Manufacturing System Selection Using FuzzyAHP

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Abstract: *A multistage, serial, unreliable manufacturing systemunder JIT environment has been considered here. JIT policy involves three important pull production systems i.e. KANBAN, CONWIP and Hybrid manufacturing systems. The present paper demonstrates the brief introduction about the three JIT techniques and application of FUZZY-AHP method to select the best possible manufacturing systems. WIP inventory, Service Level, Throughput, Lost Demand, Total Cost, Utilization of Machine and Utilization of Buffer are the chosen criteria to select the best policy.*

Key words: *JIT, KANBAN, CONWIP, HYBRID, FUZZY-AHP*

I. INTRODUCTION

This section contains introduction about the nature of problem and previous work carried out on this problem but before that a brief introduction is presented about JIT and its policies for revision. The methods use to solve the problem is also introduced briefly in this section.

Just in Time (JIT) philosophy was developed by Toyota Motor Company in Japan in the mid of the 70s by Taiichi Ohno who believed that customer should be satisfied with maximum quality in the shortest time. JIT philosophy improves the system by providing the right part at the right time, at the right place and of right quality. The key component of JIT is never ending effort to eliminate wastes and reduction in the Work-In-Process (WIP) inventory. It transfers the burden of maintaining inventory from manufacturer to supplier. The policy of JIT suffers if the reliability of the supplier is not high. *Sari (2005)* discussed usability of JIT in service sector where wastage of time such as waiting time can be reduced through JIT service as it delivers every component just in time. Therefore, the customer satisfaction level achieved was very high and as a result of JIT application, a stage of zero inventories was also achieved. JIT policy involves three pull production systems which are KANBAN, CONWIP and HYBRID.

KANBAN Systemis used to trigger action in the production line and to communicate the schedule from one workstation to another workstation through the Electronic Signals (KANBAN Card) that contains order for production. Any change in demand is also communicated through these cards.Implementation of KANBAN system results in significant benefits, which are reduced inventory level, less confusion over sequence of activities, less obsolescence of inventories while in storage, smaller floor space requirements for storing inventory, reduced lead times, improved quality, higher employee productivity and greater system flexibility. It also has a limitation that there is delay in starting the production at first work station as the KANBAN signal starts moving from end and travel to preceding work station. So to overcome this limitation, CONWIP is designed. CONWIP is stands for *Constant Work in Process*. Here the signal directly moves to first work station as a demand occurred and the production starts without delay.CONWIP reduces the manufacturing lead time, because the longer the manufacturing lead times, the higher the WIP inventory. It also reduces the manufacturing cycle efficiency, the smaller the manufacturing cycle efficiency more reduction in the WIP inventory. Spearman et. al. 1990demonstrate that CONWIP is a pull alternative to KANBAN and share the benefit of the CONWIP i.e. shorter flow time and reduced inventory level and It can also applied in some production environment where KANBAN is not suitable because of too many part numbers and because of insignificant set-ups.

In CONWIP policy if a workstation stops working or damaged then the parts gets collected before the damaged workstation and the information do not arises in time.To overcome this problem KANBAN policy implemented along with the CONWIP policy. A new system arises which is the combination of both KANBAN& CONWIP policies. This new system is known as ***HYBRID pull production system*** of production control.This new system shares all the benefits of the KANBAN& CONWIP and the limitations occurred during the production is overcome by each policy.Hybrid policy is better than the both policies. But it is very complex and not easy to implement as both the policies implemented collectively.

II. LITERATURE REVIEW

This section contains the literature of KANBAN, CONWIP and HYBRID production systems. A method to calculate the number of cards in CONWIP system was introduced by *Huang et al. (1998)* for a production line with bottleneck and simulates to verify it. This new CONWIP system was compared with the original CONWIP system in a cold rolling plant and found that new system outperform original system with lower WIP and higher throughput rate. *Sarker and Balan (1999)* proved that the raw material, finished goods and WIP inventory were dependent on each other and should have been considered collectively to minimize the total inventory cost andby scheduling the KANBAN at every stage in system and at WIP areas, the cycle time can be reduced significantly that results in improved efficiency of production system. *Duri et. al (2000)* designed a CONWIP system with inspection by using three-station production system and assumed that raw material is always available. In this system, a part inspected randomly at the end of each work station and the inspection time assumed negligible. This system performed very fast with better performance. *Chan(2001)* gave that on increasing the KANBANsize the In-process Inventory and Manufacturing lead time were increases and fill rate was decreases for both Pull and Hybrid systems when consider for single product. But in multi-product Hybrid system the Fill Rate and In-Process Inventory were increases and manufacturing lead time decreases.

Shahabudeen et. al (2002) used Simulated Annealing Algorithm Bi-Criteria Objective Function to get the number of KANBAN cards at each workstations and the lot size to achieve the best performance and determine the performance parameters. *Ovalle and Marquez (2003)* introduced CONWIP Supply Chain and showed that it has better performance and advantages over Fully Integrated Supply Chain while both policy offer same service level.*Ghamri (2006)* analyzed that KANBAN system gives better performance over CONWIP system if the number of KANBAN at each workstation is optimally set and same numbers of cards are used. However, CONWIP was superior only when less number of cards were used than KANBAN system. *Ju-Hua et. al (2008)* found the push production system with FUZZY logic control superior over the KANBAN, CONWIP and a crisp HYBRID (Local/Global Pull) system, with low WIP level and absolute superiority in order placement fluctuation control.*Ghamari and Sato (2008)* gave the superiority of Base-Stock system over KANBAN and CONWIP system in few cases andthe superiority of one over another was determined by certain parameters such as processing time of activities, number of workers for activities and number of cards employed in line. *Hossein et. al (2008)* analyzed the seven production control systems in a complex factory set up through the computer simulation and proposed that no one production system is superior over another in all the conditions. The study showed that superiority of a system is depending upon the various input parameters and type of factory setup.

Boroushaki and Malczewski (2008) implemented an extended AHP using Ordered Weighted Averaging (OWA) operator using FUZZY Quantifiers in ArcGIS to solve the eigen values and eigenvectors. The AHP_OWA was expressed by means of FUZZY linguistic quantifiers. This study enhanced the existing AHP module and increases the functionalities of ArcGIS by integrating the MCDA module into its environment. Sharma and Agrawal (2009)considered a multistage serial production system and developed a frame work with the use of various probabilistic demand patterns and analyzed KANBAN, CONWIP and Hybrid as alternatives. They have used Analytic hierarchy process (AHP) for the purpose of selection and Computational results have been reported along with the sensitivity analysis after designing and conducting various experiments. Sharma and Agrawal (2011) proposed a generalized model in just-in-time environment to handle the inherent uncertainty and imprecision of the pair-wise comparison process of AHP. They have also attempted an implementation of FUZZY techniques with triangular FUZZY number multiple product and serial production systems in which product 1 (P 1) is produced for the first 6 months and product 2 (P 2) is produced in the remaining last 6 months in a year with null setup times. The present paper also includes this important factor with trapezoidal FUZZY number.

III. EXPERIMENTAL DESIGN

In this section it is tried to make soft experimental design as realistic as possible anddescribe as: total numbers of workstations are 10, demand (D) arrival process follows Poisson distribution with mean or λ = 1.1, block seed = 3. The production rate =. 98.5% with the lowest WIP. Mean Time To Failure (MTTF) of each machine = 100 hours and Mean Time To Repair (MTTR) = 10 hourswith seed = 2 and exponentially distributed. The processing time at each work station is lognormal distributed with a mean (1.01) and SD (0.121) giving μ (mean of the included normal) = 0, σ (SD of the included normal) = 0.12, Skewness = 0.363. The production cost data at each workstation and buffer station are: Waiting cost ($) = 0.25/min, Item operational cost ($) = 0.50/ min, Item cost per use ($) = 0.75/min. After application of AHP,all the alternative have been ranked on the basis of Service level (SL), Unsatisfied or Lost demand (LD), Work in Process (WIP) inventory, Total cost (TC), Throughput (TH), Utilization of Machine (UM) and Utilization of Buffer (UB).

The manufacturing systems were analyzed by changing the WIP from 1 to 20 in 20 steps. Each replication was run for 4 months. Table 1 shows the calculated costs with respect to given alternatives.

In the very first step, a decision matrix, alternatives v/s performance measures has been constructed as shown in Table 2, by solving the above problem through the various simulation program coded in C language. In Table-2, KANBAN, CONWIP and Hybrid Production Control Policies are the possible alternatives and WIP inventory, Service Level, Throughput, Lost Demand, Total Cost, Utilization of Machine & Utilization of Buffer are the criteria with the alternative performance.

Now the normalized matrix is constructed by normalizing the every element of decision matrix. The normalized value (n_{ij}) is given by:

$$n_{ij} = 1, \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} (x_{ij})^2}} \quad j = 1, \ldots, n, \; i = 1, \ldots, m \qquad (1)$$

The Equation (1) can easily transform the performance rating to a value ranging from 0 to 1. But when the differences in performance measures are not significantly large, then Eq. (2) & Eq. (3) can be used for the normalization of performance ratings (x_{ij}):

For higher - the – better type:

$$n_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \qquad (2)$$

And for Lower – the – better type:

$$n_{ij} = \frac{\max x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \qquad (3)$$

The new (normalized) matrix obtained by substituting values of x_{ij} in above equation is shown in Table 3. This new normalized matrix is now operated

Table 1: Calculated Production Costs

Serial no.	Cost ($)	KANBAN	CONWIP	Hybrid
1	Waiting cost (10^5)	5.265	4.890	4.920
2	Item operational cost (10^5)	2.053	2.050	2.050
3	Item cost per use (10^5)	2.778	2.778	2.776
4	Total cost (10^5)	10.096	9.718	9.746

Table 2: Decision Matrix

Production Control Policy (PCP)	WIP	SL	TH	LD	TC (10^5)	UM	UB
KANBAN	60	98.58	90.03	532	10.096	0.9983	0.8409
CONWIP	42	98.57	90.02	537	9.718	0.997	0.9273
Hybrid	27	98.50	89.97	560	9.746	0.9968	0.8953

Table 3: Normalized Decision Matrix

Alternatives (PCP)	WIP	SL	TH	LD	TC (10^5)	UM	UB
KANBAN	0.00	1.00	1.00	1.00	1.00	1.00	1.00
CONWIP	0.53	0.85	0.85	0.53	0.42	1.00	0.00
Hybrid	1.00	0.00	0.00	0.00	0.00	0.00	0.50

through the proposed FUZZY-AHP methodology to obtain the final solution.

IV. THE FUZZY-AHP METHOD

Analytical Hierarchy Process (AHP) is a widely used technique developed by Thomas L. Saaty in 1970's for dealing with the Multi-Criteria Decision Making (MCDM) problems which is based on the mathematics and philosophy.

It is used to select the best possible alternatives among the all existing alternatives. First decompose the problem in a hierarchy of more easily comprehended sub-problems and these sub-problems are then calculated independently.

The elements are systematically evaluated by pair wise comparison with each other by converting these evaluations to numerical values. A numerical weight or priority is calculated for each element of the hierarchy. Therefore, we can say that in this world of ideas, we structure the realities into the hierarchy to solve their complexity.

This method can be integrated with any other MCDM method to improve the result. Here in this paper, this method is integrated with Fuzzy Logic.

Table 4: FUZZY Based Matrix

	C_1	C_2	C_3	C_4	....	C_n
E_1	C_{11}	C_{12}	C_{13}	C_{14}	....	C_{1n}
M = E_2	C_{21}	C_{22}	C_{23}	C_{24}	....	C_{2n}
E_3	C_{31}	C_{32}	C_{33}	C_{34}	....	C_{3n}
	...	....	.....	.....	....	....
E_m	C_{m1}	C_{m2}	C_{m3}	C_{m4}	...	C_{mn}

Fuzzy logic is used to minimize the uncertainty in the result. FUZZY number $p = (p_1, p_2, p_3, p_4)$ can be characterized by using a representation, based on parameters of its membership function. The FUZZY set theory used for imprecise and vague situations where uncertainty always involved. Therefore, the linguistic approach is a way to transform the human judgments in a simple manner. The method represents subjective aspects as linguistic values by means of linguistic variables to evaluate the PCP with respect to each parameter. For this purpose, an appropriate linguistic term set is chosen to describe the vague or imprecise knowledge that is shown by the 'Table 5'**.** The linear trapezoidal membership functions $\{\mu_p(x)\}$ as shown in Fig. 1, are good enough to capture the vagueness of linguistic assessments. Linguistic decision procedure

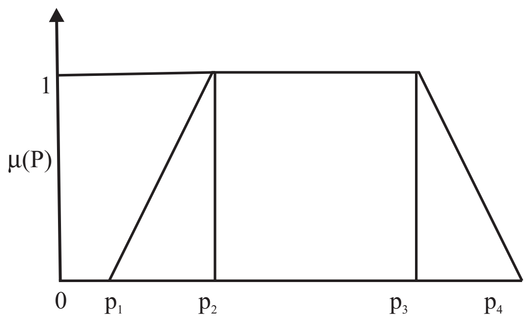

Fig. 1: Graphical Representation of Trapezoidal FUZZY Numbers and Membership Functions

transforms the linguistic description of the experts into mathematical terms with the help of membership functions. When a value falls between two preference levels, closer rule is used for the transformation of the linguistic term in to membership function. Finally,

Table 5: Preference Levels in Linguistic Terms and the Membership Function

Preference level	Membership Function
Very Weak (VW)	(0.0, 0.1, 0.2, 0.3)
Weak (W)	(0.1, 0.2, 0.3, 0.4)
Medium (M)	(0.2, 0.3, 0.4, 0.5)
Strong (S)	(0.3, 0.4, 0.5, 0.6)
Very strong (VS)	(0.4, 0.5, 0.6, 0.7)
Extremely strong (ES)	(0.7, 0.8, 0.9, 1.0)

following FUZZY methodology and analysis framework is used for the ranking of the PCP.The FUZZY-based MCDM can be expressed as:

$W = (w_1, w_{2,} \dots ,w_n)$

Where w_j, j =1, 2, . . ., n, are linguistic trapezoidal FUZZY numbers, $w = (w_{j1}, w_{j2}, w_{j3}, w_{j4}, w_{j5}, w_{j6})$. By multiplying linguistic trapezoidal FUZZY number (w_j) with Fuzzy matrix member (c_{ij}), the FUZZY evaluations can be aggregated as:

$$E_j = (c_{ij})*(w_j),\ i = 1, 2, .., m, j = 1, 2, . . , n \qquad (4)$$

For the trapezoidal FUZZY number $p = (p_1, p_2, p_3, p_4)$, the de-fuzzification value (r) can be expressed as:

$$\mathbf{r_{ij}} = \frac{p_1 + p_2 + p_3 + p_4}{4} \qquad (5)$$

With the help of 'Table 5', transformation of the Normalize Decision Matrix (Table 3) in the FUZZY decision matrix, in terms of linguistic variables has been shown by the'Table 6' and 'Table 7'.This table also includes the transformation of weights (W= 0.286, 0.194, 0.140, 0.134, 0.162, 0.052, 0.033) **(Appendix-1)** in to linguistic terms.

Table 6: Transformation of the Decision Matrix and Weight in Linguistic Terms

PCP	KANBAN	CONWIP	HYBRID	WEIGHT
WIP	VW	VS	ES	M
SL	ES	ES	VW	W
TH	ES	ES	VW	W
LD	ES	VS	VW	W
TC	ES	S	VW	W
UM	ES	ES	VW	VW
UB	ES	VW	M	VW

Now multiply the weight with the criteria values to obtain the aggregate FUZZY values for criteria and alternative in 'Table 8'.

$$R = \frac{r_{ij}}{\Sigma r_{ij}} \qquad i = 1, .., 3 \ \& \ j= 1, \dots, n. \qquad (6)$$

Final rankings (R) of the alternatives i.e. production control policies in descending order has been shown by the Table 9. For the calculation of FUZZY-AHP final ranking (R) equation (5) and equation (6) is used. The rakings obtained from FUZZY-AHP method is as **KANBAN> CONWIP> Hybrid**.

V. CONCLUION

The considered MCDM problem is solved through the FUZZY-AHP method. The first conclusion of this study is that, the KANBAN policy is the best alternative and Hybrid policy is the least possible alternative. Another conclusion is that, the result obtained from FUZZY-AHP method is same as obtained from AHP (Sharma and Agarwal, 2011). However, if we change the weight of alternatives or criteria (Sensitivity Analysis), the result/ranking of the alternatives would be different.

The future directions may include the application of other MCDM techniques in the area such as ANP, TOPSIS, VIKOR, FUZZY-TOPSIS, FUZZY-ANP etc. The other direction may be the inclusion of other JIT techniques (Alternatives) e.g. base stock, extended KANBAN-CONWIP policy etc.

Table 7: Transformation of the Linguistic Term in Membership Function

PCP	KANBAN	CONWIP	HYBRID	WEIGHT
WIP	(0.0, 0.1, 0.2, 0.3)	(0.4, 0.5, 0.6,0.7)	(0.7, 0.8, 0.9, 1.0)	(0.2,0.3, 0.4, 0.5)
SL	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.0, 0.1, 0.2, 0.3)	(0.1, 0.2,0.3, 0.4)
TH	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.0, 0.1, 0.2, 0.3)	(0.1, 0.2,0.3, 0.4)
LD	(0.7, 0.8, 0.9, 1.0)	(0.4, 0.5, 0.6, 0.7)	(0.0, 0.1, 0.2, 0.3)	(0.1, 0.2,0.3, 0.4)
TC	(0.7, 0.8, 0.9, 1.0)	(0.3, 0.4, 0.5, 0.6)	(0.0, 0.1, 0.2, 0.3)	(0.1, 0.2,0.3, 0.4)
UM	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.0, 0.1, 0.2, 0.3)	(0.0, 0.1, 0.2,0.3)
UB	(0.7, 0.8, 0.9, 1.0)	(0.0, 0.1, 0.2, 0.3)	(0.2, 0.3, 0.4, 0.5)	(0.0, 0.1, 0.2,0.3)

Table 8: Aggregate FUZZY Analysis of the Parameters

PCP	KANBAN	CONWIP	HYBRID
WIP	(0.0, 0.03, 0.08, 0.15)	(0.08, 0.15, 0.24, 0.35)	(0.14, 0.24, 0.36, 0.5)
SL	(0.07, 0.16, 0.27, 0.4)	(0.07, 0.16, 0.27, 0.40)	(0.0, 0.02, 0.06, 0.12)
TH	(0.07, 0.16, 0.27, 0.4)	(0.07, 0.16, 0.27, 0.40)	(0.0, 0.02, 0.06, 0.12)
LD	(0.07, 0.16, 0.27, 0.4)	(0.04, 0.10, 0.18, 0.28)	(0.0, 0.02, 0.06, 0.12)
TC	(0.07, 0.16, 0.27, 0.4)	(0.03, 0.08, 0.15, 0.24)	(0.0, 0.02, 0.06, 0.12)
UM	(0.0, 0.08, 0.18, 0.30)	(0.0, 0.08, 0.18, 0.30)	(0.0, 0.01, 0.04, 0.09)
UB	(0.0, 0.08, 0.18, 0.30)	(0.0, 0.01, 0.04, 0.09)	(0.0, 0.03, 0.08, 0.15)

Table 9: Final Rakings of the PCP by Fuzy Method

PCP	Aggregate FUZZY weights	Ranking (R)
KANBAN	(0.28, 0.83, 1.52, 2.35)	0.42
CONWIP	(0.29, 0.74, 1.33, 2.06)	0.37
HYBRID	(0.14, 0.36, 0.72, 1.22)	0.21

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The comparison table for chosen criteria is prepared with the help of industrial experts. The criteria priority weight obtained by pair wise comparison is shown below:

Table 10: Criteria Priority Weight

Criteria	WIP	SL	TH	LD	TC	UM	UB	WEIGHT
WIP	1	3	4	4	4	4	4	0.286
SL	1/3	1	2	2	3	4	4	0.194
TH	¼	½	1	2	2	3	3	0.140
LD	¼	½	½	1	2	3	4	0.134
TC	¼	1/3	½	½	1	5	6	0.162
UM	¼	¼	1/3	1/3	1/5	1	2	0.052
UB	¼	¼	1/3	¼	1/6	½	1	0.033

❑