New method of machine selection for product layout: 
the case of Iranpichkar factory

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Abstract
Selecting an appropriate manufacturing machine is a very important and complex problem for firms, which usually have to deal with both qualitative and quantitative criteria. Taking into account the differences among machines in terms of cost, speed, quality and after sale services, type and number of machines are important parameters to consider. Therefore, the goal of this paper is to propose the most optimal model for machine selection focusing on cost and quality of products. To achieve the goal of the paper Analytic Hierarchy Process (AHP) method is used. Finally, a case study is illustrated to demonstrate the potential of the proposed model for the selection of machine.

Key word: machine selection, machine number, qualitative, quantitative, AHP

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**Introduction**

Economic globalization, increasing market competition, short product life cycles, along with current sanctions and unemployment necessitates the use of advanced manufacturing technologies in companies (Alberti et al., 2011). Selecting the adequate manufacturing machine is a complex decision. Multiple decision makers, with different perspective and expertise, are usually involved in the process and have to deal with uncertainty (Lipshitz & Strauss, 1997; Ahn et al., 2000) at a financial level because of the difficulty in estimating the impact of unexpected changes on cash flows (Sutardi & Goulter, 1995; Franz et al., 1995). Moreover, it is often difficult to measure the positive impact on cash flows brought about by the increase in quality and flexibility which would allow quicker reactions to changes in the market (Franz et al., 1995; Kaplan, 1986). Advanced manufacturing technology, in fact, requires a high level of initial investment and usually deals with both qualitative and quantitative benefits which make the traditional investment model based on economic criteria not really suitable. Arguably these models emphasize quantitative and financial analysis, but fail to capture many of the “intangible” benefits such as: improved product quality, quick response to customer demand and better employee safety and motivation (Abdel-Kader, 1997; Chen & Small, 1996; Kaplan, 1986) which are typically more challenging to measure and monetize.

The following sections are going to present a focused theoretical background on machine selection (Section 2), the decision context for the machine selection (Section 3), a case study that illustrates the validity of the approach and its potential applicability for real cases (Section 4), and finally conclusion (Section 5).

**Literature review**

Machine selection meant to determine the optimal number of machines in each work center. This issue has attracted the attention of many researchers because of its importance. Researchers have used various methods for the decision-making process when selecting the most suitable potential machines. Arslan et al. 2004 presented a Decision Support System (DSS) involving nine criteria (flexibility, productivity, adaptability, cost, reliability, precision, space, safety and environment, service and maintenance) for machine selection using the weighted average approach and a Cost/Benefit analysis. Ayag & Ozdemir, 2006 presented the Multiple Attribute Decision making (MADM) process for machine selection based on the fuzzy AHP and Cost/Benefit analysis. Duran & Aguilo, 2008 also used the fuzzy AHP to evaluate and justify the advanced manufacturing system. Firoozian & Karimy, 2011 presented a model based on AHP and Net Present Worth (NPW). Further, Ertuğrul & Gűneş, 2007 proposed a fuzzy multiple Criterion Decision Making (MCDM) model where AHP was used to evaluate the alternatives with the criteria such as, axis size, power, spindle speed, tolerance, repeatability, cutting-tool change time, and the number of cutting tools along with other economical and commercial factor. Tabucanon et al., 1994 proposed an approach for designing and developing an intelligent Decision Support System (DSS) that is intended to ease the selection process of alternative machines for Flexible Manufacturing Systems.
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(FMS). They identified the following criteria: material of each part, machining time, set-up time, batch size, batch set-up time and average total quantity of parts required per year for each part, maximum original size of raw work piece, operations performed on parts type and number of cutting tool requirements, accuracy and spindle speed required. In addition, Wang et al, 2000 proposed a fuzzy MADM model to assist the decision-maker to deal with the machine selection problem for an FMS realistically and economically. Yazdani-Chamzini & Haji Yakhchali, 2012 presented an evaluation model based on the fuzzy AHP and MCDM techniques. They developed fuzzy technique for order performance by similarity to ideal solution (TOPSIS) to help the tunneling designers in the process of the Tunneling Boring Machine (TBM) selection in fuzzy environment based on nine criteria: face stability, rock mass permeability, grain size distribution, safety, speed of excavation, ground water control, cost, risk, and surface settlement. Aloni et al, 2011 proposed a peer-based modification to intuitionistic fuzzy multi-criteria group decision making with TOPSIS method (peer IF-TOPSIS) and applied it to a packaging machine selection problem based on twelve parameters (speed, mix flexibility, safety, technological parameters, ease of use, accessories, maintenance, price, Electric consumption, dimension, guarantee and upgrading). Taha & Rostam, 2012 presented a hybrid method of fuzzy AHP and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) for machine selection in Flight Management System (FMS). The fuzzy AHP is used to calculate the weights of criteria, and PROMETHEE is utilized to predict the ranking of alternatives through the Decision-Lab software. Then, Bo et al, 2008 presented a model based on grey theory and AHP method for machine selection in network manufacturing. Shah Hoseiny et al, 2014 offered the method based on the management machines, long and short term planning approach to the selection and use of machines. Son & Park, 1987 conducted an economic evaluation of productivity, quality, and flexibility by means of net present value (NPV). Chung & Peng, 2004, discussed the selection of machines based on machine costs on Web-based manufacturing environments. Subramanian et al, 2000 propose a method for machine selection in dynamic job shop they use three rules: lowest average cost (LAC), least average process time (LAP) and least aggregate cost and process time (LACP).

None of the above-discussed studies has suggested a method to determine the optimal number of facilities. In addition to choosing the type of machines, choosing the number of machine is important because if a machine is operated in a long time without maintenance, it may fail accidentally or the quality of outputs may be deteriorated (Lee & Kim, 2012). The resource selection problem is defined as the specification of the number of each type of resources to use in a manufacturing system (MS) for a given planned period. Most approaches that dealt with this problem are either analytical or simulation-based methods. Bullinger & Sauer, 1987 and Peng et al offer approaches strongly associated with 'try and error', whereas De Matta, et al,1999, Lin & Yang, 1996 and Miller & Davis, 1977 offer an approach based on
mathematical models connecting parameters like production needs and resource capacities to the required resource quantities. Unlike simulation-based approaches, the analytical ones are limited to small size problems due to the difficulty of handling the mathematical formulations. Gutierrez & Sahinidis, 1996 addresses the problem of determining the number of machines for each stage of a just in time (JIT) system by minimizing production, imbalance and investment costs. They modeled a problem as a mixed-integer nonlinear optimization program and a branch-and-bound algorithm was developed for its solution. Yildirim et al, 2006 proposed a framework that was applied to a flexible manufacturing system with work centers having parallel identical machines and utilized parallel neural networks to make decision on the availability of resources. In their numerical example, they estimated the number of machines at each work center. Chtouroua et al 2005 presented the development of an ES used in a simulation-based approach in order to structure the solution search mechanism. They estimated the number of machines in each station was multi-product production system. Whitney, 1985 presented an algorithm to estimate the number of machine and equipment with limited time in flexible manufacturing system.

Methodology
The goal of the current research is to determine the optimal type and number of machines. To achieve the goal of the study the following assumptions have been considered:
1. Specialized workers need machines.
2. Mass production is considered.
3. Lost demands are not permitted.
4. The machine depreciation is calculated linearly.
5. Allocation of machines to the workers is based on the Man - Machine Process Chart.
6. Inflation and interest rates are considered to be the same.
7. Output components of a workstation are exactly the entrance parts of the next station.

Then, the following attributes, parameters and decision variables have been identified:

**Attribute**
- \( i \): Machine Index
- \( j \): Work station index

**Parameters**
- \( d_{ij} \): salvage value of \( i \)th machine from \( j \)th work station
- \( o_{ij} \): optimum life of \( i \)th machine from \( j \)th work station
- \( p'_{ij} \): average maintenance cost of \( i \)th machine from \( j \)th work station
- \( p_{ij} \): cost of \( i \)th machine from \( j \)th work station
- \( f_{ij} \): average worker cost of \( i \)th machine from \( j \)th work station
- \( p''_{ij} \): average waste cost of \( i \)th machine from \( j \)th work station
- \( T_{ij} \): standard production time of \( i \)th machine from \( j \)th work station
- \( R_{ij} \): reliability of \( i \)th machine from \( j \)th work station
- \( R_{ij}l \): worker reliability of \( i \)th machine from \( j \)th work station
- \( \beta_{ij} \): waste percent of \( i \)th machine from \( j \)th work station
- \( g_{ij} \): quality of produced products of \( i \)th machine from \( j \)th work station
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$s_{ij}$ : required area of $i$th machine from $j$th work station

$\alpha_{ij}$ : estimated demand of $i$th machine from $j$th work station

$\lambda_{ij}$ : the number of workers allocated to the $i$th machine from $j$th work station

$m$ : the number of production courses periods

$a$ : the maximum value of the rial granted facilities by government

$s'$ : the available area for machines

$Tc$ : available time during a period

$r$ : demand during a period

$t$ : the minimum number of workers for the use of government facilities

$b$ : budget allocated for the purchase of machines

**Decision variables:**

$x_{ij}$ : the number of $i$th machine(s) from $j$th work station

$h$ : The percent use of government facilities

Then, multiobjective programming model was developed which is presented below:

1. 

$$\min \left[ \sum_{i=1}^{m} \sum_{j=1}^{o} (x_{ij} \left( p_{ij} - d_{ij} \right) \left( \frac{m}{o_{ij}} \right) + m p'_{ij} \right) +$$

$$m f_{ij} x_{ij} \lambda_{ij} + m p'_{ij} d_{ij} x_{ij} \left( \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} \left( 1 - \beta_{ij} \right) - h a \right) ]$$

2. 

$$\min \left[ \sum_{i=1}^{m} \sum_{j=1}^{o} \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} \beta_{ij} \left( 1 - g_{ij} \right) \right]$$

$s f$

3. 

$$\frac{x_{ij} \alpha_{ij} r \left( 1 - g_{ij} \right) - \sum_{i=1}^{m} \sum_{j=1}^{o} x_{ij} \beta_{ij} \left( \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} \beta_{ij} \right)}{T s_{ij}} \leq \frac{\alpha_{ij} r \left( 1 - g_{ij} \right) - \sum_{i=1}^{m} \sum_{j=1}^{o} x_{ij} \beta_{ij} \left( \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} \beta_{ij} \right)}{T s_{ij}} ; \quad \forall i, j$$

4. 

$$r \leq \sum_{i=1}^{m} \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} \left( 1 - \beta_{ij} \right) -$$

$$\sum_{i=1}^{m} \sum_{j=1}^{o} x_{ij} \beta_{ij} \frac{R e_{ij} R e_{ij} T c}{T s_{ij}} ; \forall j$$

5. 

$$\sum_{j=1}^{o} \sum_{i=1}^{m} x_{ij} s_{ij} \leq s'$$

6. 

$$\sum_{j=1}^{o} \sum_{i=1}^{m} x_{ij} p_{ij} \leq b + h a$$

7. 

$$h = \sum_{j=1}^{o} \sum_{i=1}^{m} \frac{\lambda_{ij} x_{ij}}{t}$$

8. 

$$x_{ij} \in Z$$

9. 

$$h \geq 0$$

There are two objective functions. The first one minimizes the cost of buying and residual values, maintenance costs, the cost of labor and wastes. By adding the amount of the loan to the cost, the first function is optimized. $m_{o_{ij}}$ shows buying process number. $mp'$ is the cost of waste during the manufacturing period. The second function maximizes the quality of produced products. $x_{ij} \lambda_{ij}$ is the number of workers of $i$th machine from $j$th work station, so $mf_{ij} x_{ij} \lambda_{ij}$ indicates total cost of workers of $i$th machine from $j$th work station. $ha$ shows the amount of use from the government's concessional lending. $\frac{R e_{ij} R e_{ij} T c}{T s_{ij}}$ indicates the number of the products that is produced by $i$th machine from $j$th work station. So $mp'_{ij} d_{ij} x_{ij} \lambda_{ij}$ indicates the costs of wastes in whole factory periods. Second objective function indicates optimum quality of produced
products. In this regard, \((1 - g_{ij})\) is used and maximum function becomes minimum, because if maximum function is used, the product by the \(i^{th}\) machine from \(j^{th}\) work station will reach its maximum (products are controlled only by \(4^{th}\) equation and maximum function increases them without limitation). The first constraint (equation (3)) with respect to the assumption 7 indicates that the input of every workstation plus to wastes of next stations should be more than the demand. Equation (4) ensures that not all demands are met by only one type of machine. It helps factory to have no problem to provide spare parts for that machine in crises, such as sanctions. Equation (5) controls the area, so that the area needed for machines, is not more than available space. Equation (6) helps to avoid purchasing machines more than the budget (plus to lean). Equation (7) states the amount of loans and facilities with respect to the number of workers, lean situation, and rules. Equations (8) and (9) indicate the limitations of variables.

To set the quality of the parts (the second goal), AHP method has been used. In fact, this is one of the most comprehensive systems designed for decision-making with multiple variables. This process is done based on paired comparisons. It is capable to involve various options in decision-making.

This model is a multi-objective programming model that consists of entirely incompatible objective functions. To solve this problem this paper used equation

\[
\text{(10) } \min \left[ W_1 \frac{Z - Z^*}{Z^*} + W_2 \frac{Q - Q^*}{Q^*} \right]
\]

\(W_1\): first function (cost) Weight \\
\(W_2\): second function (quality) weight \\
Our functions are \(Q\) and \(Z\); Where \(Q^*\) and \(Z^*\) are optimal values of \(Q\) and \(Z\) functions, which are obtained from solving each function, separately, with limitations.

**Numerical illustrations (case study)**

**Factory introduction**

“Iranpichkar” factory has product bolt line size M4 to M24. Manufacturing systems is mass production. Parts output from one station are next station input components. The depreciation period of this factory is 10 years and the discount rate is 10%. This study examines the screw production line M6 with a length of 20 mm.

**The introduction of bolt M6 * 20 production operations**

Manufacturing operations are indicated in the chart (1):

![Manufacturing operations chart](image)

**Figure 1. Manufacturing operations chart**

Technical specification cold forming machine and lathe machine
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Table 1: Specifications of cold forming machine

<table>
<thead>
<tr>
<th>Machine</th>
<th>p (million Rials)</th>
<th>d (million Rials)</th>
<th>( p' ) (million Rials)</th>
<th>( \alpha )</th>
<th>( s^2 )</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega</td>
<td>28800</td>
<td>10041</td>
<td>10</td>
<td>0.7</td>
<td>28</td>
<td>0.93</td>
</tr>
<tr>
<td>MBT</td>
<td>500</td>
<td>174</td>
<td>5</td>
<td>1</td>
<td>45</td>
<td>0.93</td>
</tr>
<tr>
<td>Malmedi</td>
<td>2560</td>
<td>892</td>
<td>0.5</td>
<td>0.7</td>
<td>10</td>
<td>0.93</td>
</tr>
<tr>
<td>NB</td>
<td>44400</td>
<td>15481</td>
<td>50</td>
<td>0.7</td>
<td>28</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Table 2: Specifications of lathe machine

<table>
<thead>
<tr>
<th>Machine</th>
<th>p (million Rials)</th>
<th>d (million Rials)</th>
<th>( p' ) (million Rials)</th>
<th>( \alpha )</th>
<th>( s^2 )</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega</td>
<td>9</td>
<td>5</td>
<td>174</td>
<td>0.74</td>
<td>9</td>
<td>0.93</td>
</tr>
<tr>
<td>MBT</td>
<td>9</td>
<td>5</td>
<td>174</td>
<td>0.74</td>
<td>9</td>
<td>0.93</td>
</tr>
<tr>
<td>Malmedi</td>
<td>10</td>
<td>2</td>
<td>167</td>
<td>0.74</td>
<td>10</td>
<td>0.93</td>
</tr>
<tr>
<td>NB</td>
<td>0.25</td>
<td>0.74</td>
<td>167</td>
<td>0.74</td>
<td>0.05</td>
<td>240</td>
</tr>
</tbody>
</table>

Table 3: View Product Line

<table>
<thead>
<tr>
<th>R (daily)</th>
<th>m (month)</th>
<th>b (million Rials)</th>
<th>( s' ) (m²)</th>
<th>( T_c ) (minute)</th>
<th>W₁</th>
<th>W₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>82192</td>
<td>240</td>
<td>90000</td>
<td>100</td>
<td>420</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

There wasn’t available data about budget and estimated rate of demand, so related numbers are hypothetical, the residual value of the machines are the book value of the tenth year discounted at the rate of 10%. The studied factory does not consider overall replacement for machines, therefore salvage value and machine optimum life is supposed to be equal to the production time.
Calculating the numerical value of products quality based on AHP method

In table 5, pairwise comparisons between products produced by cold forming and lathe machine are introduced.

In the matrix the items are compared with each other (pairwise), with respect of quality of products. Professor Saaty’s table is used for pairwise comparisons.

### Table 4: Scale of Relative Importance (according to Saaty (1980))

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Weak importance of one over another</td>
<td>Experience and judgment slightly favor one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong Importance</td>
<td>Experience and judgment strongly favor one activity over another</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrated Importance</td>
<td>An activity is strongly favored and its dominance demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Absolute importance</td>
<td>The evidence favoring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values between the two adjacent judgments</td>
<td>When compromise is needed</td>
</tr>
<tr>
<td>Reciprocals of above nonzero</td>
<td>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 compared with i.</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5: Pairwise Comparisons between Products Produced by Cold Forming

<table>
<thead>
<tr>
<th>Quality of products</th>
<th>OMEGA (Italy)</th>
<th>MBT—M3 (Russia)</th>
<th>MALMEDI (Germany)</th>
<th>NB-512 (Belgium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMEGA (Italy)</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MBT—M3 (Russia)</td>
<td>0.25</td>
<td>1</td>
<td>0.25</td>
<td>0.125</td>
</tr>
<tr>
<td>MALMEDI (Germany)</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>0.20</td>
</tr>
<tr>
<td>NB-512 (Belgium)</td>
<td>1</td>
<td>8</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 6: Pairwise Comparisons between Products Produced by Lathe Machine

<table>
<thead>
<tr>
<th>Quality of products</th>
<th>OMEGA (Italy)</th>
<th>INGERMATIC (Italy)</th>
<th>EWM (Germany)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMEGA (Italy)</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>INGERMATIC (Italy)</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>EWM (Germany)</td>
<td>0.33</td>
<td>0.33</td>
<td>1</td>
</tr>
</tbody>
</table>

Results
Results have been obtained from GAMS 24.1.3 with solver CPLEX which is illustrated in table 7.

Table 7: Results

<table>
<thead>
<tr>
<th>Machine name (lathe machine)</th>
<th>Machine number</th>
<th>Machine name (Cold forming)</th>
<th>Machine number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingematic (Italy)</td>
<td>1</td>
<td>Omega (Italy)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MBT (Russia)</td>
<td>1</td>
</tr>
</tbody>
</table>

Conclusion
Machine selection process is a technique for evaluating the appropriate alternatives and selecting the best alternative with respect to criteria under consideration. In the case study cited due to the limited market demand and competition, function of quality parts is twice the cost. Changing these weights can change the optimum solution. This method can be used for mass production systems with production line. The main goal of this study is to identify the best method of selecting the number and type of machines in mass production system. To show the potential application of the proposed model, a real world case study was illustrated. As mathematical modeling showed more accurate results than multi-criteria decision-making, it can be considered a better one for decision making in mass production factories.

References


systems, Computers in Industry, 25, 131-143.


