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Optimisation on multi-period raw material procurement and product mixing under uncertain demand via probabilistic multi-objective model approach

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Abstract: Raw material procurement and product mixing planning are two important components in manufacturer industries, based on the fact that they contribute significantly to production cost and profit. This article describes a newly developed mathematical model in the form of multi-objective optimisation, as an alternative approach that is possibly used to improve a multi-period raw material procurement and product mixing plan under uncertain demands. This process is initiated by the formulation of two objective functions, including the amount of the output to be produced, which ought to be maximised, and the minimisation of raw material procurement cost. Subsequently, a weighted objective function was formulated for use in the calculation of Pareto solution, and the optimisation problem was resolved to obtain ideal values for all decision variables. In addition, numerical experiments were also performed, in the model evaluation, resulting in the peak value for each decision variable.

Keywords: raw material procurement; product mixing; bi-objective optimisation; Pareto optimal.

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1 Introduction

A logistics and supply chain management (LSCM) contains numerous components from the upstream to the downstream, encompassing raw material supplier, carrier, manufacturer, distributor, retail, and consumer (end user) (Christopher, 2011), therefore, leading to the occurrence of numerous cost constituents. However, within manufacturing industries, the expenditure for raw material procurement tends to contribute significant values, and another component known to also play an important role is product mixing plan. In addition, there is need for optimisation, in order to attain the best performance, hence, some mathematical models were previously developed by numerous researchers. The simplest form applied in LSCM is the integer linear programming (Choudhary and Shankar, 2013), although there is also another approach, including accounting (Hilmola, 2005). Some newly approaches were also developed to maintain the logistic and supply chain management based on the environment and assumptions used in the problem solving, e.g., game theoretic was used to reduce the delivery time and carbon emission in LSCM (Jamali and Rasti-Barzoki, 2019), mixed integer programming was developed to solve carrier selection (Wicaksono et al., 2019), an inventory management model under price and time dependent seasonal demand assumption (Sharma et al., 2019), an inventory model under deteriorating items and backlog condition (Indrajitsingha, 2019), procurement model on supply chain under demand updating and loss-averse condition (Liu et al., 2019), and many more.

For further research, some implementations of LSCM models were appeared in many published research articles showing the applications the model developed before. For example, polystyrene supply chain in Brazil (de Oliveira et al., 2019), military supply chain (Bean et al., 2016; Nazeri et al., 2019), pharmaceutical industry (Janatyan et al., 2019), agriculture supply chain (Mujica Mota et al., 2019; Raut et al., 2019), and iron and steel industry (Yang et al., 2019). Those implementations show us how the supply chain model very important in many fields in order to maintain the processes faced by the decision maker.

Meanwhile, the mathematical model commonly identified in existing research articles was the single objective optimisation approach, defined as minimising the total cost, while the amount of planned production ought to be optimised. Therefore, there is need for the formulation of an optimisation model that augments these two objectives which developed and proposed in this research. In this article, a multi-objective optimisation model was developed as a new decision support approach on multi-period raw material procurement and product mixing plan, considering uncertain demand. This risk value is approached as a random variable with some know probability distribution, thus, the utility of multi-objective programming with undefined parameter, leads to the calculation of optimal decision making, in order to obtain the ideal amount for the raw material purchase from a supplier, as well as for production, and also for inventory level. This is to ensure the total minimisation of cost, and illustrating the problem requires the provision of a numerical example, using some randomly generated data for the parameters.

2 Literature review

Mathematical programming plays the role of the most utilised tool or method in solving problems of optimisation from the simplest model, encompassing linear programming to more complex forms, which consist of stochastic integer, multi objective, and fuzzy programming, etc. Furthermore, this technique has also been applied in numerous fields, which include cement manufacturing industry (Ghafour, 2018), energy optimisation (Branco et al., 2018; Rashidi and Khorshidi, 2018; Schlünz et al., 2018; Yu et al., 2018), textile industry (Andjelkovic and Radosavljevic, 2019) and petrochemical industry (Ehrenstein et al., 2019). Some newly models which were developed from the existing models above are recently published by researchers to solve more advance problems with some assumptions hold like expiry date and time varying holding cost (Sharma et al., 2018), non-instantaneous deteriorating items (Yadav and Swami, 2019), income and price dependent demand (Waliv and Umap, 2019), and intelligent supplier selection for multi-agent supply chain (Ghadimi et al., 2019). Furthermore, one of the advanced mathematical approach is the multi-objective programming, which identifies the optimal solution, e.g., through the calculation of Pareto efficient, although it only serves as an alternative solution in related problems besides others, including Nash-bargaining solution. Furthermore, the simplest means of calculating this value is by using the weighting method, which works by formulating a single objective function from a collection of all, with some weight value for each (Branke et al., 2008). There are some related articles that describe the application of Pareto solutions, including the optimisation of battery cell design (Hong and Lee, 2018), re-insurance problem (Zeng and Luo, 2013; Asimit et al., 2017; Cai et al., 2017), and radar design (Niu et al., 2018), etc.

The optimisation of an industrial activity requires a mathematical programming approach, which is significantly used as an alternative to determine optimal decisions. This was adopted by numerous researches in some supply chain activities, using a particular method, e.g., supplier (Izadikhah, 2012), and dynamic supplier selection (Ware et al., 2014; Adi Wicaksono et al., 2018), as well as dynamic supplier selection in an unknown environment (Kara, 2011), order planning (Buergin et al., 2019), lot-sizing (Ou and Feng, 2019), inventory management (Saputra et al., 2017; Luthfi et al., 2018; Agrawal and Smith, 2019), and other integrated means, encompassing inventory lot size and carrier choice (Choudhary and Shankar, 2014), supplier selection and inventory organisation (Widowati et al., 2017; Sutrisno et al., 2018), procurement and production planning (Talay and Özdemir-Akyıldırım, 2019), integrated production, replenishment, delivery, routing and inventory management (Qiu et al., 2019), and others. Meanwhile, this case study identified several published articles in the form of paper mill production (Mattila et al., 2011), automotive industry (Manello and Calabrese, 2019), sawmill (Vanzetti et al., 2018), and biopharmaceutical manufacturer (Sahling and Hahn, 2019), military inventory system (Bean et al., 2016), humanitarian relief (Hu and Dong, 2019), pig industry (Nadal-Roig et al., 2019), biomass supply chain (Nguyen and Chen, 2018), etc.

3 Methodology and MATHEMATICAL MODEl

3.1 Methodology

This section explains the method adopted in the research, defines the problem, including the notations used, and the mathematical model developed, as seen in Figure 1. This illustrated:

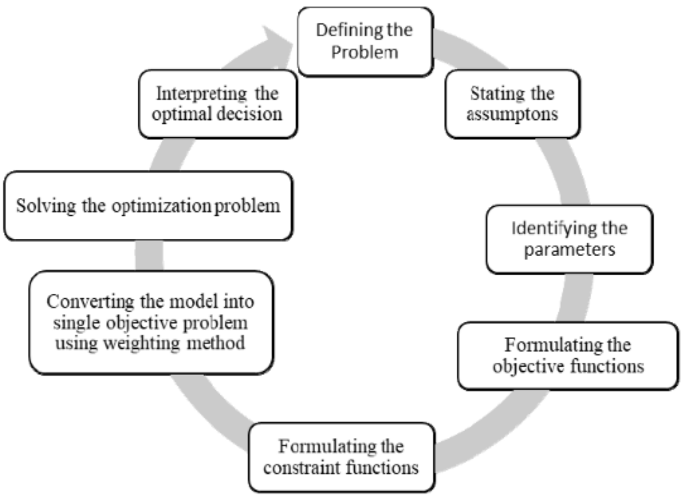
1 the section problem definition

2 some assumptions that ought to be held by the proposed model

3 the identification of parameters

4 formulating the objective functions that include the first, described as a maximisation of the total amount of product planned to be produced for all time period, and the second, which involves curtailing the entire cost occurred in the problem.

Figure 1 Methodology used in the research



In addition, the functions of constraint are defined following the modelling of conditions applied, followed by the model conversion into single objective forms, using weighting method. This is solved by employing the Generalised Reduced Gradient optimisation algorithm in LINGO 18.0, in order to obtain optimal decisions.

3.2 Problem description

Assuming a manufacturing industry plans to produce P number of product types, made from R number of raw material types, using M number of machines in a production process, over time periods 1, 2, 3, …, T, the raw material is then purchased from S number of supplier alternatives. In addition, it is assumed to be storable in a warehouse, and used for future production processes, and producing one unit requires some raw material(s) and production machine(s). Therefore, the output is adopted to meet the demand, which in this case is uncertain. Moreover, the problem is centered on how to determine the optimal amount for all decision variables (raw material volume, the selected supplier, inventory of raw material volume, and product, as well as other auxiliary decision variables), conducted in an attempt to minimise the total occurred cost and subsequently maximise the amount of products produced over all future optimisation time periods. Hence, the model adopted in this research is formulated under the following assumptions:

1. The product is a non-deteriorating item (raw material and product) during the optimisation time period.
2. The ordered raw material is delivered instantly, and is also meant to be received by the manufacturer at the same period.
3. On instances where there are some that are not delivered at the ordering period, this will commence at the subsequent time.

3.3 Mathematical notations

Let the notations used in the formulated model are shown in Table 1.

Table 1 Notations for mathematical modelling

Category	*Notation*	*Interpretation*
Index	r	Index of raw material type: 1, 2, ..., R
	s	Index of supplier name: 1, 2,..., S
	p	Index of product type: 1, 2, ..., P
	t	Index of time period: 1, 2, …, T
Decision variable	Y_p	(Initial decision variable selected before the demand value revealed) the number of the product p to be produced
	YR_p	(Recourse decision variable which is chosen after the demand value is revealed) the number of product p to be procured
	X_{sr}	Volume (unit) of raw material r to be purchased from supplier s
	Z_s	Binary variable that is 0 on instances where no raw material is purchased from supplier s, and 1 if this occurred
	S_s	The number of truck delivery from supplier s

Table 1 Notations for mathematical modelling (continued)

Category	*Notation*	*Interpretation*
Parameter	UP_{sr}	Unit price of raw material *r* of supplier *s*
	YRP_p	Unit price for product p that should be procured to after the demand value is revealed to meet the demand volume
	O_s	Order cost for supplier *s* if any raw material is purchased
	TC_s	Transport cost from supplier *s*
	P_{sr}^{d}	Unit penalty cost for defected raw material *r* from supplier *s*
	d_{sr}	Defect rate or percentage of rejected product that delivered from supplier *s*
	P_{sr}^{l}	Unit penalty cost for late delivering raw material *r* from supplier *s*
	l_{sr}	Late delivering rate for raw material *r* from supplier *s*
	l_{sp}	Required volume of raw material *r* to produced unit product *p*
	$D_p^{\min}$	Minimum demand of product *p*;
	$D_p^{\max}$	Maximum demand of product *p*;
	MH_{pm}	Required machine hour of machine *m* to produce unit product *p*
	MC_m	Machine hour maximum capacity of machine *m*
	C	Full truck load capacity
	SC_{sr}	Maximum capacity of supplier *s* to supply raw material *r*
	ϕ	Service level requirement, i.e., $(1-\phi)$ is the proportion of manufacturer demand that are not met by supplier in period *t*
	M	Big number, set to be 10^5

3.4 *Mathematical model*

There are two objective functions to be optimised, including: the total amount of products to be produced for all periods, the entire cost over all horizon periods, using the formulation as follows:

1 The total unit of all product types over all horizon time periods:

$$Z_1 = \sum_{t=1}^{T} \sum_{p=1}^{P} Y_{tp}$$

2 The total occurred cost, encompassing

a raw material purchase from suppliers for all periods

b order to supplier on instances where there are some raw material to be purchased from suppliers

c their transportation

d penalty for defected/damaged

e penalty for late delivery

f storage cost

g shortage for raw material

h storage for product

i and its shortage

j recourse cost for product procurement after revealing the demand value:

$$Z_2 = \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[X_{tsr} * UP_{tsr}] + \sum_{t=1}^{T}\sum_{s=1}^{S}[O_{ts} * Z_{ts}] \\ + \sum_{t=1}^{T}\sum_{s=1}^{S}[TC_{ts} * S_{ts}] + \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[P_{tsr}^{d} * d_{tsr} * X_{tsr}] \\ + \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[P_{tsr}^{l} * l_{tsr} * X_{tsr}] + \sum_{t=1}^{T}\sum_{r=1}^{R}[h_{tr}^{X} * i_{tr}^{X+}] \\ + \sum_{t=1}^{T}\sum_{r=1}^{R}[SOC_{tr}^{X} * i_{tr}^{X-}] + \sum_{t=1}^{T}\sum_{p=1}^{P}[h_{tp}^{Y} * i_{tp}^{Y+}] \\ + \sum_{t=1}^{T}\sum_{p=1}^{P}[SOC_{tp}^{Y} * i_{tp}^{Y-}] + \sum_{t=1}^{T}\sum_{p=1}^{P}[YRP_{tp} * YR_{tp}]$$

The constraints to be satisfied are designed as follows:

1 At the initial period (time period $t = 1$), the available raw material in the manufacturing unit, stored in the inventory, if any, plus the purchased (received) raw material, minus the amount of the current late deliveries, minus the defected/damage unit at the current shipment, minus the amount to be stored, and used in the future, minus the current amount of shortage. These ought to meet the required amount of the raw material used in the entire production process within the current period:

$$i_{0r}^{X+} + \sum_{s=1}^{S}[(1 - l_{tsr} - d_{tsr})X_{tsr}] - i_{tr}^{X+} - i_{tr}^{X-} \geq \sum_{p=1}^{P}(r_{trp} * Y_{tp}), \forall r, t = 1.$$

2 For time periods $t = 2, 3, \ldots, T$, the available raw material in the manufacturing unit at any time period t includes those stored in the inventory from previous times in addition to the amount of products that arrived due to lateness in delivery from a previous period plus the purchased of raw materials, minus the amount delivered late minus the defected/damage unit plus the shortage at the previous time period minus the amount to be stored for used in future periods, minus the current amount of shortage, should meets the required amount of the raw material used to produce all products in the current time period:

$$i_{(t-1)r}^{X+} + \sum_{s=1}^{S}[l_{(t-1)pr} * X_{(t-1)sr}] + \sum_{s=1}^{S}[(1 - l_{tsr} - d_{tsr})X_{tsr}] \\ + i_{(t-1)r}^{X-} - i_{tr}^{X+} - i_{tr}^{X-} \geq \sum_{p=1}^{P}(r_{trp} * Y_{tp}), \forall r, \forall t.$$

Special for time period $t = T$, there is no need to store raw materials, hence, the requisition for additional constraint: $i_{Tr}^{X+} = 0$.

3 At time period $t = 1$, the product at the current period subtracted from the amount decided to be stored, plus the shortage product quantity ought to meet the demand value. Meanwhile, at time period $t = 2, 3, \ldots, T - 1$), those from the previous time period in addition to the current products minus the amount decided to be stored in the warehouse plus those shortage minus the amount of shortage product at the

previous period, ought to meet demand values. Furthermore, at time period $t = T$, there was no need to have a collection of some products in the inventory, hence, the constraints are modelled as follows:

$$Y_{tp} - i_{tp}^{Y+} + i_{tp}^{Y-} \geq \tilde{D}_{tp}, t = 1, \forall p$$
$$i_{(t-1)p}^{Y+} + Y_{tp} - i_{tp}^{Y+} + i_{tp}^{Y-} - i_{(t-1)p}^{Y-} \geq \tilde{D}_{tp}, \forall t = 2,...,(T-1), \forall p$$
$$i_{(t-1)p}^{Y+} + Y_{tp} + i_{tp}^{Y-} - i_{(t-1)p}^{Y-} \geq \tilde{D}_{tp}, t = T, \forall p$$

4 The production hour of the machine for operation ought to be less or equal to the maximum capacity of the working time:

$$\sum_{p=1}^{P} [MH_{tpm} * Y_{tp}] \leq MC_{tm}, \forall t, \forall m$$

5 The total truck number to transport raw materials from the supplier to manufacturer ought to be less or equal to the maximum number of available truck:

$$\left\lfloor \frac{\sum_{r=1}^{R} X_{tsr}}{C} \right\rfloor \leq S_{ts}, \forall t, \forall s.$$

6 Maximum capacity of supplier to supply the raw material to be held:

$$X_{tsr} \leq SC_{tsr}, \forall t, \forall s, \forall r$$

7 Auxiliary constraint is applied in determining the probability of selecting a supplier to supply some raw material or not:

$$\sum_{r=1}^{R} X_{tsr} \leq M * Z_{ts}, \forall t, \forall s$$

8 Maximum capacity of the warehouse to store them and their products have to be met:

$$\sum_{r=1}^{R} X_{tsr} \leq M * Z_{ts}, \forall t, \forall s$$

9 Maximum shortage amount for both ought to have met the highest tolerance value:

$$i_{tr}^{X-} \leq \phi * \sum_{p=1}^{P} r_{trp} \cdot Y_{tp}, \forall t, \forall r \quad i_{tp}^{Y-} \leq \phi * \tilde{D}_{tp}, \forall t, \forall p$$

10 Non-negativity and integer constraint:

$$Y_{tp}, X_{tsr}, i_{tr}^{X+}, i_{tr}^{X-}, i_{tp}^{Y+}, i_{tp}^{Y-} \geq 0 \text{ and integer}$$

The mathematical model formulated above is further summarised into the following multi-objective optimisation model:

$$\max Z_1 = \sum_{t=1}^{T} \sum_{p=1}^{P} Y_{tp} \quad (1)$$

$$\begin{aligned}\min Z_2 = &\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[X_{tsr} * UP_{tsr}] + \sum_{t=1}^{T}\sum_{s=1}^{S}[O_{ts} * Z_{ts}] \\ &+ \sum_{t=1}^{T}\sum_{s=1}^{S}[TC_{ts} * S_{ts}] + \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[P_{tsr}^{d} * d_{tsr} * X_{tsr}] \\ &+ \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{r=1}^{R}[P_{tsr}^{l} * l_{tsr} * X_{tsr}] + \sum_{t=1}^{T}\sum_{r=1}^{R}[h_{tr}^{X} * i_{tr}^{X+}] \\ &+ \sum_{t=1}^{T}\sum_{r=1}^{R}[SOC_{tr}^{X} * i_{tr}^{X-}] + \sum_{t=1}^{T}\sum_{p=1}^{P}[h_{tp}^{Y} * i_{tp}^{Y+}] \\ &+ \sum_{t=1}^{T}\sum_{p=1}^{P}[SOC_{tp}^{Y} * i_{tp}^{Y-}] + \sum_{t=1}^{T}\sum_{p=1}^{P}[YRP_{tp} * YR_{tp}]\end{aligned} \tag{2}$$

Subject to: constraints (1)–(10).

Assuming that the feasible set is non-empty, i.e., the existence of at least one solution, which satisfies all constraints, then, the feasible set is closed and bounded, meaning the possibility of (1) ca being replaced by min(Z_1). Therefore, the calculation of Pareto solution for this multi-objective optimisation problem, requires the reformulation of optimisation problems as

$$\min Z = w_1(-Z_1) + w_2 Z_2 \tag{3}$$

Subject to: $w_1 + w_1 = 1$, $0 \leq w_1, w_2 \leq 1$, constraints (1)–(10).

4 Computational experiment

In this numerical experiment, the LINGO 18.0 software was employed in the resolution of optimisation problems, using the computer that has been adopted daily for personal applications, with proc. of 3.0 GHz, and memory of 4 GB.

4.1 Parameter setting

Supposing a raw material procurement problem and production planning considers three raw material types R1, R2 and R3, four suppliers S1, S2, S3 and S4, and three products P1, P2 and P3 which is modelled by (1)–(2). Then the demand values $\hat{D}_{tp}$ for all t and p is said to be random with the following probability density functions:

$$f_{\hat{D}_{1,1}}(D) = \begin{cases} 0.4 & D = 20 \\ 0.6 & D = 40 \\ 0.0 & \text{others} \end{cases}$$

$$f_{\hat{D}_{1,2}}(D) = \begin{cases} 0.4 & D = 40 \\ 0.6 & D = 60 \\ 0.0 & \text{others} \end{cases}$$

$$f_{\hat{D}_{1,1}}(D) = \begin{cases} 0.4 & D = 20 \\ 0.6 & D = 30 \\ 0.0 & \text{others} \end{cases}$$

$$f_{\hat{D}_{t=2,3,4,5,p=1,2}}(D) = \begin{cases} 0.3 & D = 40 \\ 0.7 & D = 50 \\ 0.0 & \text{others} \end{cases}$$

$$f_{\hat{D}_{t=2,3,4,5,p=1,2}}(D) = \begin{cases} 0.3 & D = 30 \\ 0.7 & D = 40 \\ 0.0 & \text{others} \end{cases}$$

The other parameters are appeared in the appendix.

4.2 Solution

The two-objective optimisation problem (1)–(2) was solved by converting it to (3) with $w_1 = w_2 = 0.5$. These weight values of 0.5 for each indicates the penalisation of 50-50 values of each function (1) and (2). Therefore, the computation results are shown in Figures 2–4.

The optimal decisions for this problem are shown by Figure 2, which indicates the raw material volume to be ordered from each supplier for specific time periods, while the second shows the product volume to be formed for each type at time period 1 and 2. This solution is corresponding to scenario-1, i.e., a condition where the demand follows the value shown in Figure 4(a). Meanwhile, Figure 3(a) indicates the optimal decision for the amount of the output planned to be produced at a specific time 1 and 2 for scenario-1, and the 32 scenarios resulted where the objective function values for Z1 and Z2, as shown in Figure 3(b).

Figure 2 The optimal decision for raw material procurement (see online version for colours)

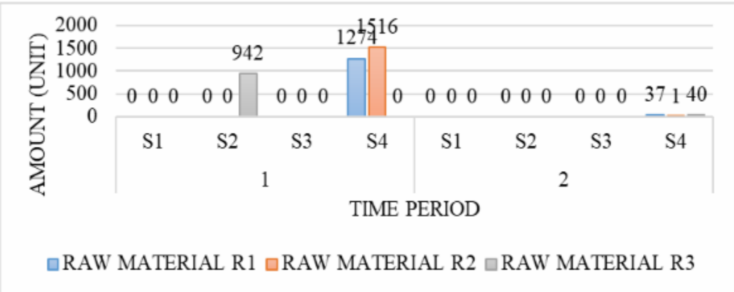
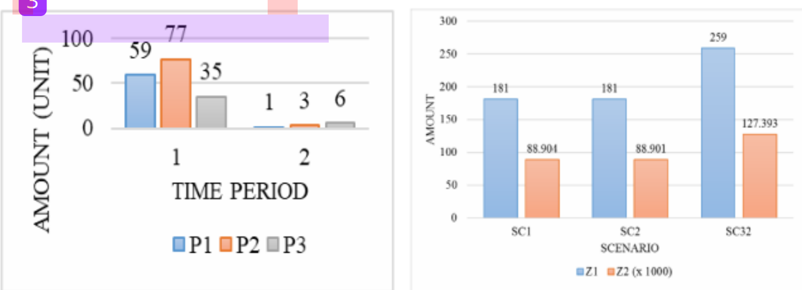


Figure 3 (a) The optimal decision for product to be produced (b) Objective functions' value (see online version for colours)

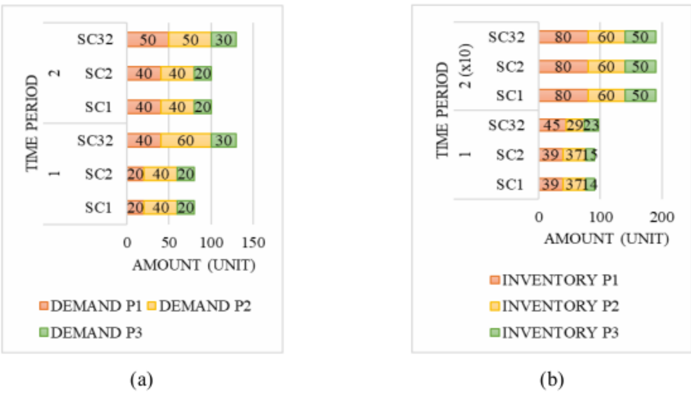


(a) (b)

4.3 Discussions and managerial insights

Assuming at time period 1, the demand value, further revealed tends to follow the scenario-1, i.e., 20 units for P1, 40 for P2, and 20 for P3, then these demanded products are possibly met at time period-1, which are 59 units of P1, 77 of P2, and 35 of P3. Therefore, the remainder unused products are stored in the inventory, which are subsequently used at the following periods. Hence, based on validation purposes, a comparison was made with some existing models, where Trivedi et al. (2017) showed the determination of optimal supplier was indicated by the optimal raw material volume to be purchased from each supplier, similar to the results shown in Figure 2. Meanwhile, the amount of the products mixed for each time and product type was determined as shown in Figure 3(a). Moreover, based on the managerial point of view, there is a possibility for managers to determine the weight value for the first and the second objective function, thus, if the outcome for the first is reduced, then the related concern is decreased. This means that the model is concerned more on the second (cost value), and these values tend to determine how concern they are with the corresponding objective function.

Figure 4 (a) Demand value (b) Inventory level (see online version for colours)



Due to the model proposed above is containing uncertainty in the parameters, then the solution determined by the model is an expectation value. Then, the actual values gained by the decision maker may be different from the results achieved by the model. In the implementation of the model proposed in this paper, the decision maker, then, may modify the probability distribution function of the random variables occurred in the problem and in the model based on his data collection. Furthermore, we suggest that the probability distribution function used in the problem solving is formulated by using sufficiently large data in order to improve the precision of the probability function and the solution achieved by the model.

5 Conclusions and future research direction

In this study, a mathematical model in bi-objective optimisation was formulated, and used as a decision-making support to identify the optimal decision for raw material procurement and product mixing problems. Therefore, the numerical experiment with a randomly generated data was performed in an attempt to evaluate and validate the proposed model, where optimal decisions were achieved, i.e. the ideal amount of raw materials, the planned produce, and the inventory at time each time period. Decision maker in any industrial field which concerning procurement and product mixing can use the model proposed in this article to maintain his managing, and, for further application, modification may also be implemented in order to synchronise the model to the problem.

In addition, there is plan to develop specific models in the next research, through the use of fuzzy uncertainty theory, in order to handle uncertain parameters that possess unknown historical data. Therefore, the optimisation model contains some fuzzy parameters that are interesting to solve.

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Appendix

Parameter values used in numerical experiment

Table a1 Unit price

Time period	*Suppliers*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	11	21	40
	S2	12	22	40
	S3	11	21	41
	S4	11	20	42

Table a2 Order cost and transport cost

Time period	*Supplier*	*Order cost*	*Transport cost*
Any	S1	50	120
	S2	20	120
	S3	40	80
	S4	20	95

Table a3 Defect product penalty cost

Time period	*Supplier*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	1	2	4
	S2	2	2	5
	S3	1	3	5
	S4	1	2	5

Table a4 Defect rate

Time period	*Supplier*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	0.02	0.03	0.02
	S2	0.03	0.01	0.01
	S3	0.02	0.02	0
	S4	0.01	0.02	0.01

Table a5 Late delivery rate

Time period	*Supplier*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	0.01	0	0.00
	S2	0.02	0.03	0
	S3	0.01	0.02	0.02
	S4	0.02	0.04	0.01

Table a6 Late delivery penalty cost

Time period	*Supplier*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	0.5	1	2
	S2	0.2	1.5	2.5
	S3	0.2	1	2
	S4	0.5	1.5	2

Table a7 Raw material required to produce the product

Time period	*Raw material*	*Product*		
		P1	*P2*	*P3*
Any	R1	4	12	4
	R2	10	10	4
	R3	5	8	2

Table a8 Shortage cost

Time period	*Product*	*Shortage cost*	*Raw material*	*Shortage cost*
Any	P1	1	R1	5
	P2	2	R2	4
	P3	3	R3	4

Table a9 Required machine working hour to produce product unit

Time period	*Product*	*Machine*		
		M1	*M2*	*M3*
Any	P1	2	2	4
	P2	2	1	2
	P3	1	2	4

Table a10 Machine working hour max. capacity

Time period	*M1*	*M2*	*M3*
Any	1,200	800	1,000

Table a11 Supplier maximum capacity to supply raw material

Time period	*Supplier*	*Raw material*		
		R1	*R2*	*R3*
Any	S1	4,500	4,500	5,000
	S2	4,000	2,500	4,500
	S3	2,500	4,000	6,000
	S4	8,500	4,000	8,000

Table a12 Inventory capacity and holding cost for raw material

Time period	*Parameter*	*Raw material*		
		R1	*R2*	*R3*
Any	Inventory maximum capacity (unit)	1,500	2,000	1,200
	Holding cost per unit	1	1	2

Table a13 Inventory capacity, recourse/shortage product price, and holding cost for product

Time period	*Parameter*	*Product*		
		P1	*P2*	*P3*
Any	Inventory maximum capacity (unit)	800	600	500
	Recourse product price	750	750	800
	Holding cost	2	3	5

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