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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 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 & Güneş, 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

(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 achiev 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 identified:

Attribute

i: Machine Index

j: Work station index

Parameters

d_{ij} : salvage value of ith machine from jth work station

o_{ij} : optimum life of ith machine from jth work station

p'_{ij} : average maintenance cost of ith machine from jth work station

p_{ij} : cost of ith machine from jth work station

f_{ij} : average worker cost of ith machine from jth work station

p''_{ij} : average waste cost of ith machine from jth work station

Ts_{ij} : standard production time of ith machine from jth work station

Re_{ij} : reliability of ith machine from jth work station

$\mathrm{Re}l_{ij}$: worker reliability of ith machine from jth work station

β_{ij} : waste percent of ith machine from jth work station

g_{ij} : quality of produced products of ith machine from jth work station

s_{ij} : required area of ith machine from jth work station

α_{ij} : estimated demand of ith machine from jth work station

λ_{ij} : the number of workers allocated to the ith machine from jth 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 ith machine(s) from jth work station

h : The percent use of government facilities

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

1.

$$Min\left[\sum_j\sum_i (x_{ij}\left(\left(p_{ij}-d_{ij}\right)\left(\frac{m}{o_{ij}}\right)+mp'_{ij}\right)+ mf_{ij}x_{ij}\lambda_{ij}+mp''_{ij}d_{ij}x_{ij}\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}\beta_{ij}-ha)\right]$$

2.

$$Min\left[\sum_j\sum_i x_{ij}\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}\beta_{ij}\left(1-g_{ij}\right)\right]$$

$s.t$

3. $$x_{ij}\le\frac{\alpha_{ij}r}{\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}\left(1-\beta_{ij}\right)-\sum_{l=j+1}^{n}x_{il}\beta_{il}\frac{\mathrm{Re}l_{il}\ \mathrm{Re}_{il}Tc}{Ts_{il}}}\quad;\quad\forall i,j$$

4. $$r\le\sum_i x_{ij}\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}\left(1-\beta_{ij}\right)-\sum_i\sum_{l=j+1}^{n}x_{il}\beta_{il}\frac{\mathrm{Re}l_{il}\ \mathrm{Re}_{il}Tc}{Ts_{il}};\forall j$$

5. $$\sum_j\sum_i x_{ij}s_{ij}\le s'$$

6. $$\sum_j\sum_i x_{ij}p_{ij}\le b+ha$$

7. $$h=\sum_j\sum_i\frac{\lambda_{ij}x_{ij}}{t}$$

8. $x_{ij}\in Z$

9. $h\ge 0$

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. $\frac{m}{o_{ij}}$ 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 ith machine from jth work station, so $mf_{ij}x_{ij}\lambda_{ij}$ indicates total cost of workers of ith machine from jth work station. ha shows the amount of use from the government's concessional lending. $\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}$ indicates the number of the products that is produced by ith machine from jth work station. So $mp''_{ij}d_{ij}x_{ij}\frac{\mathrm{Re}_{ij}\ \mathrm{Re}l_{ij}Tc}{Ts_{ij}}\beta_{ij}$ indicates the costs of wastes in whole factory periods. Second objective function indicates optimum quality of produced products. In this regard, $\left(1-g_{ij}\right)$ is used and maximum function becomes minimum, because if maximum function is used, the product by the ith machine from jth work station will reach its maximum (products are controlled only by 4th 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 (10).

$$(10)\quad Min\left[W_1\frac{Z-Z^*}{Z^*}+W_2\frac{Q-Q^*}{Q^*}\right]$$

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):

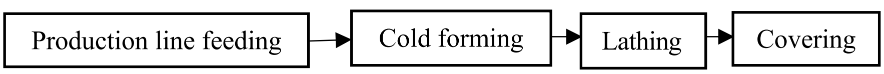

Figure 1. Manufacturing operations chart

Technical specification cold forming machine and lathe machine

Table 1: Specifications of cold forming machine

	p (million Rials)	d (million Rials)	p' (million Rials)	α	s (m^2)	Re
omega	28800	10041	10	0.7	28	0.93
MBT	500	174	5	1	45	0.93
Malmedi	2560	892	0.5	0.7	10	0.93
NB	44400	15481	50	0.7	28	0.93

	F (million rial)	p'' (rial)	Ts (Minute)	β (%)	$\mathrm{Re}l$	λ	O (month)
Omega	15	700	0.010	9	0.74	1	240
MBT	15	700	0.033	12	0.74	1	240
Malmedi	15	700	0.029	10	0.74	1	240
NB	15	700	0.005	10	0.74	0.25	240

Table 2: Specifications of lathe machine

	P (million Rials)	d (million Rials)	p' (million Rials)	α	s (m^2)	Re
Ingermatic	500	174	5	0.7	9	0.93
Omega	500	174	5	0.7	9	0.93
EWM	480	167	2	0.7	10	0.93

	f (million rial)	p'' (rial)	Ts (Minute)	β (%)	$\mathrm{Re}l$	λ	o (month)
Ingermatic	15	800	0.00125	3	0.74	1	240
Omega	15	800	0.00125	3	0.74	1	240
EWM	15	800	0.01111	6	0.74	1	240

Production line Specifications

Table 3: View Product Line

R (daily)	m (month)	b (million Rials)	s' (m^2)	Tc (minute)	W_1	W_2
82192	240	90000	100	420	1	2

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, 6, 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))

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 highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	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.	

Table 5: Pairwise Comparisons between Products Produced by Cold Forming

Quality of products	OMEGA (Italy)	MBT—M3 (Russia)	MALMEDI (Germany)	NB-512 (Belgium)
OMEGA(Italy)	1	4	1	1
MBT—M3(Russia)	0.25	1	0.25	0.125
MALMEDI(Germany)	1	4	1	0.20
NB-512(Belgium)	1	8	5	1

Table 6: Pairwise Comparisons between Products Produced by Lathe Machine

Quality of products	OMEGA(Italy)	INGERMATIC (Italy)	EWM (Germany)
OMEGA(Italy)	1	1	3
INGERMATIC(Italy)	1	1	3
EWM(Germany)	0.33	0.33	1

Results

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

Machine name (lathe machine)	Machine number	Machine name (Cold forming)	Machine number
Ingermatic (Italy)	1	Omega (Italy)	5
		MBT(Russia)	1

Table7: Results

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.

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