



# Using Macbeth Method for Technology Selection in Production Environment

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**Abstract:** Technology selection has a very crucial role to any company aiming for competitive advantage in the globalized world. In a competitive environment, firms try to meet customer demand and their increasing quality expectations, at the same time finding ways to decrease costs using factors such as flexibility, quality and innovativeness. Technology selection and evaluation problem have many criteria (both subjective and objective factors) that conflict with each other. To overcome this problem multi criteria decision making methods are developed. In this study MACBETH method is used to select and evaluate technology alternatives. Decision makers' opinions are evaluated to rank the alternatives.

**Keywords:** Technology Selection, Multi Criteria Decision Making, Macbeth Method

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## 1. Introduction

Companies seek new technologies not only to create new products or services but also to obtain customers' attention and competitive advantage. Choosing a new technology or to improve the current one shows its impact in the long-term period, therefore focusing only on short-term benefits could be misleading. The selection of the best technology is a process that should be considered thoroughly due to its impact on future decisions of companies about competitive and manufacturing advantages. This selection may be easy when it is calculated by one criterion like buying the cheapest one. However, the problem of technology selection and evaluation includes many tangible and intangible criteria. Furthermore, these problems may have uncertain structure due to include vague and ambiguous data effected by subjective human judgements [1, 2]. Determining the right criteria for the company, using these to compare each alternative and different alternatives with different properties make the selection problem more complex and difficult to solve.

As [3] implies, technological change is one of the main drivers of competition. For an unknown company, it can be a great equalizer, diminish the effect of competitive advantage and push forward others to the forefront. Technology affect a firm's value chain strongly and also all the processes required

for a product or service.

From a managerial point of view, new or better technologies help companies to reach its customers effectively and timely in global markets, which is under the effect of fierce competition. Continuous technological advances in the external and internal business environments has pressured firms to seek new technological innovation [4]. This research includes risk and challenges of failure in nature, therefore it's important to assess all the relative factors in the decision process.

Although this study focuses on production technologies, everything a firm does involves some kind of technologies and any of these technologies can have significant impact on competition. Technology affects competitive advantage through determining relative cost position or differentiation. Because technology is in every activity of a production or service process, its impact can be bigger than anticipated [3].

Selection of technology is a key performance asset for companies. If this selection is done properly (using the right decision criteria), the selected technology can be properly used to achieve success and lead to solutions of identified problems. On the other hand, if it is not handled with care or done poorly, it can result in waste of resources like time and money or even an unsatisfied customer.

Any increase in competitiveness results not only a decrease in profitability but also a continuous increase in quality. With the limited resources, the optimal way to increase quality and prevent the loss of profit is based on productivity. Efficient usage of inputs (information, resources, equipment...) improves productivity, which simultaneously improves profitability and competitiveness. In modern economics, technology-based production becomes the dominant factor in economic development. Modern production technologies (like computers, robots, flexible manufacturing technologies and etc.) is the key success factor in global markets.

With more technology focused production, companies can produce products having greater added values. This results not only as an increase in company's profitability but also as a bigger impact in the general economic system. Main factor in gaining competitiveness advantage due to productivity is based on using the right technology for the right job.

The technology selection aims at identifying the critical evaluation criteria which the decision maker should concentrate its selection interest on, and therefore prioritizes its usage towards the final decision making point. The relevant or alternative technologies considered in the process can be selected from extensive literature survey or from a panel of experts in the problem area or even from the competitors [5].

Any selection problem like technology, supplier and etc. have many criteria that conflict with each other. Decision maker has the goal to determine the best one between the given alternatives or rank these alternatives from the best to the worst according to criteria. Most of the time these criteria can be conflicting values. For the decision makers each and every one of the criterion may have different importance than the other one. The features of problem mentioned show that Multi-Criteria Decision Making (MCDM) methods can be applied to selection and evaluation problem. In this study a MCDM method called MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) is used to select and evaluate technology alternatives. This method produce an interval numerical scale based pairwise comparison judgements, and aggregate weighted scores of alternatives through this scale. After that, ranking of alternatives is made according to overall attractiveness of criteria.

## 2. Macbeth Method

MACBETH method can be defined as a set of techniques that are designed to investigate a number of alternatives having multiple criteria and conflicting objectives [6]. It is based on multi-attribute value theory. This method makes pairwise comparison using semantic judgements obtained by decision makers and quantifies relative attractiveness differences of alternatives. Basically, it is used to judge the performance of alternatives with respect to a range of decision criteria expressed in ordinal (qualitative) measures.

In MACBETH, the decision maker needs to compare two criteria at a time with qualitative judgments about their difference of attractiveness based on a pre-defined semantic judgment scale. This method not only provides facility to check consistency of the decision maker's judgments, but also suggests improvements in the judgments, if they are found to be inconsistent. Further, based on linear programming, these consistent judgments are transformed into a suitable numerical scale, identified as the MACBETH scale. Finally, the weighted global scores representing the overall attractiveness of the alternatives are computed using an additive aggregation model to rank the alternatives [7, 8].

In addition, by sensitivity and robustness analyses, on one hand, the consistency of decision makers are measured, on the other hand, the improvement opportunities of judgements are determined. Due to this feature, it is said that MACBETH is a robust technique [7].

Macbeth method is used for supplier selection in [7], evaluation and selection of flexible manufacturing systems in [9], industrial performance measurement in [10]. Also hybrid models are developed like [11] which uses Macbeth with fuzzy AHP (analytical hierarchical process) for evaluation of renewable energy alternatives, [12] combines Macbeth with MAUT (multi-attribute utility theory) for portfolio selection, and [13] proposed an integrated model of MACBETH and COPRAS (Complex Proportional Assessment) methods for the selection of air compressor unit of a textile company.

The steps of the approach are given below [14, 15].

Step 1. Decision process allows decision makers to evaluate both quantitative criteria, which have numeric scales formed by max and min values, and qualitative criteria with verbal indicators that change according to features of criteria. These criteria are given as decision nodes.

Step 2. For every criteria, differences of attractiveness are determined according to judgements with pair-wise comparisons. The link between each decision node is identified using seven semantic categories from worst to best: "no, very weak, weak, moderate, strong, very strong, extreme." If the range between two nodes is very large, the intensity of linkage is strong, and identified as extreme or very strong. These decision nodes and their indicators of intensities with verbal categories are shown in judgement matrix. According to feature of the criterion, more than one semantic categories can be selected.

Step 3. MACBETH uses linear programming approach to determine attractiveness of criteria and analyzing consistency of judgements. The system also checks if there is an inconsistency between judgements. When an inconsistency occurs, system give suggestions to the decision maker to overcome the problem. If not, a value scale is produced for each criterion. Value scales measure attractiveness in the range of 100 and 0.

Step 4. Weights of criteria are determined and then, these weights are entered as rating ratios.

Step 5. After all these operations, the weighted criteria are aggregated by interval scale, and the alternatives are ranked

according to them.

### 3. Application

In this study technology selection problem of a small company with flexible manufacturing capabilities is examined. Company is seeking to improve its competitive advantage with its new technology installment. There are four alternatives. Decision maker in the company has determined the given qualitative and quantitative criteria for the selection process:

- Purchasing cost (Total buying price of the alternative) - PC
- References (Technology supplier's business references) - RF
- System compatibility (Conformity with company's current manufacturing process) - SC
- Flexibility (Conformity with company's different products and future extension plans) - FL
- Technical support (After sale support for the equipment) - TS
- Capacity (the ability of the alternative to cope with the changing demand in future) – CP

From the six criteria PC is non-beneficial attributes whereas the RF, SC, FL, TS and CP are beneficial attributes. The decision is given by using the M-MACBETH software. The decision tree is given in Figure 1.

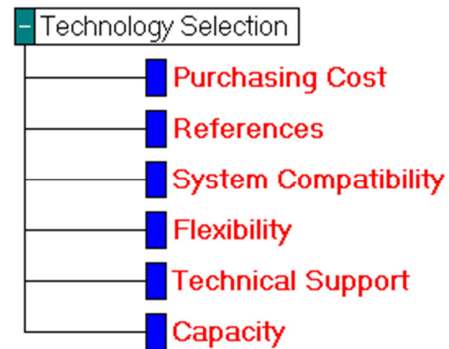


Figure 1. Decision tree for the problem.

A decision maker from the company is asked express the performance value of the alternatives with respect to each criterion. A seven ordinal performance levels, given in descending order of importance as 'very good' (VG), 'good' (G), 'medium good' (MG), 'fair' (F), 'medium poor' (MP), 'poor' (P) and very poor' (VP) is used. The decision criteria and their performance levels are entered into M-MACBETH software according to descending order of their attractiveness. For beneficial criteria, VG being the most attractive performance level is selected as the upper performance level, while VP being the least attractive level is chosen as the lower performance level. In case of purchasing cost criterion the choices are just opposite.

An example from the System Compatibility criterion is given in Figure 2.

-	+	Qualitative level	Short
1		Very Good	VG
2		Good	G
3		Medium	M
4		Poor	P
5		Very Poor	VP

Figure 2. Performance levels of 'System Compatibility' criterion.

Then, according to the decision maker preferences, relationships between each criterion's performance levels are identified and consistency of the judgments is checked. The identified differences of attractiveness for performance levels using a seven point scale is shown in Figures 3 for Flexibility

criterion. In this step the density of the relation on the decision nodes are measured and an evaluation scale is created [16, 17]. In MACBETH, decision maker can also give the interval values like weak- moderate or strong-very strong.

	VG	G	M	P	VP	Current scale	
VG	no	moderate	positive	positive	positive	100	v. strong
G		no	mod-strg	positive	positive	75	strong
M			no	moderate	positive	50	moderate
P				no	moderate	25	weak
VP					no	0	very weak

Figure 3. Comparison of performance levels for 'Flexibility' criterion.

The performance of the four alternatives with respect to each criteria is given in Figure 4.

Options	PC	RF	SC	FL	CP	TS
Alt 1	M	M	M	G	P	G
Alt 2	P	G	P	M	G	VG
Alt 3	G	VG	G	M	G	M
Alt 4	VG	G	G	G	M	G

Figure 4. Performance value of the alternatives.

In MACBETH, criterion weights are determined based on decision makers' opinions. A 7-point scale is used to measure attractiveness of each criterion over another criterion. Consistency of these decisions are controlled by M-Macbeth software. Weighting judgments and the scores for technology selection is given in Figure 5 and Figure 6, respectively.

	[PC]	[RF]	[SC]	[FL]	[CP]	[TS]	[all lower]	Current scale	
[PC]	no	weak	moderate	moderate	moderate	strong	positive	26.15	extreme
[RF]		no	weak	weak-mod	moderate	strg-vstr	positive	23.08	v. strong
[SC]			no	weak	mod-strg	strg-vstr	positive	20.00	strong
[FL]				no	moderate	strong	positive	16.92	moderate
[CP]					no	moderate	positive	12.31	weak
[TS]						no	positive	1.54	very weak
[all lower]							no	0.00	no

Figure 5. MACBETH weighted judgments for the technology selection.

Options	Overall	PC	RF	SC	FL	CP	TS
Alt 1	55.48	50.00	55.56	60.00	75.00	30.00	77.78
Alt 2	63.41	75.00	77.78	30.00	50.00	80.00	100.00
Alt 3	64.78	25.00	100.00	80.00	50.00	80.00	55.56
Alt 4	55.23	0.00	77.78	80.00	75.00	60.00	77.78
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00	100.00
[all lower]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.2615	0.2308	0.2000	0.1692	0.1231	0.0154

Figure 6. Table of scores for technology selection.

Purchasing cost has the highest criteria weight with 0.2615 following by references and system compatibility criteria. Technical support criterion has the lowest weight in this decision problem. Each alternatives' scores based on the criteria are calculated and then weighted with the criteria weight to find the overall scores. Overall scores are used to rank the alternatives. Alt 3 – Alt 2 – Alt 1 – Alt 4 is the result of the decision process.

## 4. Results and Discussion

Small or big any company in a competitive environment seeks solutions to gain advantage over its competitors. In its simple form, this can be achieved by effective usage of the resources. Search for effectiveness mainly points the technology usage which is an integrated part of any kind of actions in the company like transportation technologies, information technologies, production technologies and etc.

In this paper, selection of the technology is discussed as a competitive point of view. Through different alternatives, it's very difficult to comprehend and analysis the related factors. Many solution approaches are developed and a MCDM method known as MACBETH is used for this problem. Decision makers can evaluate both quantitative and qualitative criteria within a given scale. Also decision makers can use interval values for the pairwise comparison which is an advantage from the classical methods like AHP.

Four different alternatives are compared by using six criteria. After the evaluation process, the alternatives are ranked as Alt 3 – Alt 2 – Alt 1 – Alt 4. For further studies, robustness of the decision model and sensitivity analysis of the criteria can be investigated.

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