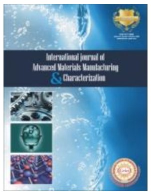

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Evaluation of Metal Strip-Layout Selectionusing AHP and TOPSIS Method

Chittaranjan Das.V[1], Srinivas. C[2]

[1&2]Dept. of Mechanical Engineering, RVR & JC College of Engineering, Guntur - 522 019, A.P.

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A B S T R A C T

Stamping dies are used to produce very large numbers of identical parts from sheet metal. Due to the high volumes of parts produced, even small inefficiencies in material utilization per part can lead to very large amounts of wasted material over a die's life . Strip-layout design is an important step in the planning stage of sheet metal work on metal stamping. It is an experience-driven activity and the quality of strip-layout is highly dependent on the knowledge and skill of die designers. However, due to the complexity in strip-layout, it is impossible to judge the efficient layout manually by the designer. This paper presents a strip-layout selection procedure pertaining to metal die stamping work in complex layout situations. The procedure is based on a combined TOPSIS and AHP method. The proposed Strip layout index helps to evaluate and rank of any given set of strip-layout alternatives for a given engineering design. The procedure is illustrated by means of an example.

Introduction

During the design process for stamping dies, decisions must be made about the orientation of the stamped part on the strip. The orientation determines how efficiently raw material is utilized, and in an operation such as stamping where large amounts of material are processed, small inefficiencies per piece can accumulate into huge wastes of material in the long term. In stamping, sheet metal parts of various levels of complexity are produced rapidly, often in very large volumes, using hard tooling. Maximizing material utilization in stamping is of paramount importance. Raw materials typically represent 75% or more of total costs in stamping facilities, [1] so a poorly designed die can significantly increase a company's operating costs over its life. Due to the high volume of parts produced, even small inefficiencies in material utilization per part, can lead to very large amounts of wasted material over a die's life. Hence, the choice of an efficient strip-layout is an important step during die design, because as only the optimum layout can reduce wastage of the strip material and reduce the overall cost of production.

- Corresponding author: Chittaranjan Das
- E-mail address: vcd2k2@yahoo.co.in
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Traditional strip-layout design is manual, highly experience-based activity and therefore tedious, time consuming and error-prone [2-3]. The blanks cutting from cardboard were manipulated to obtain a good strip-layout. This trial and error procedure of obtaining suitable strip-layout with maximum material utilization is still being used in most of the small scale and even in some medium scale sheet metal industries worldwide. The quality of strip-layout achieved by using traditional methods depends on the experience and knowledge of designers. On the advent of computer aided design (CAD) systems, the process of strip-layout design was somewhat made easier and the design lead-time was reduced. However, well-trained and experienced die designers were still required to operate these CAD systems. Most of the applications of CAD in strip-layout design are aimed mainly at achieving better material utilization by rotating and placing the blanks as close as possible in the strip. However, the strip-layout with maximum material saving may not be the best strip-layout, indeed the die construction may become more complex, which could offset the savings due to material economy unless a large number of parts are to be produced. The system developed by Schaffer [4] reported to calculate the stresses due to bending moment on cantilevered die projections and if the system finds that the stress level is above the yield stress of die steel material, then the system distributes the cutting operations over several stages in order to keep the stresses within the reasonable limit. One of the limitations of the system is that it does not give any importance to the complexity of die and punches during staging of operations. Adachi etc.[5]developed an integrated CAD system for design of progressive die. The system outputs also include generation of strip-layout for progressive die. But the user has to specify the sequence of operations himself to obtain the strip-layout. Nee[6-7] developed some experimental packages for analysis on press capacity, the use of coiled or strip stock and cost factors in order to solve for near-optimum layout and nesting problems for both sheet metal and metal stamping blanks. All of his work focused on the general strip-layout design process and the expert rules involved do not tackle other stamping operations such as piercing, bending, forming, etc. The system developed by Duffy and Sun [8] used knowledge-based system approach to generate strip-layout for progressive stamping dies. The system was implemented in IDL, which is a knowledge-based system language. The system has the capability to generate strip-layout; however, it has not been implemented and its capabilities in real life have not been tested. The Computer Aided Die Design System (CADDS) developed by Prasad and Somasundaram [9] also has one module for the strip-layout for progressive die. In this module, the die type is selected, depending on the input parameters. If the selected die is progressive, strip development is subsequently carried out according to the rules incorporated in the strip-layout module. But the major limitation of the system is that it supports mainly blanking and piercing operations. Singh and Sekhon [10] developed a low cost modeller. Even though a good amount of research work was carried out in the past on strip layout , there is a need for a simple, systematic and logical scientific method or mathematical tool to guide user organizations in taking a proper strip layout selection decision. The objective of a strip layout selection procedure is to identify the strip layout selection attributes and obtain the most appropriate combination of strip layout selection attributes in conjunction with the real requirement. Thus, efforts need to be extended to determine attributes that influence strip layout selection, using a simple logical approach, to eliminate unsuitable strip layout to strengthen the existing strip layout selection procedure. This is considered in this paper using a combined multiple attribute decision making method.

Multiple attribute decision

Making (madm) methods

The multiple attribute decision making (MADM) refers to an approach of problem solving that is employed to solve problems involving selection from among a finite number of alternatives. An MADM method is a procedure that specifies how attribute information is to be processed in order to arrive at a choice. The methods of MADM include, weighted sum method (WSM), weighted product method (WPM), technique for order preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP),ELECTRE, etc. Of these methods, TOPSIS and AHP are more widely used decision making methods. Both TOPSIS and AHP are logical decision making approaches and deal with the problem of choosing an alternative from a set of candidate alternatives which are characterized in terms of some attributes [11-15]. The TOPSIS technique is based on the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution. The ideal solution is a hypothetical solution for which all attribute values correspond to the maximum attribute values in the database comprising the satisfying solutions; the negative-ideal solution is the hypothetical solution for which all attribute values correspond to the minimum attribute values in the above-mentioned database. TOPSIS, thus, gives asolution that is not only closest to the hypothetically best, but which is also farthest from the hypothetically worst. The analytic hierarchy process (AHP) is a powerful and flexible decision making process to help people set priorities and make the best decision when both tangible and nontangible aspects of a decision need to be considered. By reducing complex decisions to a series of one-on-one comparisons, then synthesizing the results.

Methodology

The main procedure of the combined TOPSIS and AHP method is as follows:

Step 1:Determine the objective and evaluation attributes. In the present case, short-list the strip layout on the basis of the attributes satisfying the requirements.

Step 2: Formulate a decision matrix with each alternaitve as a row and each column to one attribute. Therefore, an element d_{ij} of the decision matrix "D" gives the value of the j_{th} attribute in original real values, that is, non-normalized form and units, for the i_{th} alternative. Thus,if the number of alternatives is "M" and the number of attributes in "N", then the decision matrix is an M×N matrix can be represented as:

$$D_{MXN} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \cdots \\ \cdots \\ M \end{array} \begin{array}{c} Attribute\,1 \quad 2 \quad 3 \quad \ldots \quad \ldots \quad N \\ \begin{bmatrix} d_{11} & d_{12} & d_{13} & \ldots & \ldots & d_{1N} \\ d_{21} & d_{22} & d_{23} & \ldots & \ldots & d_{2N} \\ d_{31} & d_{32} & d_{33} & \ldots & \ldots & d_{3N} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ d_{M1} & d_{M2} & d_{M3} & \ldots & \ldots & d_{MN} \end{bmatrix} \end{array} \quad (1)$$

Step 3: Obtain the normalized decision matrix, R_{ij}. This can be represented

$$R_{ij} = \frac{d_{ij}}{\left\{\sum_{j=1}^{M} d_{ij}^2\right\}^{0.5}} \qquad (2)$$

Step 4: 1. Find out the relative importance of different attributes with respect to the objective. To do so, one has to construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of the analytic hierarchy process [14,15]. An attribute compared with itself is always assigned the value 1 so the main diagonal entries of the pair-wise comparison matrix are all 1. The numbers 3, 5, 7,and 9 correspond to the verbal judgments "moderate importance", "strong importance","very strong importance",and "absolute importance"(with 2, 4, 6, and 8 for compromise between the previous values).Assuming N attributes, the pair-wise comparison of attribute i with attribute j yields a square matrix $A_{N \times N}$ where a_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, a_{ij}=1 when i=j and a_{ji}=1 / a_{ij}. This can be described as

$$
\begin{array}{c}
\quad\quad\quad\quad Attribute\quad 1 \quad 2 \quad 3 \quad \ldots \quad \ldots \quad N \\
A_{NXN} = \begin{array}{c} 1 \\ 2 \\ 3 \\ \ldots \\ \ldots \\ M \end{array}
\begin{bmatrix}
a_{11} & a_{12} & a_{13} & \ldots & \ldots & a_{1N} \\
a_{21} & a_{22} & a_{23} & \ldots & \ldots & a_{2N} \\
a_{31} & a_{32} & a_{33} & \ldots & \ldots & a_{3N} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
a_{N1} & a_{N1} & a_{N1} & \ldots & \ldots & a_{MN}
\end{bmatrix}
\end{array} \quad (3)
$$

The relative normalized weight (Wj) of each attribute by (i) calculating the geometric mean of ith row and (ii) normalizing the geometric means of rows in the comparison matrix. This can be represented as

$$GM_i = \left\{\prod_{j=1}^{N} a_{ij}\right\}^{1/N} \quad (4)$$

and

$W_j = GM_i / \sum_{i=1}^{N} GM_i$(5)

The geometric mean method of AHP is used in the present work to find out the relative normalized weights of the attributes because of its simplicity and easiness to find out the maximum Eigen value and to reduce the inconsistency in judgments.

2. Calculate matrix A3 and A4 such that A3=A1×A2 and A4=A3 / A2, where A2=[W1, W2, ..., WN]^T.

3. Find out the maximum Eigen value λmax that is the average of matrix A4.

4. Calculate the consistency index CI=(λmax − N) /(N − 1). The smaller the value of CI, the smaller is the deviation from the consistency.

5. Obtain the random index (RI) for the number of attributes used in decision making[14,15]

6.Calculate the consistency ratio CR=CI/RI. Usually, a CR of 0.1 or less is considered as acceptable and it reflects an informed judgment that could be attributed to the knowledge of the analyst about the problem under study.

Step 5: Obtain the weighted normalized matrix V_{ij}. This is obtained by the multiplication of each element of the column of the matrix R_{ij} with its associated weight W_j. Hence, the elements of the weighted normalized matrix V_{ij} are expressed as

$$V_{ij} = W_j R_{ij} \quad (6)$$

Step 6: Obtain the Ideal (best) and Negative-Ideal (worst) solutions in this step. The ideal (best) and negative ideal (worst) solution can be expressed as

$$V^+ = \left\{\left(\sum_i^{max} V_{ij} \Big/ j \in J\right), \left(\sum_i^{min} V_{ij} \Big/ j \in J\right) / i = 1,2, M\right\}$$
$$= \{V_1^+, V_2^+, V_3^+, \ldots \ldots \ldots, V_N^+\} \quad (7)$$

$$V^- = \left\{\left(\sum_i^{min} V_{ij} \Big/ j \in J\right), \left(\sum_i^{max} V_{ij} \Big/ j \in J'\right) i = 1,2,, M\right\}$$

$$=\{V_1^-, V_2^-, V_3^-, \ldots \ldots \ldots, V_N^-\} \quad (8)$$

Where, $J = (j = 1,2, \ldots \ldots .., N)/j$is associated with beneficial attributes and $J' = (j = 1,2, \ldots \ldots .., N)/j$is associated with non-beneficial attributes.

Step 7: Obtain the separation measures. The separation of each alternative from the ideal one is given by Euclidean distance by the following equations.

$$S_i^+ = \left\{\sum_{j=1}^{N}\left(V_{ij} - V_j^+\right)^2\right\}^{0.5}, i=1,2,3.........,M \quad (9)$$
$$S_i^- = \left\{\sum_{j=1}^{N}\left(V_{ij} - V_j^-\right)^2\right\}^{0.5}, i=1,2,3.........,M \quad (10)$$

Step 8: The relative closeness of a particular alternative to the ideal solution can be expressed in this step as follows.

$$C_i = S_i^- / (S_i^+ + S_i^-) \quad (11)$$

Step 9: A set of alternatives is made in the descending order in this step, according to the preference value indicating the most preferred and least preferred feasible solutions.

Step 10: Take a final decision keeping in view the practical considerations. All possible constraints likely to be experienced by the user are looked in during this stage.

A computer program was developed using C language, for Strip layout index helps to evaluate and rank of any given set of strip-layout alternatives for a given engineering design.

Example

Example is considered to demonstrate and validate the combined TOPSIS and AHP. Singh etc.[11] and R.V.Rao [26] presented a strip-layout selection methodology using digraph and matrix, AHP respectively. The strip layout selection considers six alternative strip layouts and five attributes, and the data are shown in Table 1. Now, various steps of the methodology, proposed in Section 3, are carried out as described below.

Step 1: The objective is to evaluate the six alternative strip layouts and the attributes are material utilization (*U*r), die cost (*D*c), stamping operational cost (*O*c), required production rate (*P*r), and job accuracy (*J*a). Table1presents the estimated quantitative values of *U*r , *D*c, *O*c, *P*r and assigned qualitative values of *J*a.

Table 1: Alternative strip-layouts of metal blanks with the data[26]

Layout	Ur (%)	Dc (Rs.)	Oc (Rs.per 1000 pieces)	Pr (pieces /min)	Ja
1	0.26	25000	130	80	4
2	0.40	28560	138	120	3
3	0.33	31109	90	150	3
4	0.32	31702	150	125	2
5	0.31	32390	160	110	2
6	0.31	32663	116	108	2

Step2:Finding out the relative importance of different factors with respect to the objective:*U*r , *P*r , and *J*a are beneficial factors

and higher values of these factors are desired for the given stamping operation. It may be mentioned here that Singh and Sekhon [10] have assigned values to *J*a qualitatively and higher values on the qualitative scale indicate better job accuracy *D*c and *O*c are the non-beneficial factors and lower values of these factors are desired for the given stamping operation.

Step3:The quantitative values of the strip layout selection attributes, which are given in Table 1, are normalized. The normalized weights of each attribute are calculated following the procedure presented in step 3 and these are given below:

$$R_{6x5} = \begin{bmatrix} 0.32728 & 0.33620 & 0.40005 & 0.27821 & 0.58977 \\ 0.50351 & 0.38408 & 0.42467 & 0.41731 & 0.44233 \\ 0.41540 & 0.41836 & 0.27696 & 0.52164 & 0.44233 \\ 0.40281 & 0.42633 & 0.46159 & 0.43470 & 0.29488 \\ 0.39022 & 0.43558 & 0.49237 & 0.38253 & 0.29488 \\ 0.39022 & 0.43925 & 0.35697 & 0.37558 & 0.29488 \end{bmatrix}$$

Step4:The relative importance of attributes (a_{ij}'s) is also assigned, as per the procedure outlined in Sect.3. Let the user makes the following assignments:

$$\begin{array}{cc} Attribute & \begin{array}{ccccc} U_r & D_c & O_c & P_r & J_a \end{array} \end{array}$$

$$A1_{5X5} = \begin{array}{c} U_r \\ D_c \\ O_c \\ P_r \\ J_a \end{array} \begin{bmatrix} 1 & 3 & 5 & 1 & 1 \\ 1/3 & 1 & 3 & 1/3 & 1 \\ 1/5 & 1/3 & 1 & 1/5 & 1/3 \\ 1 & 3 & 5 & 1 & 1 \\ 1 & 1 & 3 & 1 & 1 \end{bmatrix}$$

The normalized weights of each attribute are: *W*ur= 0.295092, *W*dc= 0.137821,*W*oc = 0.058117, *W*pr = 0.295092, *W*j = 0.213877.The value of λmax is 5.14657 and CR= 0.036642 which is much less than the allowed CR value of 0.1. Thus, there is good consistency in the judgments made.

Step5:The weighted normalized matrix,V_{6X5} is Calculated as shown below.

$$V_{6x5} = \begin{bmatrix} 0.09657 & 0.04633 & 0.02325 & 0.08209 & 0.12613 \\ 0.14858 & 0.05293 & 0.02468 & 0.12314 & 0.09460 \\ 0.12258 & 0.05765 & 0.01609 & 0.15393 & 0.09460 \\ 0.11886 & 0.05875 & 0.02682 & 0.12827 & 0.06306 \\ 0.11515 & 0.06003 & 0.02861 & 0.11288 & 0.06306 \\ 0.11515 & 0.06053 & 0.02074 & 0.11083 & 0.06306 \end{bmatrix}$$

Step6:The next step is to obtain the ideal (best) and negative-ideal (worst) solutions using Eqs. (7) and (8) respectively. These are given as:

V^+	V^-
0.14858	0.09658
0.04634	0.06003
0.01610	0.02861
0.15393	0.08210
0.12614	0.06307

Step7:The next step is to obtain the separation measures using Eqs. (9) and (10):

$S1^+$	$S1^-$
0.08897	0.06476
0.04538	0.07382
0.04241	0.08362
0.07608	0.05132
0.08440	0.03595
0.84713	0.03511

Step 6:The relative closeness of particular alternative to the ideal solution is calculated using Eq. (11):
C1=0.421263 C2=0.619296 C3=0.663497 C4=0.402836 C5=0.298721 C6=0.293049

The strip layout index is arranged in descending as:

3-2-1-4-5-6.It may be noted that the above ranking may change if the user assigns different relative importance values to the attributes. The same is true for the approach proposed by Rao [26]. From the above values, it is clear that the strip-layout designated as 3 is the best choice for the stamping operation for the given conditions. The second choice is 2, third choice is 1, fourth choice is 4, fifth choice is 5 and the last choice is 6. The above results obtained using TOPSIS are matching well with the results given by Rao[26] so far as the alternatives 3,2,1 and 4 are concerned. Alternative 5 is proposed as the sixth choice and 6 as the fifth by Rao[26] in this paper. However, results presented in this paper are more dependable as there exists consistency in the judgments made regarding the relative importance of factors.

Conclusions

A logical procedure based on a combined multiple attribute decision making method (using TOPSIS and AHP together) is suggested which helps in selection of a suitable strip layout from among a large number of available alternative strip layouts for a given engineering design application.The measures of the attributes and their relative importance are used together to rank the alternatives, and hence it provides a better accurate evaluation of the alternative strip layout.The proposed method is a general method and offers a more objective and simple strip layout selection approach.

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