An analytical hierarchy process and fuzzy inference system tsukamoto for production planning: a review and conceptual research

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Abstract
Production planning is an area that is very important on the corporate strategy-level decision-making, especially in the manufacturing companies. The problems that often arise in the production planning are the factors that affect the decline of production and uncertainty that often complicate the decision-making in the production process. These factors are derived from the company's internal and external factors. The purpose of this study is to introduce the Analytical Hierarchy Process as an effective method that can help to determine the priority of the production factors, so as to facilitate and accelerate decision-making. Other than the AHP methods, this paper will introduce the Tsukamoto Fuzzy Inference System as a method that can help to determine how much product to be manufactured by the company using the variables in the form of fuzzy numbers. These methods hopefully can assist in a better decision making process in the production process and manufacturing generally.

1. Introduction

Production planning is compulsory in manufacturing enterprises. Production planning is a tactical planning that aims to give a decision, based on the company's resources in order to meet customer's demands [1]. Production planning function in making sure everything necessary to make the product is available, and in accordance with the specified schedule beforehand. Planning the production of a product can be tricky, because it requires cooperation between several functional units within the company [2]. Production managers play an important role in production planning. One of the tasks of the production manager is as a decision maker to determine how much product will be produced.

Each company is generally established with the aim to gain profit and maintain its viability. In an effort to maintain its existence, every company will do its best to meet customer's demands. However, in meeting those demands, often a company faces various problems. One of it is the uncertainty in factors of production planning [6]. Uncertainty can be categorised into two types which are environmental uncertainty and uncertainty of the system. Environmental uncertainty refers to the uncertainty that would be beyond the scope of control of the production process, such as demand and supply uncertainty. While the system uncertainty refers to the uncertainty associated with the production process, such as production uncertainty, uncertainty of production time, quality and production failure [3,4].

Uncertainty that occurs normally comes from the factors of production within the company. Factors of production themselves can be divided into two, which is internal and external. Internal production factors are factors that are directly related to the production processeses such as capital, labour, technology and raw materials. While external factors are the factors of production that are not directly related to the production process, such as inventory, suppliers and market demand [5, 7].

Production planning practitioners are usually aware of the problems they face in determining the amount of production. It is common for them to confront uncertainy in many factors of production. One of the cases that are often encountered is the presence of an excess or shortage of production facilities and production output. This case happens on a regular basis in the enterprise and always has a direct impact on the cost of production and storage, as well as profits. In order to facilitate the decision-making process in production planning and provide a basis for future research, some researchers use variety of methods to resolve the problems of uncertainty in many fields, such as research [4] which is decomposed in the table 1.

Conceptual models	**Analytical models**
Yield factors	Hierarchy process
Safety stocks	Matematical programming
Safety lead times	(LP, MILP, NLP, DP, and MOP)*
	Stocastic programming
Hedging	Deterministic approximations
Overplanning	Laplace transforms
Line requirements planning	Markov decision process
Flexibility	
Intelligence artificial based models	**Simulation models**
Expert system	Monte Carlo techniques
Reinforcement learning	Probabilistic distributions
Fuzzy set theory	Heuristic methods
Fuzzy logic	Freezing parameters
Neural network	Network modelling
Genetic algorithms	Queuing theory
Multiagent system	Dynamic systems

* LP = linear programming; MILP = mixed-integer linear programming; NLP= nonlinear programming; DP= dynamic programming; MOP= multi-objective programming.

Table 1. Clasification for the general type of uncertainty models in manufacturing system

Table 1 shows the methods that can be used to cope with the uncertainty. All of the listed models and methods starting from the conceptual models down to simulation models are widely used to deal with the uncertainty in the manufacturing system. All of these models are established to make it easier for practitioners in the company to overcome the uncertainty. For the purpose of model development in the field of production planning, this paper proposes two methods to be presented as a means of decision-making process on complex issues and a lot of uncertainty. The methods that this paper emphasises are firstly, the analytical hierarchy process and secondly, the fuzzy inference system Tsukamoto.

This study will discuss the previous literature review and only introduce to the audience with some of the research related to the production planning, as evidence that there has been much development of the methods to help companies achieve their targets.

2. **Analytical Hierarchy Process**

AHP is a method that was first introduced by Thomas L. Saaty, a mathematician from the University of Pittsburgh, USA in 1977. He successfully developed the AHP method to solve the problem of decision-making in 1980 [8,9,10]. AHP is a simple and flexible decision-making method that can accommodates creativity in the design of a problem. This method is also designed to solve the problem of multi-criteria decision-making (MCDM) which has been proven to be very effective in analyzing complex problems. With AHP, complex problems can be systematically arranged in a hierarchical relationship [13,12]. AHP analysis intended usage is to create a model of unstructured problems and is usually applied to solve problems of scalable and those that require opinion (judgment). AHP includes qualitative and quantitative aspects of the human mind [12,13]. Qualitative aspects define the issue and hierarchy while the quantitative aspects express assessment and preferences concisely. Therefore, AHP requires assessment on respondents of the study who is expert in decision making.

According to Saaty [13], AHP can be used for decision-making such as: setting priorities, generating a set of alternative, choosing alternative, choosing alternative best policy, establishing various requirements, allocating resources, predicting outcomes and assessing risks, measuring achievement, designing the system, planning and solving conflicts. Based on [12], many outstanding works have been published based on AHP. It included the applications of AHP in different fields such as planning the best alternative, resources allocations, resolving conflicts, optimisation, investment decisions and sosial-economics planning. In any case of prioritization, AHP is often used as a tool. As in the study done by Kardi Teknomo [19] using the AHP as a method for making the selection decisions for campus transportation, Doraid dalalah *et al.* [20], in a study he was using AHP to analyse the selection of cranes, Debmallya Chatterjee *et al.* [21] also using AHP as a method of decision-making in the selection of the best banks in India. While Fashiar [22], applying a multi-criteria AHP on an ergonomic approach, to select the best material heandling.

Nowdays, so many researchers are trying to combine the AHP method with other methods to solve problems. Thus, many studies created a combined AHP with different versions and the studied problems also varied. Merging is done in order to achieve better results. Merger is also done for developing the models of the AHP method. Yusuf [23], has been combining AHP with Goal Programming Program as a model to determine the best supplier. Meanwhile, Rezaie *et al.* [10], combined AHP with DEA (Data Envelopment Analysis) to determine ranking of the intelligence of parameters for people with epileptic. In addition, another example for the development of the AHP method, such as Hidayat *et al.* [24] which uses a model FAHP (Fuzzy Analytic Hierarchy Process) to identify risks and develop strategies of the palm oil supply chain. The investigation of this model is used to determine the interest rate risk to the supply chain actors.

In the development of AHP, it is still rarely used for decision-making in the field of production planning, especially in Malaysia. This paper is intended to introduce the AHP model in the production planning to be applied in Malaysia. Many production problems can be solved by the AHP model, such as production problems that caused a decrease in the amount of production. By using AHP, priority of the factors that influence it will be sought, so it can look for the appropriate solutions to minimize their impact. To obtain a rational decision by using AHP, basically there are several steps that need to be considered using this method, among others:

1. Defining the problem and determining the desired solution.
2. Creating a hierarchical structure that begins with a general purpose, followed by the criteria and sub-criteria.
3. Establishing pairwise comparison matrix that describes the relative contribution or influence of each element on each level objectives or criteria above. Comparisons are made based on the judgment of a choice or decision-makers by assessing the level of interest of an element compared to other elements.
4. Normalising the data by dividing the value of each element in the matrix paired with a total value of each column.
5. Calculating eigenvalues vector and tested for consistency, if not consistent then the data (preferences) should be repeated.
6. Repeating steps 3, 4, and 5 for the entire level of the hierarchy.

7. Calculating eigenvector of each pairwise comparison matrix. Eigenvector value is the weight of each element. This step synthesizes choice and prioritization of the elements at the lowest level of the hierarchy to the achievement of objectives.
8. Test the consistency of the hierarchy. If it does not comply with CR <0.1, the assessment should be repeated again.

To determine the factors that affect the priority of the decline in production quantities, the first thing to identify is the criteria for the study from literature or to find out directly from the company. From the conducted literature study, there are two types of factors found: internal and external. The internal factors are divided into capital, labour, technology, and raw materials. While external factors such as inventory, suppliers and market demand. The next step is to create a hierarchical structure. In the hierarchical structure it is necessary to determine the goal you want to target, criteria and sub-criteria, such as:

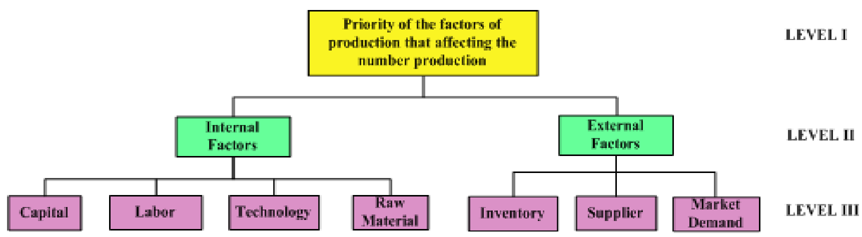

Figure 1. The concept of hierarchical problem solving priority factors of production

Explanation :
Level I : Goal
Level II : Criteria
Level III : Sub-criteria

After creating the hierarchy, the next step is to create a questionnaire with the goal is to determine the respective interests of the top level then performed pairwise comparisons between criteria and sub-criteria. Questionnaires were distributed to a sample that is usually a team of managerial and production manager of the company who knows quite well the ins and outs of production of the company. Scale used by Saaty scale, such as:

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An Activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highst possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	when compromise is needed
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compered with i	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table 2. Saaty scale pairwise comparisons [30]

The next step after getting the results from the questionnaire is to establish a comparison matrix such as:

	A_1	A_2	...	A_n
A_1	1	a_{12}	...	a_{1n}
A_2	a_{21}	1		a_{2n}
⋮	⋮	⋮	⋱	⋮
A_{n1}	a_{n1}	a_{n2}	...	1

Figure 2. Pairwise Comparison Matrix [30]

A n×n matrix is a reciprocal matrix, which is assumed that there are n elements w_1, w_2,. . . , wn that make up the comparison. Values are pairwise comparisons between w_i, w_j presented in a matrix w_i, $w_j = a_{ij}$ with i, j = 1, 2, 3, ..., n while the value of a_{ij} is the value of the comparison matrix that reflects the value of the respective interests of A_i to A_j in order to obtain the matrix normalized. Value of $a_{ij} = 1$, for i = j (diagonal matrix has a value of 1), or if the operating elements of A_i with A_j have the same interest rate, the value of $a_{ij} = a_{ji} = 1$. When the elements of the weighting vector operations expressed by W, with W = (w_1, w_2, ..., w_n) then, the intensity of the interests of the operating elements A_1 to A_2 is = a_{12}, so the pairwise comparison matrix can $\frac{w_1}{w_2} = a_{12}$, so the comparison matrix pairs can be expressed as follows:

	A_1	A_2	...	A_n
A_1	w_1/w_1	w_1/w_2	...	w_1/w_n
A_2	w_2/w_1	w_2/w_2		w_2/w_n
⋮	⋮	⋮	⋱	⋮
A_n	w_n/w_1	w_n/w_2	...	w_n/w_n

Figure 3. Pairwise Comparison Matrix [30]

After getting the results of pairwise comparisons, then the next step is to normalize the data. Normalization of data is done by the following formula:

a. Summing the values of each column in the pairwise comparison matrix, the total value of the column is denoted by S_{ij}

$$S_{ij} = \left(\sum_{i=1}^{n} a_{ij}\right) \quad (1)$$

Explanation:
S_j = Total value of the column
a_{ij} = Element in row i and column j
i, j = 1, 2, 3..n

b. Dividing the value aij in each column with the number of values in a column, the result of the division is denoted by VE_{ij}

$$\left(VE_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right) \quad (2)$$

Explanation :

VE_{ij} = Normalized Comparison Matrix Pairewise

S_j = Total value of the column

a_{ij} = Element in row i and column j

i, j = 1, 2, 3..n

c. Calculating the relative priority vector of each criterion by summing all the values of each row of the matrix has been normalised and dividing by the number of elements of each row i. Priority criterion i is denoted by P_{ij} matrix has been normalized and denoted by M_i.

$$P_{ij} = \sum_{i=1}^{n} \frac{M_i}{n} \quad (3)$$

Explanation :

P_i = Value Eigenvector Normalisation (Factor Priority)

M_i = Number of rows matrix normalisation

n = Number of factors / criteria

Eigenvector value is the weight of each element. This step synthesises choice and prioritisation of the elements at the lowest level of the hierarchy to the achievement of objectives. If it is known elemental ratios A_i with A_j is then theoretically the matrix characterised by positive reverse, ie $a_{ij} = 1 / a_{ij}$. The weights is expressed in vector $w = (w_1, w_2, w_3, \ldots, w_n)$. W_n value stating the weights criteria of A_n entire set of criteria on the subsystem. If a_{ij} represents the degree of the interest factor i to factor j, and the degree of interest expressed a_{ik} of factor j on factor k, then the decision to be consistent, the interests of the k i factor, must be equal to $a_{ij} \cdot a_{jk}$ or if $a_{ij} \cdot a_{jk} = a_{ik}$ for all i, j, k. For a matrix to be consistent with the vector w, then a_{ij} element can be written as:

$$a_{ij} = \frac{w_i}{w_j} \; ; i, j = 1, 2, 3, \ldots, n \quad (4)$$

so the consistency matrix is:

$$a_{ij}.a_{jk} = \frac{w_i}{w_j} . \frac{w_j}{w_k} = \frac{w_i}{w_k} = a_{jk} \quad (5)$$

from equation (5) above, it can be decomposed into:

$$a_{ij} = \frac{w_i}{w_j} = \frac{1}{w_j / w_i} = \frac{1}{a_{ji}} \quad (6)$$

from equation (6) the following equation can be obtained:

$$a_{ij} = \frac{w_j}{w_k} = 1 \quad (7)$$

Thus for the consistent pairwise comparison matrix the equation is as follow:

$$\sum_{i,j=1}^{n} a_{ij} \cdot w_{ij} \cdot \frac{1}{w_{ij}} \; n \; ; i, j = 1,2,3, \ldots, n \quad (8)$$

$$\sum_{i,j=1}^{n} a_{ij} \cdot w_{ij} = n w_{ij} \; ; \; i, j = 1,2,3, \ldots, n \quad (9)$$

The above equation is equivalent to the matrix equation below:

$$A \cdot w = n \cdot w \quad (10)$$

In matrix theory, this formulation was expressed as w is the eigen vector of the matrix A with eigenvalues n. Note that n is the dimension of the matrix itself. In the form of a matrix the equation can be written as follows:

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

But in practice it can not be guaranteed that:

$$a_{ij} = \frac{a_{ik}}{a_{jk}} \qquad (11)$$

Mulyono (2004: 337-338) states if aij not based on the exact size as $w1,w2,w3,\ldots,wn$ but on subjective judgement, then aij will deviate from the real ratio of wi/wj and consequently $Aw=nw$ cannot meet again. But the matrix theory can provide convenience in two ways:
First, if $\lambda = \lambda_1,\lambda_2,\lambda_3,\ldots,\lambda_n$ are number that satisfy the equation $Aw=\lambda w$, where λ is eigenvalue of matrix A, and if $a_{ii}=1$ for i, then :

$$\sum_1^n \lambda_i = n \qquad (12)$$

If $Aw=\lambda w$ fulfilled, then all eigenvalue equal to zero value, except the *e*igenvalue is valued at n. So obviously in the case of consistency, n is the largest eigenvalue.

Secondly, if one a_{ij} reciprocal of the matrix A change very little, then the eigenvalue also will change very little accordingly. The combination of the two explains that if A diagonal matrix, consisting of $a_{ij}=1$ and if A consistent, then a small change in a_{ij} hold the largest eigenvalue λ_{maks} close to n, and the remaining eigenvalue close to zero. If A is a pairwise comparison matrix, then to obtain a priority vector, w has to looked for that satisfies.

$$Aw=\lambda_{maks}.w \qquad (13)$$

The next step is to calculate the pairwise consistency of assessment which has been done. The consistency of the pairwise assessment can be evaluated by calculating Consistency Ratio (CR). Saaty set if the CR value less than or equal to 10% (CR ≤0.1) then the result assessment is said to be consistent. The formulation to calculate is:

$$CR = \frac{CI}{RI} \qquad (14)$$

Where, CI = Consistency Index (consistency index) and RI = Random Consistency Index.
CI values using the formula:

$$CI = \frac{(\lambda max - n)}{(n-1)} \qquad (15)$$

λ_{max} is the maximum value of the matrix eigenvalue n. Maximum eigenvalues obtained by summing the results of the comparison matrix multiplication with the main eigenvector (priority vector) and dividing by the number of elements. CI values would be meaningless if there is no reference to whether the CI matrix showed a consistent or inconsistent. Saaty provided a reference sample of 500 pieces of random matrices, with a 1-9 ratio, for some order matrix. Saaty [13], to get the average value of the Random Index (RI) as follows:

Size of Matrix	Random Consistency
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table 3. Nilai Random Index (RI) [31]

If the resulting value is consistent, then this means that all of the elements have been grouped homogeneously and the relation between each criterion has been logically justified, then the next value arranged from the highest to the lowest sequence. The factor with the highest value can be said to be a factor that needs to be prioritised.

3. **Fuzzy Inference System Tsukamoto**

Fuzzy Logic is an area of soft computing that enable a computer system to reason with uncertainty. Fuzzy logic was first introduced by Lotfi A. Zadeh in 1965. Basic Fuzzy Logic is the theory of fuzzy sets. In fuzzy set theory, the role of the degree of membership as a determinant of the presence of elements in a set is very important. Degrees of membership function as a major characteristic of the fuzzy logic reasoning. In many ways, fuzzy logic is used as a way to map the problem of inputs leading to the expected output. For instance, warehouse manager told the production manager how much inventory at the end of this week, then production manager will set the number of items that must be produced tomorrow [34]. One example of an input-output mapping in graphical form as shown in Figure 1.3

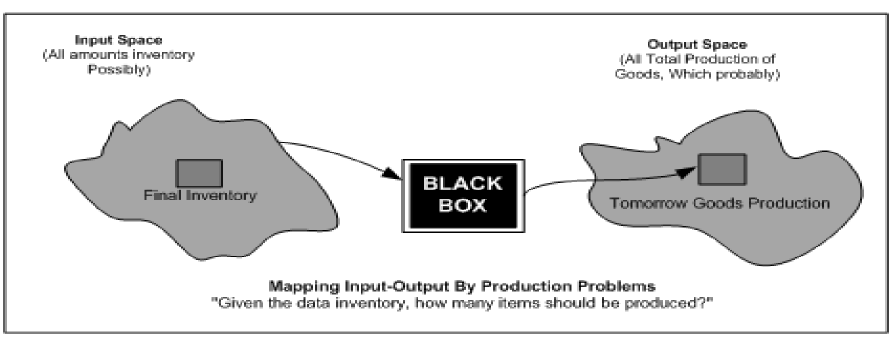

Figure 1.3 Examples of Input-Output Mapping adapted from [35]

Fuzzy logic can be considered as a black box that connects the input space to output space.The black box contains a way that can be used to process data inputs into outputs in the form of good information. One application of fuzzy logic that has grown very broad today is a fuzzy inference system (Fuzzy Inference System/FIS), the computing system that works on the principle of fuzzy reasoning, reasoning like humans do by instinct. For example, the determination of the production of goods, decision support systems, data classification systems, expert systems, pattern recognition systems, robotics, and so on.

Tsukamoto method first introduced by Tsukamoto, 1979, which is one of the methods of decision-making. This method applies to any used monotone reasoning rule, the intention is to use the system with only one rule. The implications of each rule in the form of implications "Cause and Effect" or Implications "Input-Output" in which the antecedent and the consequent has to be related. Each rule is represented using fuzzy associations, with monotonous membership function. Then, to determine the outcome of a firm (Crisp Solution) is used with formulas assertion (defuzzyfication) called "centered average method".

There are 3 steps in using the Tsukamoto method:

1. Fuzzification
2. Inference
3. Defuzzyfication

   This formulation is to determine the crisp output value that will be the number of goods produced (Z), by changing the input (in the form of fuzzy sets derived from the composition of fuzzy rules) into a number of fuzzy sets in the domain. This is the centered average method equation :

$$Z=\frac{\sum_{i=1}^{n} \alpha i z i}{\sum_{i=1}^{n} \alpha i} \quad (16)$$

From the literature study, there are still a few researchers who apply this method for production planning. The few researchers who apply this method is Ginanjar [39]. He applied the Tsukamoto method in the decision support system to determine the amount of production of goods. Tsukamoto method is used to optimise the production number by looking at the data demand, inventory and production of canned food in the month of January 2010 from the results of the calculation method of Tsukamoto, the amount of production is 4500, while the production on the 20th day is of 3000 package only, so the company will experience a shortage of 1500 production of packaging, while inventory at day 20 only 473 packs. Thus on the 20th day of 1027 the company still lack of packaging. This is certainly going to hurt the company, because if the company can not meet the demand of consumers, then consumers are not satisfied with the service of the company and can cause a bad image for the company Then, the research conducted Firmansyah & Firda, similar to that done Ginanjar is to optimise the number of items to be produced. But the studied products are medicine. The results of this study can help the enterprise's production planning and control.

4. Conclusion and Future Research

Problems that often arise in production planning is dominated by the factors of production itself, either from internal factors and external factors. On each of these factors, uncertainty and ambiguity often occur in the processing stage. To reduce the uncertainty in production planning, many researchers have tried to solve this problem. Most of the previous studies focused on the factors of production factors such as labour and so on. Among the factors of production, it is closely related to one another and are equally important in realising the company's production goals. So far there have not been studies that measure the interests among these factors. In accordance with the objective of this study, AHP is introduced as a method which can help measure interest among these factors by determining the order of priority of these factors. This method has been widely used for prioritization and has been proved flexible to complex problems.

In addition, the problem of uncertainty which is no less important in the production, is the uncertainty of the amount of production. Some cases of uncertainty has been successfully sought for a solution by previous researchers. One of the methods used, are fuzzy method which is known as a method that can resolve the problem of uncertainty and ambiguity. Uncertainty problem is complex because of the number of production usually occurs due to the production manager at a loss to determine the amount of production that is due to the uncertainty of other factors such as the amount of inventory and raw materials. Based on the second objective which is to introduce the Tsukamoto FIS method as a method that can help to resolve the problem of uncertainty. This method can resolve uncertainty by using fuzzy sets. This method is very simple but very effective. This method is still rarely used and applied by researchers to solve production problems. Expected outcome from this paper is to put the attention back on this method while developing and apply it to the production line.

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