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Order Acceptance Decision in Make-to-Order System: Satisfaction Level Based Approach

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ABSTRACT

In make-to-order (MTO) system, deciding which order to accept and which to reject from an incoming orders is one of the most challenging tasks for the decision maker (DM) of manufacturer. When the new order arrives, order acceptance (OA) decision is affected by two kinds of satisfaction level. One is the satisfaction level expected by the DM. This level indicates the acceptance threshold of DM. Next is the satisfaction level that will be generated by the order. In this paper, we propose a method that reflects OA decision as interplay between the DM's acceptance threshold and satisfaction level generated by the order. We investigate this less researched topic in a job shop environment with uncertain scenario. In the proposed method, the DM's acceptance threshold is shown to be the function of workload in the production system and their aggressiveness. While, we consider four criteria to access the satisfaction level generated by the order. They are reputation in terms of delivery reliability, profit both at present and in the future and the utilization of available capacity. We present a numerical analysis by considering various parameters under two different cases of due dates to demonstrate the working mechanism and effectiveness of proposed method.

Keywords: *OA decision, make-to-order, satisfaction level, uncertainty*

1. INTRODUCTION

OA is a decision carried out with the co-ordination among the area of marketing and production. It includes the activities such as interaction with the customer for fixing price and due date, forecasting the future demand, planning the production system and physical distribution. Traditionally, this problem is solved by always accepting orders as long as sufficient capacity is available. Most of the previous researchers (Hans, 1994; Ivanescu et al., 2002; Nandi and Rogers, 2004; Ebben et al., 2005) have given emphasis to schedule or available capacity as a basis for accepting the order. But every incoming order does not guarantee to generate profit (Piya et al., 2006). As Guerrero and Kern (1988) puts in "Accepting orders without considering their possible costly impact on capacity can mean the firm is paying for the privilege of accepting an order". Therefore always accepting an order when the capacity is available is myopic. Such a policy can prevent the system from accepting more profitable orders in the future (Mainegra et al., 2007). Order usually arrives with certain due date attached to it at which customer wants to receive the delivery. Since orders in MTO system are often specific to a particular customer with no repetition of demand for the same product (Haskose et al., 2004), it is highly difficult to determine whether the order if accepted can be finished within the agreed due date. When on-time delivery is crucial, it may be necessary to reject some orders to avoid delay penalty and processing delays for other profitable orders (Lewis and Slotnick, 2002). But, rejection of order means loss of profit and may also have negative impact in terms of future arrival of order from the same rejected customer. As Hill (2000) states that "the most important orders are the one that you turn down". Therefore, the strategy of OA should be formulated in such a way as to accept as many profitable orders as possible and deliver them on time so that company can prosper in the long run.

When the new order arrives, the DM considers some kind of satisfaction received from the order for making decision. The satisfaction may be from a single criterion like schedule or profit as have been considered by previous literatures. It may also be from the multiple criteria like schedule feasibility, profit and reputation as considered in Piya et al. (2006). But, the result may be better if the decision is based on the average satisfaction generated from multiple criteria. In this paper, we define and integrate four criteria (i.e., delivery reliability under uncertainty, profit, future influence and the utilization of available capacity) to access the average satisfaction generated by an order. This integrated value is then compared with the DM's acceptance threshold to decide whether to accept or reject an incoming order. Such concept of comparison for profit was used by Matsui (1985), considering present load in the system, with deterministic processing time. We consider load at present and expected load in the future for determining the acceptance threshold of DM.

The reminder of paper is organized as follows. The next section discusses about the research on related field carried out in the past. Section 3 is dedicated to explain the framework of this paper. Section 4 describes the proposed method in details. The effectiveness is investigated by considering numerical analysis in section 5. Finally, concluding remark and future research direction is highlighted in section 6.

2. RELATED RESEARCH

Even though OA decision is one of the most crucial activities for the management of MTO system, we can find very shallow body of literature in this field. In this section, we will classify and review the past literatures on OA according to their assumption of customer arrival in the system. Some of the previous papers have considered the problem with static arrival of customer i.e., the arrival of customer is known in advance or customers have already arrived in the system and the company has to make a decision of which order to accept and which to reject from the pool of orders. On the other hand, others have considered dynamic arrival i.e., customer arrival is irregular over time and is not known to the manufacturer prior to their arrival.

Static arrival: We can find few researchers who have contributed to the research on OA by considering static arrival of customer. Pourbabi (1992) proposed mixed binary linear programming model for job selection using net profit in the context of Just-in-time manufacturing. Slotnick and Morton (1996) studied the problem in a periodic decision setting where the problem is to select a subset of orders among the set that maximizes revenues. Ghosh (1997), in the same setting, showed that the Slotnick and Morton (1996) version of job selection problem is NP-hard. Lewis and Slotnick (2002) extended the work of Slotnick and Morton (1996) to the multi-period case by considering that the rejection of order will result in no future jobs from the same customer. Slotnick and Morton (2007) formulated the problem of OA decision as an integer program which performs both sequencing and order acceptance jointly. The same problem is later solved by Rom and Slotnick (2009) using genetic algorithm to improve the performance for large size problems. Fabrice and Roel (2011) devised two exact branch-and-bound algorithms to decide the potential orders to retain from the subset of orders for profit maximization.

Dynamic arrival: Most of the researchers in the field of OA have conducted the research by considering dynamic arrival of customer. Wester et al. (1992) proposed three different OA approaches among which two approaches are based on workload and the other is based on making detail schedule after an arrival of new order. Hans (1994) proposed two different approaches among which hierarchical approach utilizes aggregate characteristics of already accepted orders for OA decision. In the latter approach, OA and production scheduling is integrated. Wang et al. (1994) presented a neural network approach where OA decision is based on the multiple criteria such as profit, customer credit and available capacity. Raaymakers et al. (2000) analyzed the performance of workload rules for OA from the result of case study. Orders are accepted if the workload on each work center remains below a pre-specified level. The paper by Ivanescu et al. (2002) considered available capacity as an acceptance rule and compared three order acceptance policies in a setting with erlang distributed processing times. Combining the strength of scheduling policy and regression policy Ivanescu et al. (2006) proposed a hybrid policy by using simulated annealing technique. Ebban et al. (2005) analyzed different workload rules that vary from rules based on aggregate information to a method that considers precedence relationships, release date and due dates of orders for OA decision. Using AHP and TOPSIS techniques Gharehgozli et al. (2008) developed two phase comprehensive order acceptance decision making structure.

All the above reviewed literatures have considered either static or dynamic arrival of an order. By distinguishing the customers into two different categories, Piya et al. (2008) analyzed OA problem for the joint arrival of customers. Moreover, Mahdokht et al. (2011) studied the problem of order acceptance decision in hybrid Make to Stock / Make to Order production systems. Although, in the recent year uncertainty in production is receiving a lot of attention as it can cause production disturbances (Li and Ierapetritou, 2008), most of the previous literature on OA is based on the assumption that all the data related to an order are deterministic. Many kinds of uncertainty arise during production. A major one is on processing time which is especially true for new or unique product (Wang et al., 2002). Only few papers on OA (Ivanescu et al. 2002, Ivanescu et al. 2006 and Ebban et al. 2005) have considered the decision with stochastic processing time. In these papers concept of safety margin is used to resolve uncertainty. The problem is to find the value of safety margin for each incoming order.

In this paper, we propose an integrated approach to OA decision in a complex job shop environment with both static and dynamic arrival of customer. The proposed approach considers the satisfaction level generated by an order and the DM's threshold level of satisfaction which indicates his/ her acceptance threshold. We model the strategy for a situation where order may have uncertain processing time. This uncertainty is solved by using robust method. To our knowledge no previous literature has consider the concept of satisfaction level as decision criteria to OA.

3. OA FRAMEWORK

The OA framework consists of customers and the manufacturer as shown in Figure 1. Customers place an order with certain information such as the order specification, demand quantity and due date to the manufacturer. Distinguishing the customers into various classes based on the urgency of delivery is a regular practice in company (Rogers, 2007). Rather than by urgency of an order, Piya et al. 2008 classified the customers on the basis of regularity of their arrival. This paper also utilizes the same classification. The first one is repetitive customer, who is characterized by the customer that has long term contract with the company. This category shows the customer with static arrival. Giving discount to the customer or paying penalty for the delivery of order after promised due date has become a competitive leverage to lure the customers (Slotnick and Sobel, 2001). But, even such customer will not accept the delivery after certain time of expiration of due date. Our model captures this practical situation by defining two due dates for repetitive customer. Earliest due date is the date at which customer prefers to receive the delivery. If the delivery is between the earliest due date and the latest due date, company incur tardy penalty for late delivery. Latest due date is the date after which customer will not accept delivery. As the order from this customer is regular in nature, we assume that the processing time for such customer order is deterministic and its arrival can be forecasted by the manufacturer. But, if an order from repetitive customer is rejected, the company has to reduce the price of product by certain rate in the future as a penalty for rejection. This shows the influence of repetitive customer order on profit, both at present and in the future.

The next category is non-repetitive customer. It represents dynamic arrival of an order. The customer who is not regular or new to the company falls in this category. The customer will provide only one due date. Delivery made after this date will not be entertained by them. For such customer order, it is difficult to explicitly determine the actual processing time and forecast its arrival. For this reason, we assume uncertain processing time for this category of customer.

Once the order is submitted by the customer, manufacturer has to decide whether to accept it or not. The decision will be based on the comparison between two factors:

1) Order satisfaction level: We integrate the indexes of four different criteria to calculate order satisfaction level.
   i) Robustness index
   ii) Capacity utilization index
   iii) Profit index
   iv) Future influence index

   Among these criteria, the first two show the quality of schedule whereas the remaining two are related to the profitability aspect of an order.
2) DM's acceptance threshold: DM's acceptance threshold indicates the threshold value at or above which the incoming order will be accepted. This will be calculated by considering the workload in the system and the aggression of decision maker.

4. PROPOSED METHOD

As shown by the flow chart in Figure 2, once a new order arrives, forecast the arrival of order from repetitive customers (a). Next, schedule the new order with previously accepted orders that have not yet been started to production and the forecasted orders. Check whether the schedule of new order with already accepted orders and forecasted orders is feasible or not (b).

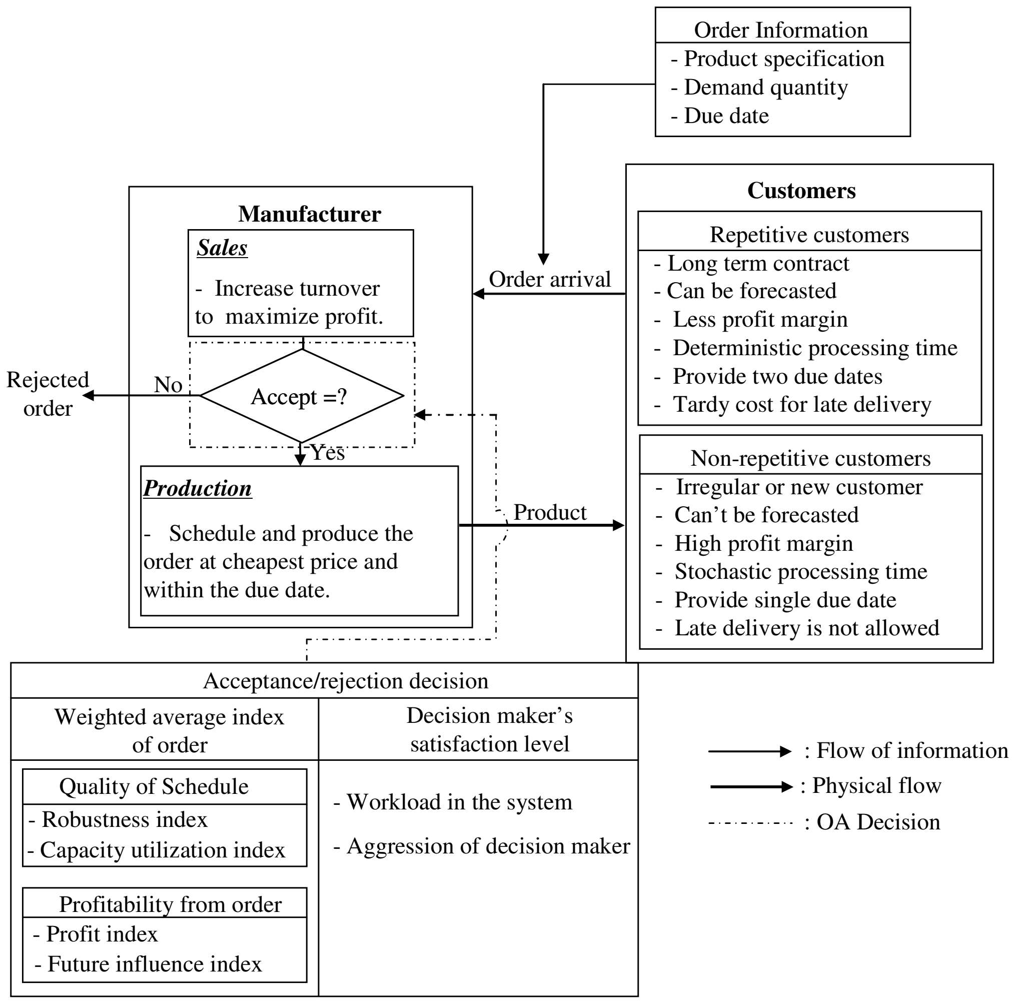

Figure 1. Framework of integrated approach to OA decision

[1] If the schedule is feasible, calculate the order satisfaction level (c), DM's acceptance threshold (d) and compare them (e). The new order will be accepted if the order satisfaction level is greater than or equal to the DM's acceptance threshold (f), otherwise rejected (g).

[2] If the schedule is infeasible, then reschedule the operation in conflict. After rescheduling, check whether the new schedule is feasible or not (h). If it is found feasible, go to step [1].

[3] If the schedule is infeasible even after rescheduling, then check whether the infeasibility is between the new order and the orders that have already been accepted (i). If the statement is true then reject the new order (j).

[4] If the infeasibility is between the new order and the repetitive customer order then the decision is made by comparing order satisfaction level between them (k). From the comparison, if the order satisfaction level of new order is better than that of the repetitive customer order, the new order will be accepted and the order from repetitive customer rejected (l). Otherwise, the order from repetitive customer will be accepted by rejecting non-repetitive customer order (m).

From the flow chart, it can be seen that the proposed method consists of forecasting, scheduling, rescheduling, integration, calculating DM's acceptance threshold and comparison. To develop mathematical models for these processes, following assumptions are considered.

- The pre-emption of work is not allowed.
- Movement of work from one work center to another is negligible.
- The set up time and cost to switch from one customer order to another is negligible

4.1 *Forecasting*

Forecasting is necessary to know the arrival of order from repetitive customer in the future. This allows the manufacturer to reserve available capacity for the repetitive customer order. Assuming that order from such customer fluctuates randomly (Piya et al. 2006), quantity and date of arrival is forecasted by using exponential smoothing method.

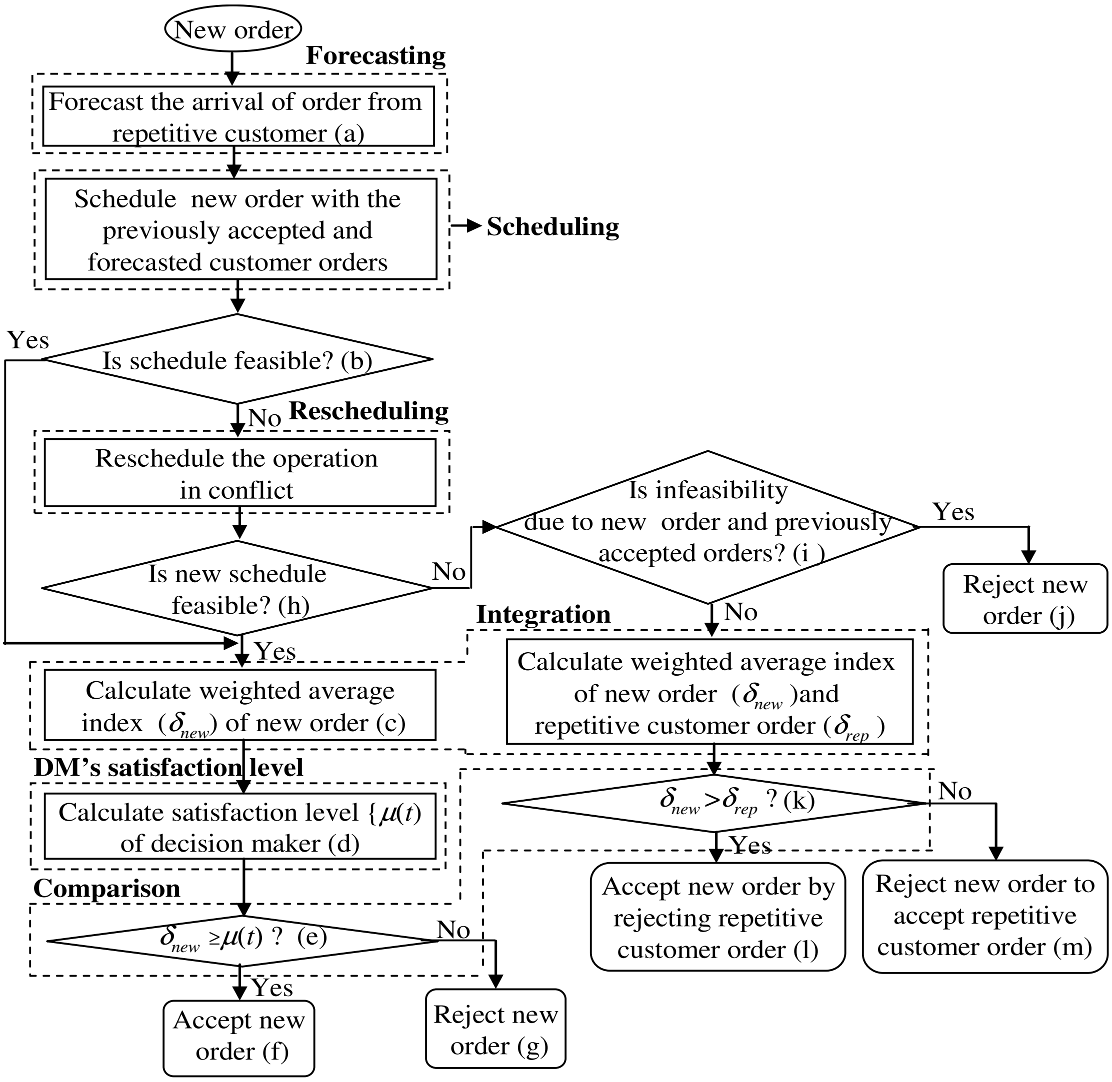

Figure 2. Flowchart of integrated approach to OA decision

Table 1. Notations

i	Unit in the order ($i = i_{st}, i_{st}+1, \ldots, i_l-1, i_l$)	t_o	Arrival time of order o
n	Operation of an order (n=1, 2,…., N-1, N)	q_o	Total quantity of order o
φ_o	Maximum percentage of uncertainty for order o	d_o	Due date of order o
C_o^I	Capacity utilization index of order o	R_o^I	Robustness index of order o
F_o^I	Future influence index of order o	P_o^I	Profit index of order o
SP_o	Selling price per unit of order o	f	Future period
β	Rate of reduction in selling price	σ	Coefficient of selling price
Z_o	Profit/unit processing time of order o	Wl(t)	Workload at time t
Wl_o	Effective workload for order o	Cap_o	Effective capacity for order o
Nrep	Number of repetitive customer	γ	Decision maker's coefficient
e_{on}	Release date for operation n of order o without workload		
$\underline{r}_{on}$	Lower bound on release date for operation n of order o		
$\overline{r}_{on}$	Upper bound on release date for operation n of order o		
$\overline{d}_{on}$	Upper bound on due date for operation n of order o		
ER_{oin}	Earliest release date for i unit of operation n of order o		
CT_{oin}	Completion time for i unit of operation n of order o		
Δ_{on}	Delay for operation n of order o due to reserved capacity		
p_{on}	Minimum processing time for operation n of order o		
ρ	Coefficient of satisfaction level for profit per unit processing time		
U_o	Unit production cost per unit processing time of order o		
h_o	Unit finished goods inventory holding cost per unit time for order o		
P_{on}	Unit cost of processing operation n of order o		
F_o	Future influence per unit processing time of order o		
$\overset{v}{d}_o$	Earliest due date of repetitive customer order o		
T_o	Unit tardiness cost for order o per unit time		
δ_{new}	Order satisfaction level of new order		
δ_{rep}	Order satisfaction level of repetitive customer order		
K	All the orders accepted in the past and order forecasted from repetitive customers		
ψ	Percentage of uncertainty in processing time		
$\overline{\lambda}$	Upper limit on decision maker's acceptance threshold		
$\underline{\lambda}$	Lower limit on decision maker's acceptance threshold		
$\mu(t)$	Decision maker's acceptance threshold at time t		

4.2 Scheduling

When a new order arrives, it is decomposed into the operations involved in the order. Then, time window is calculated for each operation which consists of lower bound at which the operation of an order can be started and the upper bound at which the operation must be finished. As EDD scheduling rule minimizes maximum lateness, we use EDD method to schedule new order with orders that have already been accepted but not yet started production and orders that are forecasted to arrive in the future while maintaining the precedence relationship.

Forward scheduling method is utilized to calculate the lower bound $\underline{r}_{on}$. For first operation of an order, it will be equal to the arrival date t_o. Otherwise,

$$\underline{r}_{on} = t_o + \sum_{n=1}^{n-1} p_{on} \tag{1}$$

On the other hand, as shown in Equations (2) and (3), backward scheduling method is utilized to calculate the upper bound $\overline{d}_{on}$ for all the operations of an order.

$$\overline{d}_{on} = \max\left\{ \overline{r}_{on} + q_o p_{on} \ , \ \overline{d}_{o(n-1)} + p_{on} \right\} \tag{2}$$

where,

$$\overline{r}_{on} = \max\left\{ d_o - q_o \max_{n} \ p_{on} - \sum_{x=n}^{N-1} p_{ox} \ , \overline{r}_{o(n-1)} + p_{o(n-1)} \right\} \tag{3}$$

4.3 Rescheduling

The schedule will become infeasible when the operation of different orders need processing on the same machine at the same time. The infeasibility may be between the operations of new order and the order that has already been accepted but not yet started production. Or it may be between the operations of new order and the forecasted order. To convert infeasible schedule into feasible one, right hand shift method of rescheduling is used as it is a popular method and is easy to implement (Subramanyam and Raheja, 2003). The schedule is said to be feasible if all the operations of orders can be released and finished within the above calculated time windows. Feasible schedule will ensure the completion of orders without becoming tardy.

4.4 Integration

Integration is necessary to know the satisfaction level generated by the order. This is done by taking the weighted average index of four different criteria. These criteria and the method to integrate them will be explained next.

4.4.1 Robustness Index

Robustness can be defined as the degree to which system can function properly even when the actual parameter values are different from those assumed. We consider the robustness of an order in terms of percentage increase in processing time than expected. The idea is to check the level of tolerance of base schedule*against increase in the length of processing time. This helps hedge against the uncertainty in processing time, which is quite common in MTO system.

To calculate robustness index, it is assumed that the minimum processing time and the maximum percentage of uncertainty for incoming order is known to the company. Then, as shown in Equation (4), the operation of an order with least slag divided by the product of total processing time and maximum percentage of uncertainty gives the robustness index. Here, least slack is selected because it indicates the operation whose slack has the lowest ability to withstand uncertainty in processing time as compared to the slack of other operations of order.

$$R_o^I = \frac{[\bar{d}_{on} - CT_{oin}]_{least}}{[(q_o - 1)\max_n p_{on} + \sum_{n=1}^{N} p_{on}]\varphi_o} \tag{4}$$

In Equation (4), completion time (CT_{oin}) for each operation can be calculated by using iterative method. This method considers the precedence relationship between operations of an order and shop floor information for the calculation.

4.4.2 Capacity Utilization Index

Capacity utilization index is calculated by considering the capacity that will be wasted while producing an order. The objective is to accept orders which involve less wastage of capacity. This index is an important measure to increase the utilization rate of available capacity. As shown in Equation (10), it is obtained by subtracting total wastage of capacity from the total reserved capacity and then dividing the obtained value by total reserved capacity. The wastage of capacity will be equal to the capacity reserved for the given operation of an order minus total processing time of that operation.

$$C_o^I = \frac{\left(\sum_{n=1}^{N}\left(CT_{oi_l n} - ER_{oi_{st} n}\right) - \sum_{n=1}^{N}\left\{\left(CT_{oi_l n} - ER_{oi_{st} n}\right) - q_o p_{on}\right\}\right)}{\sum_{n=1}^{N}\left(CT_{oi_l n} - ER_{oi_{st} n}\right)} \tag{10}$$

4.4.3 Profit Index

In Piya et al. 2008 profit is calculated by neglecting the capacity necessary to produce the order. Sometimes the order may have high profit but it may require more of the available capacity to produce the order. If the order consumes more capacity with low return per unit of utilized capacity it might be better to reject the order. Therefore, in this paper, we consider profit per unit processing time to calculate profit index. While calculating profit index it is assumed that the DM's satisfaction on profit will be at the highest level when it is equal to or more than certain percentage (ρ) of production cost. Then, profit index is given by the following equation.

$$P_o^I = \frac{Z_o}{\rho U_o} \leq 1 \tag{11}$$

where,

$$Z_o = \frac{SP_o}{\sum_{n=1}^{N} p_{on}} - U_o \tag{12}$$

$$U_o = \frac{q_o \sum_{n=1}^{N} p_{on} P_{on} + h_o \sum_{i=i_{st}}^{i_l} (d_o - CT_{oiN})}{q_o \sum_{n=1}^{N} p_{on}} \tag{13}$$

* Base schedule: The schedule of an order with minimum processing time

ER_{oin} = max [t_o, Δ_{on}] when $i = i_{st}$ 1 and $n = 1$ (5)

ER_{oin} = $ER_{oi(n-1)} + p_{on}$ when $i = i_{st}$ and $n = 2, 3, \ldots, N-1, N$ (6)

ER_{oin} = max [$ER_{o(i-1)n} + p_{o(n-1)}$, Δ_{on}] when $i = i_{st}+1, i_{st}+2, \ldots, i_l-1, i_l$ and $n = 1$ (7)

ER_{oin} = max [$ER_{oi(n-1)} + p_{on}$, $ER_{o(i-1)n} + p_{o(n-1)}$] when $i = i_{st}+1, i_{st}+2, \ldots, i_l$ and $n = 2, 3, \ldots, N$ (8)

CT_{oin} = $ER_{oin} + p_{on}$ when $i = i = i_{st}+1, i_{st}+2, \ldots, i_l-1, i_l$ and $n = 1, 2, \ldots, N-1, N$ (9)

Equation (12) calculates the profit per unit processing time of an order. On the other hand, Equation (13) calculates the production cost per unit processing time necessary to produce the order. It consists of total cost of processing the order, finished goods inventory holding (FGI) cost and total processing time. To calculate FGI cost, the completion time for each unit of last operation of an order is taken into consideration.

4.4.4 Future Influence Index

Future influence index indicates the influence of repetitive customer order on profit, both at present and in the future. It is calculated with the assumption that if the order from such customer is rejected, company has to reduce the selling price of product by the rate β for some f' future period as a penalty for rejection. Then, the future influence index is given by Equation (14) which indicates that the DM's satisfaction on profit at present and in the future for repetitive customer will be at the highest level when it is equal to or more than certain percentage (ρ) of production cost.

$$F_o^I = \frac{(Z_o + F_o)}{\rho U_o} \leq 1 \tag{14}$$

where

$$F_o = \frac{\sum_f q_o \beta SP_o}{\sum_f \sum_{n=1}^{N} q_o p_{on}} \tag{15}$$

Equation (15) indicates the loss per unit processing time the company has to bear for certain future period if the order from repetitive customer is rejected now.

When the order from repetitive customer is finished before the earliest due date then the production cost can be calculated by replacing due date d_o with earliest due date $\overset{v}{d}_o$ in Equation (13). But, if the order is finished between the earliest and the latest due dates then, as shown in Equation (16), it is calculate by considering both the holding cost and tardy cost.

$$U_o = \frac{q_o \sum_{n=1}^{N} p_{on} P_{on} + h_o \sum_{i=i_{st}}^{i_l} \left(CT_{oi_lN} - CT_{oiN} \right) + T_o q_o \left(CT_{oi_lN} - \overset{v}{d}_o \right)}{q_o \sum_{n=1}^{N} p_{on}} \tag{16}$$

The value of Z_o in Equation (14) can be obtained by using Equation (12).

4.4.5 Order satisfaction level

The above four criteria are integrated into a single value by giving weight to each measure to obtain satisfaction level of an order. We use weighted average method because we have to integrate number of criteria with different units. Such integration is not possible by the traditional method of obtaining the average value. Also, using weighted average method, the DM can assign different weight to different criteria based on his/ her experience and priority. For example, if the OA decision is related to the order which is similar to the one that they dealt with in the past, robustness index may be given less weight. This is due to the reason that the company can say with some certainty about the actual time that will be incurred to produce this order. Similarly, if the DM gives high priority on immediate profit, then profit index should have more weight as compared to future influence index and so on.

For non-repetitive customer order, order satisfaction level involves the integration of robustness index, capacity utilization index and profit index because the order from such customer will not have any influence on profit in the future.

Let w_1, w_2 and w_3 be the weight for R_o^I, C_o^I, p_o^I respectively, where $(w_1 + w_2 + w_3) = 1$, then

$$\delta_{new} = w_1 R_o^I + w_2 C_o^I + w_3 P_o^I \tag{17}$$

On the other hand, for repetitive customer order, instead of profit index, future influence index is used to calculate order satisfaction level. This is due to the reason that, as shown in the Equations (14), future influence index includes the profit at present also

$$\delta_{rep} = w_1 R_o^I + w_2 C_o^I + w_3 F_o^I \tag{18}$$

In Equation (18), the value of R_o^I will be equal to 1 because for repetitive customer order the processing time is deterministic.

Therefore, order satisfaction level expresses an average satisfaction received by DM from the order in terms of robustness against uncertainty, capacity utilization and profit or future influence.

4.5 *DM's acceptance threshold*

The DM's acceptance threshold $\mu(t)$ is calculated by considering the amount of workload in the system. This is because higher the load in the system, risk involved in accepting the new order, in terms of delivery reliability, will be high. So the value of $\mu(t)$ should be high and vice-versa. The steps to calculate DM's acceptance threshold are as follow:

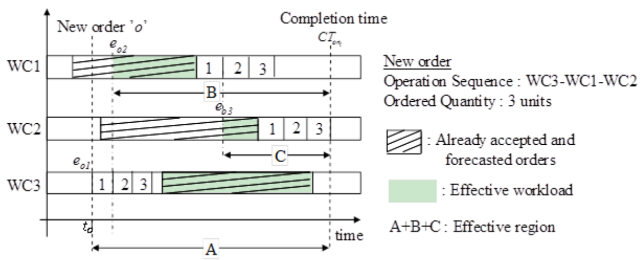

Figure 3. Calculation of workload in the system

i) Calculate the workload in the system.

In a conventional method, the workload is calculated by summing, within a certain time frame, the load of all the orders in the available resources that have been accepted in the past. We argue that, while checking the capacity of resource to produce a new order, it is not wise to calculate the workload by considering those loads which will not have any effect for the processing of new order. Therefore, we propose a new definition of workload, hereafter known as effective workload, which will be based on only those loads that have effect on the release of new order. For this we define a new parameter called "effective region".

As shown in Figure 3, effective region is the region of schedule, for each work centre where the operation of new order will be processed, from the starting time of operation without workload to the completion time of last operation with workload. The workload of already accepted orders and the forecasted orders within this region is known as effectiveworkload. Mathematically,

$$Wl(t) = \frac{Wl_o}{Cap_o}\ , \quad 0 \le Wl(t) \le 1 \tag{19}$$

$$Cap_o = (CT_{oi_lN} - t_o) + \sum_{n=2}^{N} CT_{oi_lN} - \left\{ER_{oi_{st}(n-1)} + p_{o(n-1)}\right\} \tag{20}$$

$$Wl_o = \sum_{k\in K} \sum_{n\in(1,2,...,N)} p_{kn} I(t) \left[e_{on}, CT_{oi_lN}\right] \tag{21}$$

As shown in Equation (19), the workload at any time 't' is calculated by dividing effective workload by the capacity of work center at effective region. Therefore, the work load will vary in between (0-1). In relation to Figure 3, Equation (20) will determine the capacity of work center in the regions A, B and C. Equation (21) implies the summation of processing time, within the time frame (e_{on}, CT_{oi_lN}) of all the orders that were accepted in the past and forecasted to arrive in the future. $I(t)$ is an indicator whose value is 1 at a defined interval. Otherwise, it will be 0. When n =1, e_{on} is equal to t_o. Otherwise,

$$e_{on} = \left\{ER_{oi_{st}(n-1)} + p_{o(n-1)}\right\} \tag{22}$$

ii) Calculate the DM's acceptance threshold $\mu(t)$.

To obtain the value of $\mu(t)$, we assume that the DM will fix the lower and upper limit on the acceptance threshold. The lower limit is the least value desired by the DM from an order irrespective of workload in the system. On the other hand, the upper limit is the highest value expected by the DM when workload is very high. Then, the value of $\mu(t)$ can be calculated by Equation (23).

$$\mu(t) = \left\{\underline{\lambda} + \left(\overline{\lambda} - \underline{\lambda}\right) wl(t)\right\}^{\gamma} \le \overline{\lambda} \tag{23}$$

When γ =1, Equation (23) satisfies the equation of straight line. When γ <1, then the straight line becomes convex. The convexity increases with the decreasing value of γ. Conversely, when γ>1, then the straight line becomes concave and it increases with the increasing value of γ.

4.6 Comparison

As shown in Figure 2, two different kinds of comparison may arise during OA decision.

i) When there is no conflict for schedule, the decision for acceptance of new order is done by comparing order satisfaction level of new order (δ_{new}) with the DM's acceptance threshold $\mu(t)$.
ii) When the conflict for schedule among repetitive customer and non-repetitive customer orders cannot be resolved even by rescheduling**.** In such case, any one of the order between repetitive and non-repetitive customers should be rejected. The decision is carried out by comparing order satisfaction level of repetitive customer order (δ_{rep}) and non-repetitive customer order (δ_{new}).

5. NUMERICAL ANALYSIS

The purpose of numerical analysis is to show the working mechanism and the effectiveness of proposed method. The analysis illustrates the effect of various parameters on the proposed method and explains the situation when the proposed method outperforms the benchmark method. The set up considered in the analysis and the result obtained will be discussed next.

5.1 Experimental Set up

For the analysis, we consider a system that consists of four different work centers with one resource at each center. During the analysis, two different categories of customers i.e., repetitive and non-repetitive, are generated. The orders from non-repetitive customers are assumed to arrive according to Poisson's process. For repetitive customers order, forecasting method as explained in section 4.1 is used to generate their arrival in the system.

The profile of orders is developed by considering the factors as shown in Table 2. The number of operations per order is uniformly distributed between 2 and 4. The processing time of an order is generated by considering the relationship between the operations of order with the work center. For example, if the order involves operation at work center 1 then the processing time is uniforly distributed between 90 and 300 minutes. This processing time shows the minimum processing time. The processing sequence of an order on the work center is selected randomly. For repetitive customer, the quantity in an order is uniformly distributed between 6 and 9. On the other hand, it is uniformly distributed between 3 and 6 for non-repetitive customer. During the analysis, the selling price and production cost is selected such that the profit margin varies uniformly between \$1000 and \$4400. The unit inventory holding cost and tardiness cost per unit time is distributed between (\$2, \$5) and (\$15, \$30) respectively.

We compared proposed method with the benchmark, which will accept the order if it generate feasible schedule by EDD method and provide profit to the manufacturer, for the combination of different parameters at two cases of due dates as shown in Table 3.

Table 2: Factors used to generate the profile of orders

Number of operations/order	$U(2,4)$	
Processing time/ work center (WC)	WC1=U(90,300)mins	WC3=U(100,260)mins
	WC2=U(120,300)mins	WC4=U(150,360)mins
Quantities/order	For repetitive customer = $U(6,9)$	
	For Non-repetitive customer = $U(3,6)$	
Profit margin/unit	U($1000,$4400)	
Unit inventory holding cost/unit time	U($2,$5)	
Unit tardiness cost/unit time (repetitive customer only)	U($15,$30)	

a) The percentage of uncertainty, ψ: The percentage of uncertainty indicates the actual processing time uncertainty in the operation of an order. Higher the value of ψ, more will be the uncertainty in processing time.
b) Coefficient of selling price, σ: The coefficient of selling price will affect the price of an order. Increase in its value will increase the selling price and vice-versa.
c) DM's coefficient, γ: The DM's coefficient shows the aggression of DM for OA decision. Increase or decrease in its value will affect the DM's acceptance threshold for OA decision.
d) Future period, f: An increase in the future period increases the number of periods until when there will be influence of repetitive customer on profit, if the order is rejected

Table 3: Parameter value for the numerical analysis

Due date	Parameter			
	ψ(%)	σ	γ	f
Tight: $(0.7 \sim 1.1)\sum_{n=1}^{N} p_{on}$	0	1.0	0.8	2
↕	10	1.3	1.0	3
Loose:1.2*Tight due date	15	1.5	1.4	4

We generate five replications of the problem with the set up as mentioned above and conduct the analysis. The result obtained from this replications are then aggregated to obtain the average result of proposed and benchmark methods.

The performance of two methods is compared in terms of following measures.

(i) *Acceptance ratio* (%): The ratio of repetitive and non-repetitive customers accepted by proposed and benchmark methods.
(ii) *Undelivered order*: Order accepted but not able to deliver by the company within acceptable due date. This shows the percentage of unsatisfied customers.
(iii) *Percentage utilization and profit*: Percentage utilization indicates the total capacity that is utilized for the productive work. On the other hand, profit is the net income received from all the orders.

For the simplicity, the value of φ_o for all the operations of an order is fixed at 0.3. During the analysis, equal weight is given to four different criteria while calculating order satisfaction level and the value of ρ is fixed at 1. Similarly, the upper and lower limits on the DM's acceptance threshold are fixed at 1.0 and 0.21 respectively.

5.2 Results and Discussion

From the average result obtained by aggregating five replications we can conclude the following findings.

(i) *Acceptance ratio*

Figure 4 shows the effect of future influence of repetitive customer order on the acceptance ratio. In the proposed method, along with the present profit, the manufacturer is highly concerned towards the effect of profit from the customers in the future as well. From the figure it is evident that as compared to the benchmark method, proposed method gives more preference to the repetitive customer which is shown by the high acceptance ratio. As the number of future period 'f' for which there will be effect of repetitive customer order on profit increases, the proposed method accepts as many repetitive customers as possible. This will improve the long term benefit for the manufacturer. On the other hand, the benchmark method is unresponsive towards the increase in the value of 'f'. With the increase in the number of repetitive customers, the acceptance ratio will increase in both the methods. But the rate of increment is considerably high in the case of proposed method than the benchmark.

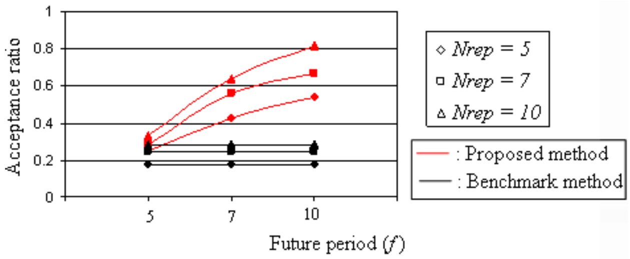

Figure 4. Effect of future influence on acceptance ratio

(ii) *Undelivered order*

For the brevity of the problem, from here onwards, we will discuss the result obtain only when the value of f is equal to 2. This is because the result can be generalized for the case when the value of f is equal to 3 and 4. The effect of processing time uncertainty on OA decision can be seen from Figure 5. The number of orders accepted by both the concept will be high when there is no uncertainty in the processing time. As the uncertainty increases, the number of accepted orders decreases. The increase in uncertainty will also increase the number of undelivered orders. The effect of uncertainty is high for benchmark method in terms of undelivered orders. From Figure 5, it is seen that even though the number of orders accepted by benchmark method is high, the undelivered orders is also very high as compared to the proposed method. This is due to the reason that the benchmark method does not consider uncertainty while making OA decision. On the other hand, to make OA decision, the proposed method checks the robustness up to which the new order can sustain the amount of uncertainty in processing time. As Merit (1990) states that it is better to tell customers up front that you cannot meet a delivery date than disappoint them on the day they expect to receive the goods, the benchmark method will have negative impact on the future arrival of order from the same customer.

As compared to the tight case, the number of customers accepted by both the method is more when the due date is loose. This is due to the reason that the slack of each operation of an order increases with the increase in the due date. This increased slack helps absorb certain amount of uncertainty in the system. Even in the case of loose due date, the performance of proposed method is better than the benchmark as it incur less number of undelivered orders.

Figure 5(a), Figure 5(b) and Figure 5(c) show the effect of γ on the OA decision. For the same percentage of uncertainty, in the proposed method, the number of accepted orders decreases with the decreasing value of γ. When the value of γ is high (γ= 1.4), the number of undelivered orders in the proposed method is more. This is due to the reason that, as the value of γ becomes high, the proposed method tends to accept even that order which is not so profitable and/or the order with less slack. Conversely, when the value of γ is low (γ= 0.8), the proposed method tends to accept only those order which is profitable and/or order with more slack. Therefore, from the analysis we can conclude that the aggressiveness of DM can be manipulated by varying the value of γ in Equation (23). This shows that the effectiveness of proposed method depends highly on the value of γ selected by the DM. On the other hand, there won't be any effect of γ on the OA decision by a benchmark method. If the value of γ is very low, the number of rejections will be high in the proposed method. This may lead the benchmark method to outperform proposed method.

(iii) *Percentage utilization and profit*

Figure 6 shows the relationship between the profit and percentage utilization. It is obvious that with the increase in the coefficient of selling price (σ), total profit will increase in both the methods. In the case of proposed method, along with the increase in total profit, the percentage utilization also increases. This is due to the fact that when the profit of an order increases, the profit index will also increase, which in turn will increase order satisfaction level. It leads to the increase in the total number of accepted orders. For the benchmark concept, increase in the coefficient of selling price (σ) does not affect percentage utilization of available capacity. This is because, even though there is change in the value of σ, the total number of orders accepted by the benchmark method will be same as it only considers whether the order is going to generate profit or loss, rather than considering the amount of profit the order is going to generate if accepted.

The total profit and percentage utilization of available capacity for the proposed method decreases with the decrease in the value of γ. This is due to the reason that the total number of accepted orders by the proposed method decreases as the value of γ decreases (Figure 5). On the other hand, there won't be any effect of γ on profit and percentage utilization in benchmark method. With the benchmark method, for some cases, even when the percentage utilization is high, the profit is less than the proposed method, especially when σ =1.0 and γ= 0.8, which is in contrast to the general concept. This is because the benchmark method does not consider uncertainty for OA decision. Due to this even though it accept orders and uses some capacity to produce these orders, the company will not be able to deliver all of them within their acceptable due date. Instead, in the proposed method, the company will reject the orders by considering the capacity of schedule, including these orders, to absorb the amount of uncertainty.

The effect of uncertainty on profit and percentage utilization can be seen on both the methods. Both the parameters decrease with the increase in the percentage of uncertainty. From Figure6 (a) and Figure 6(b), it is evident that for any percentage of uncertainty, the total profit of the proposed method is more than that earned by the benchmark method. From the analysis of Figure 5 and Figure 6 it can be concluded that, for most of the combinations of ψ, σ and γ, proposed method outperforms benchmark method with respect to the performance criteria like undelivered order, profit and percentage utilization. This can be attributed to the schedule feasibility along with the combined effect of robustness index, capacity utilization index, profit index and/or future influence index considered for OA decision. The robustness index helps minimizing the number of undelivered orders. Decrease in the number of undelivered orders indicates satisfaction to the customers. While, the profit index helps selecting those orders which generate more profit to the company. This is done by comparing the profit of order with the DM's threshold level. Therefore, even when the number of accepted orders is less in proposed method, the total profit is higher than that of the benchmark. The increased profit will improve the satisfaction level of manufacturer.

6. CONCLUSION

In this paper, we have studied OA decision problem in a complex MTO job shop environment. Proposing a method based on the satisfaction level, we tried to provide new insight into the problem of OA decision. Two types of satisfaction level were defined in the paper. One is the satisfaction level generated by an order. Next is the satisfaction level of DM at a particular time i.e., DM's acceptance threshold. Irrespective of feasible schedule as used in a traditional approach, we consider the capacity of feasible schedule to sustain the degree of uncertainty as one

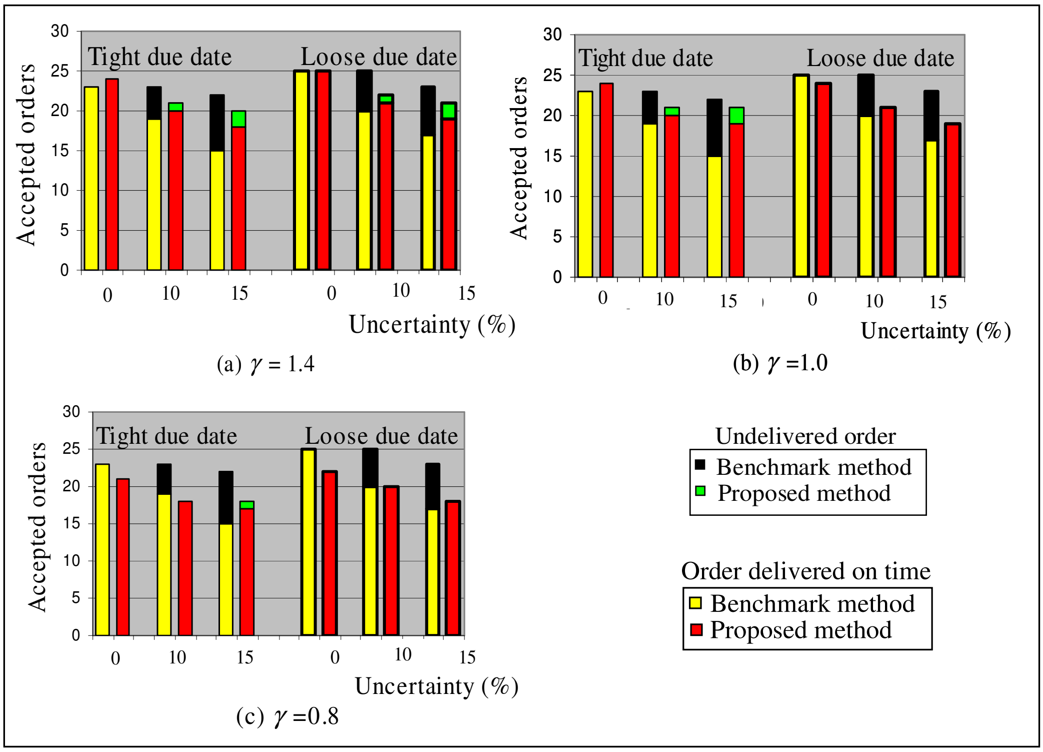

Figure 5. Effect of processing time uncertainty on OA decision

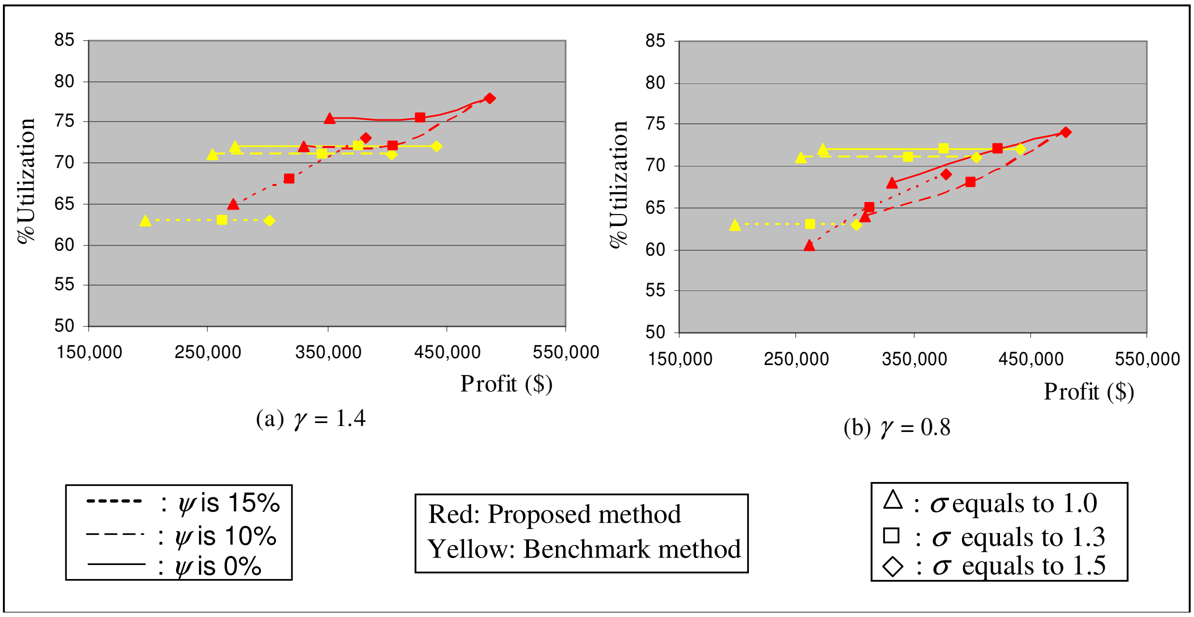

Figure 6. Relationship between profit and percentage utilization

among four different criteria used to calculate the satisfaction level generated by an order. The proposed method considers order's profitability in terms of short and long run. It tries to accept the order with less wastage but generate more profit per unit of utilized capacity. This type of approach will ensure long run sustainability and profit to the company. In the proposed method, DM's acceptance threshold is shown to be affected by the workload in the shop floor and his aggression. From the analysis, it is seen that the level of aggression of DM plays a pivotal role in OA decision. Therefore, the DM should be very cautious while considering the aggression level. He may choose the value based on the forecast of future customer arrival and the amount of workload.

From the numerical analysis we can conclude that the traditional method of accepting all the incoming orders when the capacity is available is short sighted. This kind of approach may confuse the decision maker to accept those orders which may degrade the reputation of manufacturer and also does not generate profit in the long run. Therefore, the manufacturer must have proper strategy to hedge against the stochastic nature of an order. The OA policy should not operate by giving much emphasis on maximizing the resource utilization. Rather, it should consider the reliability of achieving the pre-specified due date and try to accept those orders which will be beneficial to the company at present and in the future as well.

In this paper, we considered that the order from non-repetitive customer will not have any influence in the future. Sometimes the new customer may submit a trial order. In such case the customer may never return back if his or her order is rejected. Based on this, research can be extended to include future influence of order from non-repetitive customer. Also, at present only one manufacture and customers are considered in the OA framework. In reality, purchased order in MTO system accounts for almost 70-80% of total product cost (Bore *et al*., 2001). It means that, along with manufacturer, supplier also plays a major role in fulfilling the order of customer. The next interesting research direction may be to consider the effect of supplier on OA decision.

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