A framework for multiple-criteria sequencing problems

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Abstract- This study considers a sequencing problem with multiple criteria. These criteria include quantitative and qualitative data. In this paper the sales and the production departments of the studied company wish to emphasize specific viewpoints or certain combinations of criteria. As a result of different job sequences may produce. The sales department presents an analytic hierarchy process technique to identify the most-preferred sequence. On the contrary, the production department uses the shortest processing time approach to generate a sequence with the lowest production cost. Based on these different sequences, a weighting method is developed to combine these sequences and to estimate their criterion weights so that we can obtain a rational sequence. The proposed method is conceptually easy and can be used to solve large-sized problems. Currently, the developed method is implemented in the studied company, and it reports a satisfactory result.

Keywords: Sequence, Weight, Criteria, Quantitative, Qualitative

1. Introduction

A weighting method is an approach to determine the weights of sequencing jobs. Its principle ideal is based on the fact that when a decision maker considers a multiple criteria sequencing problem, certain viewpoints or criteria will be emphasized, and therefore, several preferred job sequences may be generated. To illustrate this approach, let us consider the problem of sequencing a set of jobs with multiple criteria for a textile company. The company's salesman receives orders from different customers. An order is composed of one or several jobs, each containing a request to produce a product with a given type. How to sequence these jobs is very difficult when certain different viewpoints are involved. In the studied company, the sales department is more concerned with the performance of an order in terms of customer relationship, order quantity, earned profit and payment method. The production department is more concerned with the performance of this order in production cost. These different viewpoints may result in different criteria, and thereby different job sequences are constructed. On the basis of different sequences being created, we develop a weighting method to consolidate these different sequences, and estimate their criterion weights so that we can produce a rational sequence.

In the past our decisions on sequencing jobs were often biased because we considered only on those criteria that could be expressed in numeral values. Managers faced with sequencing jobs can no longer rely on traditional measures because so many qualitative criteria are not considered. In this study these criteria can be classified as quantitative or qualitative. Quantitative criteria can be measured in physical terms and can be presented in numeral values. In a sequencing problem, quantitative measures of performance include completion time, flow time and tardiness. In contrast, qualitative criteria cannot be measured in physical terms. These measures include customer relationship and payment method for each order job

After discussing the criteria of sequencing problem, the production department will apply the shortest processing time (SPT) approach to reduce the production cost. The details will be discussed in the later section of the SPT approach. However, the sales department has determined that only four criteria are really important to the department. They are customer relationship, order quantity, earned profit and payment method. The sales department has to decide on the trade-off between these criteria. In this paper, the analytic hierarchy process (AHP) technique is used in order to present managers with a set of choices so that they can decide on the trade-off. From the practical viewpoint, there are two reasons that the AHP technique can be adopted. First, it can be used in decision making for ranking jobs based on quantitative and qualitative criteria. Second, the sales department can easily derive a preferred sequence in a short time by running the AHP-based software "Expert Choice" (Forman and Saaty, 1991).

In the literature, there are some researches applying the AHP technique to solve problems. Balubaid and Alamoudi (2015) examined the use of the analytical hierarchy process as a decision-support model for contractor selection. This model can assist project management teams in identifying contractors. Mahapatra et al. (2015) presented a unique approach of combining Data Envelopment Analysis and Analytic Hierarchy Process for evaluating the performance of an organization. Srichetta and Thurachon (2012) used the fuzzy analytic hierarchy process in determining the relative importance of the decision criterion in order to eventually select the best product of notebook computers. Norris (1992) employed the AHP to evaluate six just-in-time techniques for improving manufacturing efficiency. Muralidhar et al. (1990) presented the AHP to select a computer operating system. Zeki (2002) applied the AHP for the evaluation of the hardware and software components for a computer-aided system. Chan (2003) used the AHP to select the best possible suppliers. Cambron and Evans (1991) applied several layout design algorithms to generate candidate layouts. These candidates were evaluated by using the AHP. Mohammad and Ashraf (2003) employed the AHP for the selection of a manufacturing system among feasible alternatives based on the RMS (Reconfigurable Manufacturing System) study. Leung et al. (1992) considered a manufacturing problem and presented the AHP for evaluation of expert system. Arbel and Seidmann (1984) directly used the AHP to evaluate a flexible manufacturing system. Canada and Sullivan (1989) proposed the AHP to sample manufacturing investment decisions. Andijani and Anwarul (1997) provided the AHP to determine the most-preferred allocation with respect to the three conflicting objectives. Weber (1993) modified the AHP procedure for a manufacturing environment and applied it to decide the best way to automate a machine shop.

In all the above paper, the AHP technique can be used to select the best alternatives. In this study, the most-preferred sequence can be achieved by applying the AHP for the sales department. For completeness, we briefly explain the AHP technique in the next section.

2. The AHP technique

One of the most useful approaches for deciding weights of criteria is the AHP, which was developed by Saaty (1980). The AHP technique is a robust and flexible multi-criteria decision analysis methodology. The first step of this approach is to formulate a decision problem in a hierarchical structure. The hierarchy should be constructed so that elements at the same level must be related to some or all elements in the next higher level. In a typical hierarchy, the top level reflects the overall objective of the decision problem. The elements in the intermediate levels may affect the decision. The lowest level comprises the decision options. This type of hierarchy provides a simple illustration of all the factors affecting the decision and their relationships. Prioritizations of elements in each level are pairwise compared with their importance in making the decision. The pairwise comparisons made by the decision maker are assigned numerical values based on the 1 to 9 scale recommended by Saaty (1986). These comparisons represent a ratio of the weight assigned to one alternative versus the weight assigned to another. An important property we would like each pairwise comparison matrix to possess is consistency. A common practice shows that the consistency ratio (C.R.) less than or equal to 0.1 is acceptable. If the C.R. value is greater than 0.1, the pairwise comparison matrix may contain some contradictory information. A few pairwise comparisons may need to be adjusted by a decision maker to make the judgments more consistent. Employing the AHP technique on a pairwise comparison matrix returns the weights needed to determine the final alternative rankings. The total weight assigned to an alternative can be found by tracing the paths that lead from the goal down to the alternative, multiplying the weights of the branches in the path to determine the weight of the path, and adding these path weights together.

Example 1. As an illustration of the AHP technique, consider a sequencing problem with four orders and four criteria (i.e., customer relationship, order quantity, earned profit and payment method). Assume that each order consists of one job. The AHP model for the problem is given in figure 1. The comparison matrix is shown in table 1. The preferences for alternative jobs with respect to the criteria are presented in tables 2-5.

In table 1, we summarize the column values. These sum values for customer relationship, order quantity, earned profit and payment method are 8.53, 11.33, 1.40 and 18.00, respectively. The normalized relative weight on customer relationship versus customer relationship is $(1/8.53) = 0.117$. The normalized relative weight on customer relationship versus order quantity is $[(1/3)/8.53]$ which is equal to 0.039. Following the same procedure, we can obtain the normalized relative weights shown in table 6. In the table we can compute the average weight of each row. Further, $C.R. = 0.014$ is generated by applying the AHP technique. The consistency ratio tells us that there is no need to reevaluate the pairwise comparison responses. Using the data in tables 2-5, we also calculate the normalized relative weights as done above for the goal in table 6. Finally, we calculate the normalized relative weights to produce the average of the rows in each criterion. Selecting the average of the rows in each criterion, a matrix A is generated. The matrix A is computed as follows:

$$A = \begin{bmatrix} 0.261 & 0.219 & 0.219 & 0.300 \\ 0.087 & 0.094 & 0.094 & 0.325 \\ 0.049 & 0.094 & 0.094 & 0.325 \\ 0.603 & 0.594 & 0.594 & 0.051 \end{bmatrix}.$$

Recall that the average of the rows for the goal in table 6 have been produced. Generate a matrix B by selecting the average of the rows for the goal. The matrix B is shown as follows: $B = \begin{bmatrix} 0.190 \\ 0.099 \\ 0.663 \\ 0.047 \end{bmatrix}$.

Now, the decision matrix ($A \times B$) can be constructed as follows: $A \times B = \begin{bmatrix} 0.231 \\ 0.103 \\ 0.096 \\ 0.570 \end{bmatrix}$.

According to the weights of the decision matrix, the most-preferred sequence (Job 4, Job 1, Job 2, Job 3) is produced.

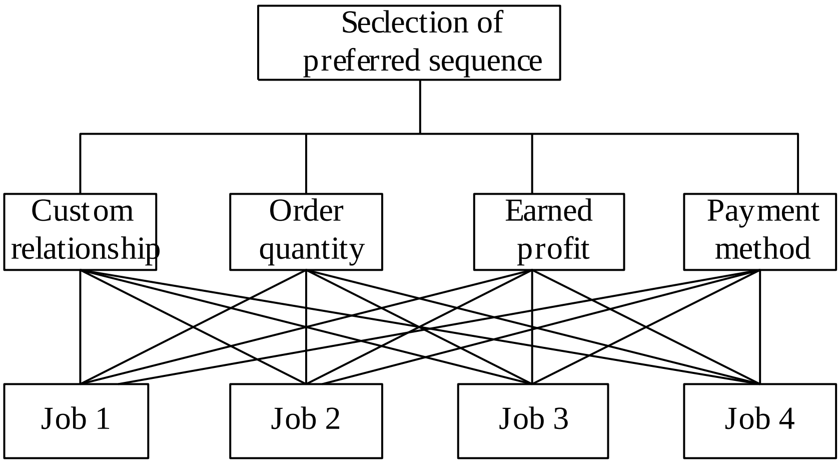

Figure 1. AHP sequencing model.

Table 1. Comparison of criteria with respect to goal.

	Customer Relationship	Order Quantity	Earned Profit	Payment Method
Customer Relationship	1	3	1/7	5
Order Quantity	1/3	1	1/7	3
Earned Profit	7	7	1	9
Payment Method	1/5	1/3	1/9	1

Table 2. Performance of alternatives with respect to customer relationship.

	Job 1	Job 2	Job 3	Job 4
Job 1	1	5	5	1/3
Job 2	1/5	1	3	1/9
Job 3	1/5	1/3	1	1/9
Job 4	3	9	9	1

Table 3. Performance of alternatives with respect to order quantity.

	Job 1	Job 2	Job 3	Job 4
Job 1	1	3	3	1/5
Job 2	1/3	1	1	1/5
Job 3	1/3	1	1	1/5
Job 4	5	5	5	1

Table 4. Performance of alternatives with respect to earned profit.

	Job 1	Job 2	Job 3	Job 4
Job 1	1	3	3	1/5
Job 2	1/3	1	1	1/5
Job 3	1/3	1	1	1/5
Job 4	5	5	5	1

Table 5. Performance of alternatives with respect to payment method.

	Job 1	Job 2	Job 3	Job 4
Job 1	1	1	1	5
Job 2	1	1	1	7
Job 3	1	1	1	7
Job 4	1/5	1/7	1/7	1

Table 6. The normalized relative weights with respect to goal.

	Customer Relationship	Order Quantity	Earned Profit	Payment Method	Average
Customer Relationship	0.117	0.265	0.102	0.278	0.190
Order Quantity	0.039	0.088	0.102	0.167	0.099
Earned Profit	0.820	0.618	0.716	0.500	0.663
Payment Method	0.023	0.029	0.080	0.056	0.047

Table 7. The processing times for the jobs in Example 1 (in weeks).

	Job 1	Job 2	Job 3	Job 4
Processing time	4	1	2	3

3. The SPT approach

Most papers in the scheduling field use the SPT rule to minimize the total flow time, which leads to rapid turnover of all jobs, reduces in-process inventory and decreases utilization of resource. Therefore, the production department applies the SPT approach to reduce the production cost. To illustrate this approach, the following example is given.

Example 2. In table 7 we consider a sequencing problem with the same jobs in Example 1.

Using the SPT approach, the production department creates the job sequence (Job 2, Job 3, Job 4, Job 1).

4. Development of the weighting method

A weighting method is developed to calculate the weights of jobs in two sequences. Its principle ideal is based on the fact that when a decision maker considers a multiple criteria sequencing problem, certain criteria will be emphasized, and therefore, different job sequences may be generated. Suppose a job in one sequence has a weight indicating its priority. The priority of the job in this sequence may different from that in another sequence. For example, Job 4 is sequenced in the first position in Examples 1 and it is sequenced in the third position in Example 2. Since the two sequences have the same set of jobs, the calculated weight of each job can be generated by using the proposed method. Denote by k a combination parameter of two sequences for identifying which sequence is more important, where $0 \le k \le 1$. Let n be the number of jobs for sequencing. Now, the steps of the weighting method can be outlined as follows:

Step 1: Let S be the job sequence obtained from the sales department. Let S' be the job sequence obtained from the production department. If S is equal to S', stop. Otherwise, go to Step 2.

Step 2: Denote by α_i and α_i' the weights of the ith position job in S and S', respectively. Set $j = 1$.

Step 3: Denote by w_j the calculated weight of job j. Let job j in S be placed in position l and the job in S' be placed in position m. Set $\alpha_l = n - l + 1$ and $\alpha_m' = n - m + 1$. Compute $w_j = k\alpha_l + (1-k)\alpha_m'$.

Step 4: Set $j = j + 1$. If $j = n + 1$, go to Step 5; otherwise, return to Step 3.

Step 5: Rearrange all jobs in the descending order of the calculated weights. If two jobs have the same calculated weight, place the job with more important criteria in the front. Stop.

Example 3. Assume that $k = 0.7$. Applying the weighting method to the same data as in Examples 1 and 2 yields the following results:

In Step 1, the two sequences are $S =$ (Job 4, Job 1, Job 2, Job 3) and $S' =$ (Job 2, Job 3, Job 4, Job 1). Applying Step 3, the weights of Job 1 in S and S' are $\alpha_2 = 4 - 2 + 1 = 3$ and $\alpha_4' = 4 - 4 + 1 = 1$ respectively. So, we calculate $w_1 = 0.7 \times 3 + (1 - 0.7) \times 1 = 2.4$. Following the same procedure, we have $w_2 = 0.7 \times 2 + 0.3 \times 4$ =2.6, $w_3 = 0.7 \times 1 + 0.3 \times 3 = 1.6$ and $w_4 =$ $0.7 \times 4 + 0.3 \times 2 = 3.4$. In Step 5, the final sequence is (Job 4, Job 2, Job 1, Job 3).

5. Discussion

In this paper we consider a sequencing problem with multiple criteria. The problem differs from that of other sequencing problems in that both quantitative and qualitative criteria are under consideration. In our research, we emphasize the specific criteria or certain combinations of criteria. As a result of these different criteria approaches, different sequences may result. We want to derive a procedure to combine these sequences so that we can obtain a rational sequence. No previous work has examined this problem directly. Therefore, there is a need to develop sequencing method to solve the problem.

In this study the sales department considers the problem with multiple criteria, which include quantitative and qualitative data. How to solve this problem is very difficult. The AHP technique is a popular tool used in decision making for ranking alternatives based on quantitative and qualitative criteria. It is utilized to identify the preferred sequence. On the other hand, the production department applies the SPT approach to find a sequence with the smallest total flow time. The total flow time decreases as the inventory level decreases. Therefore, the production cost will be lowered. Based on these different sequences, we develop a new weighting method to combine these sequences and to estimate their criterion weights so that we can obtain a rational sequence. It is noted that the purpose of this paper is not to develop complicated algorithms, but to provide a solution to different criteria faced by a decision maker. In this paper the selection of k value is determined by the decision maker. If $k = 1$ or 0, one sequence is completely ignored. Therefore, the selection of k value is an important issue. The weighting method also gives added insights into the analysis of the problem. It is very useful in aiding the decision maker to understand the outcome from different criteria. The weighting method is a very versatile methodology with applications in many practical fields, for example, alternative selection, project selection, performance measurement, etc. The proposed method is conceptually easy and can be used to solve large-sized problems. Recently, the method was implemented in the studied company, and it has reported a satisfactory result. However, the weighting method presented in this paper is appropriate not only for this company, but also for those companies where certain different criteria are involved. In the near future, we will try to improve our method by considering some other factors encountered in the company.

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一個多準則排程問題之架構

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摘要

本研究考慮一個多準則的排程問題，這些準則包含了定量與定性的資料。在本文中，我們所研究的公司銷售與生產部們期望能專注在自己特殊的觀點或合併一些準則，這樣可能導致於不同工件的排序。銷售部門提供一種層級分析法來說明這是最佳的排程。相反的，生產部門使用最短處理時間的方法來產生最低生產成本的排程。根據這些不同的排程，我們發展出一種全重法來合併這些排程，同時去估計這些準則的全重，這樣我們就可得到較合理的排程。本文提供的方法是一種簡單的概念，並且可用來解決較大型的問題，目前此方法已經在本研究公司實施，並且報告得知還有一個滿意的結果。

關鍵字：排程，權重，準則，定量，定性。