Lead Time Estimation of A Production System using Fuzzy Logic Approach for Various Batch Sizes

A. Sudiarso and R.A. Putranto

***Abstract* — A company strategy is to provide goods and services for consumers so that the consumers can accept the products and realize that the values of the products exceed their prices, i.e. value for money. However, the consumers may not only look at the product prices when they decide to buy the products but also several other factors, such as the product lead time.**

A research was conducted to determine the lead time required in a make-to-order company. The factors that influence the lead time for example the number of demand, stock on hand, and the batch size were used for calculation. In this paper, lead time calculations were performed by simulating the mathematical models. The simulation results were used as a basis to build the fuzzy membership functions.

The results show that the lead time calculations using fuzzy logic approach are similar to the simulation results. Statistical tests show that there is no significant difference between the output of fuzzy logic and the output of the simulation, so that the fuzzy approach can be used for estimating the lead time without the need for simulation.

***Index Terms* — batch size, fuzzy logic, lead time, make-to-order, production system.**

I. Introduction

A key element in developing the operational strategies for a company is to provide goods and services to the customers so that the benefits for the customers are greater than the product prices. Currently, the customers do not only use the product price as the only factor when making a decision to buy a product. Baker (2001) said that less than 10% of consumers make the decision to buy a product just based on the product price, most customers will also consider the other customer service attributes. The lead time period and the product reliability should be used as two other important factors in the customer service element.

There are four basic competitive priorities i.e. cost, quality, delivery, and flexibility, where speed of delivery is one factor in making purchasing decisions [1]. Satisfying the needs of customers for a short lead time is one of corporate responsibility in maintaining the continuity of the supply chain flow [2]. Lead time is defined as the time required in a production unit to transform raw materials into final products through a production process [3].

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A. Sudiarso is with the Department of Mechanical and Industrial Engineering, Gadjah Mada University, Jl. Grafika 2 Yogyakarta Indonesia 55281 (phone/fax: +62-274-521 673; e-mail: a.sudiarso@ugm.ac.id).

R.A. Putranto was a student and has graduated from the Department of Mechanical and Industrial Engineering, Gadjah Mada University, Jl. Grafika 2 Yogyakarta Indonesia 55281.

A study was conducted to develop mathematical models to calculate the lead time [4]. In the study, there were two main equations: the first equation was used for calculating the lead time and the second one was an objective function to maximize the profits to obtain the optimum price. The lead time from these models needs to be validated to represent a real system.

The models involve the calculation of batch size, stock on hand (inventory), demand, and the lead time. With the demand and supply that contain uncertainty and various possible batch sizes, it is necessary to develop a model that accommodate these conditions. The use of fuzzy logic is expected to overcome the uncertainties that occur in the real system.

II. Research Methodology

The research began with calculating the lead time using mathematical models from a reference [4]. The next step was to build a simulation to validate the calculations. The software used for simulation was ProModel 4.2. The simulation results were evaluated and compared with the calculation results from the mathematical models. In the simulation, loading and unloading times were added to better represent a real system. The simulations were re-run to obtain the final results.

The results from simulation were then used as a basis to build the fuzzy membership functions. The fuzzy logic optimization was performed, for example by varying the membership functions, i.e. the type and domain of each membership function. The best results were obtained by comparing the error calculated using the fuzzy logic approach to the simulation outputs.

III. Mathematical Models

The mathematical models use two main equations as follows [4].

$$D(p,l) = a - b_p p - b_l l \quad (1)$$

$$\prod = (p - c_0)x - \sum_{j,1} c_{jk} q_{jk} x - \sum_{j,2} c_{jk} q_{jk} x / B - h \times I \quad \ldots (2)$$

where

$$q_{jk} x \le Q_{jk} \qquad k = 1, \forall j, \quad (3)$$

$$q_{jk} x / B \le Q_{jk} \quad k = 2, \forall j, \quad (4)$$

$$0 < x < D(p,l) \quad (5)$$

The constants are b_p = 0.1 units/\$, b_l = 4 units/day, a = 500 units/month, and c_0 = \$500/unit, and h = \$50/unit. The assumptions of the system are stated as follows:

a. there is no lead time of raw materials from the suppliers/inventory to the work station,
b. the rules is First Come First Served (FCFS),
c. the batch size is constant during the process,
d. backlog of orders cannot exceed the buffer limit in front of the first stage and new orders will be accepted after the order backlog equal to the buffer limit,
e. there is no transit time between workstations,
f. no breakdown is assumed at the workstations,
g. various batch sizes can be applied to the process,
h. process yield is 100%, meaning that all products are free from defects,
i. delivery reliability level is not less than 99%,
j. the demand, the inventory, and the batch size become the input variables in the fuzzy logic system, while the output of the fuzzy logic is the lead time.

The values of parameters used for calculations are shown in Table 1 and the structure of the production system is given in Figure 1.

Table 1. The values of parameters [4]

Parameter	W_{12}	W_{11}	W_{22}	W_{21}	W_{31}	W_{32}
c_{jk} ($/hour)	30	60	60	90	50	60
Q_{jk} (hour)	240	720	240	960	960	240
q_{jk} (hour)	4	1.5	7.8	2.4	2.1	6.9
std [q_{ik}] (hour)	0.5	0.2	0.8	0.3	0.3	0.5

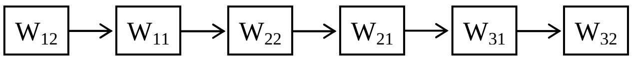

Figure 1. The structure of the production system [4]

IV. Results and Discussion

The simulation results are given in Table 2. The outputs of the simulation were slightly different from the lead time calculation using the mathematical models.

Table 2. Simulation results of lead time calculation

a	*B*	*p*	*D*	*I*	*Π*	LT
300	5	1,781	98	13	64,873	6.01
400	5	2,540	122	17	173,400	6.99
500	5	3,350	137	21	305,600	7.96
600	5	4,261	142	24	445,900	7.96
700	5	5,190	145	25	590,100	7.96
300	10	1,682	98	16	64,873	6.01
400	10	2,441	122	20	173,400	6.99
500	10	3,250	137	22	305,600	6.99
600	10	4,160	142	23	445,900	7.96
700	10	5,090	145	25	590,100	7.96
300	15	1,649	98	17	64,873	6.01
400	15	2,408	122	20	173,400	6.99
500	15	3,217	137	23	305,600	6.99
600	15	4,127	142	24	445,900	7.96
700	15	5,056	145	24	590,100	7.96
300	30	1,621	98	28	64,873	6.01
400	30	2,380	122	33	173,400	6.99
500	30	3,189	137	37	305,600	6.99
600	30	4,098	142	38	445,900	7.96
700	30	5,028	145	39	590,100	7.96

The simulation produce outputs that do not reflect the real conditions. In a real system, for the same number of products, if the batch size increases, the lead time should be shorter. Inversely, a smaller batch size normally results in a longer lead time [5,6,7].

The simulation results also show that the results have not been considered representative. From Table 2, it can be observed that there is no significant difference if using different batch sizes. It should produce a different lead time if a different batch size is used.

Therefore, it is recommended to modify the system i.e. by adding a loading and unloading time for processing at each workstation that uses a batch processing. In the mathematical model, the addition of loading and unloading time is added to the calculation of processing costs at the workstation that uses a batch processing, which in turn will effect on the lead time. The loading and unloading time is also added on the simulation model, by directly adding the processing time to cover loading and unloading time. After re-running the simulation, the results of lead time calculation were produced as shown in Table 3.

It is clear from Table 3 that the output of the simulation results better represent a real system. The bigger the batch size, the shorter the lead time due to a less frequent setup, loading and unloading activities. After all, the output of the simulation will be used as a basis to build the fuzzy membership functions.

Table 3. The results of lead time calculation after modifications

a	*B*	*D*	*I*	LT
300	5	98	13	23.62
400	5	122	17	28.51
500	5	137	21	32.42
600	5	142	24	34.38
700	5	145	25	35.35
300	10	98	16	12.90
400	10	122	20	15.84
500	10	137	22	16.81
600	10	142	23	17.79
700	10	145	25	18.77
300	15	98	17	8.99
400	15	122	20	10.96
500	15	137	23	11.94
600	15	142	24	12.92
700	15	145	24	12.92
300	30	98	28	6.08
400	30	122	33	7.07
500	30	137	37	7.07
600	30	142	38	8.06
700	30	145	39	8.06

The fuzzy logic approach for estimating the lead time of production system consists of three input variables and one output variable. The input variables are the demand, the batch size, and the inventory level, while the output variable is the lead time. A screen capture of the fuzzy system is shown in Figure 2.

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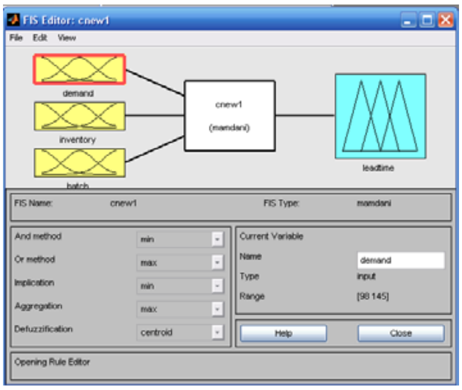

Figure 2. The developed fuzzy system

An optimization was carried out to try to obtain best possible results that close to the real systems, in particular by:

1. varying the type of membership functions,
2. shifting the domain of membership functions,
3. changing the defuzzification methods.

The optimization process was done by changing each of these individual parameters and recording the results, then performing a combination of these changes. The optimization results of the fuzzy logic system are shown in Table 4 and Table 5.

Table 4. Fuzzy optimization results

FIS	**Type**	**Input**	**Type**
FIS type	mamdani	Demand	gaussmf[5]
And method	min	Inventory	gaussmf[5]
Or method	max	Batch	trimf[5]
Implication	min	**Output**	**Type**
Aggregation	max	Lead Time	trapmf[5]
Defuzification	mean of maximum	Rules	15

Table 5. The results of lead time calculation using fuzzy logic approach

a	*B*	*D*	*I*	LT
300	5	98	13	20.72
400	5	122	17	28.03
500	5	137	21	34.18
600	5	142	24	34.33
700	5	145	25	34.03
300	10	98	16	13.40
400	10	122	20	13.40
500	10	137	22	17.82
600	10	142	23	20.72
700	10	145	25	20.72
300	15	98	17	8.13
400	15	122	20	7.69
500	15	137	23	13.40
600	15	142	24	13.40
700	15	145	24	13.40
300	30	98	28	7.40
400	30	122	33	6.67
500	30	137	37	7.10
600	30	142	38	6.67
700	30	145	39	7.40

After optimization, statistical tests were performed i.e. an inspection approach and a confidence interval approach. The results of the statistical tests show that there is no significant difference between the output of fuzzy logic and the output of the simulation (MAPE: 9.38%). Thus, the fuzzy logic approach can be used to estimate the lead time. Using this approach, the lead time analysis can be done in a relatively short time without the need for simulation.

V. Conclusion

1. A fuzzy logic approach can be used to estimate the lead time of production system. Statistical tests show that there is no significant difference between the output of fuzzy logic and the output of simulation.
2. The system was developed based on the addition of loading and unloading time to the previous mathematical models for each workstation to better represent a real system.

List of Notations

D : demand (unit)
Π : profit ($)
a : capacity of the market (unit)
b_p : price sensitivity (unit/$)
b_l : lead time sensitivity (day/$)
p : product price per unit ($)
l : recommended lead time (day)
c_0 : raw material cost per unit ($)
c_{jk} : cost per unit of activity j at level k ($)
q_{jk} : capacity of activity j at level k (hour)
x : number of products (unit)
B : batch size (unit)
h : inventory cost per unit ($)
I : average WIP in the system (unit)
LT : lead time from simulation (day)

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