
		5	116.479	1151.39	1620057.32
		6		1517.99	1356326.39
		7	126340.66	84044.07	675356.78
		8	383944.92	84044.07	790537.19
		9	126340.66	84044.07	952900.04
		10	126340.66	84044.07	1028637.98
		11	1642547.03	557.966	114247.46
		12	126340.66	84044.07	646424.66
2	1	1		75076.03	74410.03
		2		88578.02	89083.7
		3		75488.02	82387.9
		4		12512.98	87611.33
		5		12111.97	87079.006
		6		79513.02	89524.34
		7		84494.03	96261.6
		8		77274.02	89561.6
		9		13991.98	28413.57
		10		69343.03	82861.6
		11		96193.75	
		12		76904.01	76501.36
	2	1	82868	7791.96	8457.96
		2	89568	7689.98	484.28
		3	96268	14079.97	7180.1
		4	82868	77055.01	1956.66
		5	96268	77456.02	2488.99
		6	82868	10054.98	43.65
		7	89568	5073.96	6.396
		8	96268	12293.97	6.396
		9	20999.9	13991.98	6.396
		10	96268	13524.96	6.396
		11	89568	74.249	96101.31
		12	82868	5963.98	6533.31
3	7	4	103284.9	33431.76	
		5	76065.44	46483.23	492764.19
		6	45.498	89698.59	92091.89
		7	45.498	444371.38	45863.78
		8	354113.24	33856.8	31189.24
		9	110212.6	5646.05	10347.4
		10	206887.7	252760.4	238372.97
		11	27125.18	112466.75	29712.6
		12	77440.8	80207.21	87814.8

Table 6 shows the sensitivity analysis of the assembling/manufacturing cost of the final product by the LP-metric method (i.e., p=1 and γ=0.6). It is completely reasonable that the SC cost is enhanced (or total profit is reduced) by enhancement of the final product cost. Also, the reduction of the final product cost resulted in the reduction of the total cost (or enhancement of the total profit).

Table 6. Sensitivity analysis of the final product cost

Final product costs	Scenario	First objective function
$C_j - C_j * 0.1$	1	14170100
	2	14321700
	3	13917400
$C_j - C_j * 0.05$	1	13466600
	2	13626600
	3	13199900
C_j	1	12763100
	2	12931500
	3	12482400
$C_j + C_j * 0.1$	1	11356000
	2	11541300
	3	11047400
$C_j + C_j * 0.15$	1	10652500
	2	10846100
	3	10329800

Table 7 shows the sensitivity analysis for the demand of the final product by the total weighted method ($w_1 = 0.3,\ w_2 = 0.7$). The total profit is increased by the enhancement of the demand for the final product. Also, the enhancement of the final product's demand resulted in increasing the total cost; however, the increased income is more than the increase in cost. It is completely reasonable that by enhancement of the final product demand, the total profit is increased.

Table 7. Sensitivity analysis of the final product demand

Final product costs	Scenario	First objective function
$D_{c,j,t,s} - D_{c,j,t,s} * 0.1$	1	9292245.9
	2	9001518.8
	3	8748927.4
$D_{c,j,t,s} - D_{c,j,t,s} * 0.05$	1	9808710.9
	2	9501838.3
	3	9235220.1
$D_{c,j,t,s}$	1	10325180
	2	10002160
	3	9221512.8
$D_{c,j,t,s} + D_{c,j,t,s} * 0.15$	1	11356790
	2	11002800
	3	10685520

4.3. Managerial insights

We provide managerial insights that can be derived from the computational experiments, we consider the interaction between several issues in BTO systems, such as outsourcing, pricing and especially using PM in these systems. A PM method can help the BTO managers to have on-time systems and followed by satisfied customers.

5. Conclusion

This paper developed a joint bi-objective build-to-order (BTO) supply chain and maintenance model under uncertainty. Maximizing the profit and availability of machines were two objectives of the presented model. Also, pricing and outsourcing were the novel issues in BTO systems considered in this paper. The preventive maintenance (PM) was based on the constant intervals times, in which a Weibull's graph is used to estimate a Weibull distribution for a failure rate function. It is noted that there are two types of demands, namely the demand for elements producing in-home and the demand for the final products.

The bi-objective model was solved by the Lp-metric and total weighted methods to convert to a single objective function, which was useful for the model. Because of considering the uncertainty in this model, Mulvey's robust optimization approach was used. Three possible scenarios good, fair, and poor with probabilities of 0.2, 0.5, and 0.3 are considered to examine the proposed model, respectively. The sum of all probabilities is equal to 1. After validating the model and gathering the data from the north wood industry, computational results were analyzed. Furthermore, the sensitivity analysis was carried out for the final product cost and final product demand. The results of the sensitivity analysis were reasonable, by increasing the final product cost, the profit decreased and enhancement in demand made increasing in the total profit. Finally, we provide managerial insights that can be derived from the computational experiments, we consider the interaction between several issues in BTO systems, such as outsourcing, pricing and especially using PM in these systems. A PM method can help the BTO managers to have on-time systems and followed by satisfied customers. An age-based preventive maintenance policy in BTO systems is an interesting issue for future studies. Also, game theory with multi-players will be beneficial in this system. Proposing a good solution method (e.g., ε-constraint)can be considered another extension of this research. Considering a queuing model in BTO systems can be considered for future work as well.

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