AN INTEGRATED AHP-QFD APPROACH FOR EVALUATING COMPETING TECHNOLOGICAL PROCESSES

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ABSTRACT

A major challenge for decision makers in business organization is making appropriate choices among competing high-tech projects. The objective of this paper is to explore a multi-criteria analytical model that can be used for the selection and management of competing manufacturing technologies. The model uses an integrated approach combining Analytic Hierarchy Process (AHP) and Quality Function Deployment (QFD) as the basis for selecting a preferred alternative from a set of competing projects. Integration of the two techniques helps to provide a more effective selection process. Two competing chemical processes to produce drugs are used as a case study to demonstrate and validate the AHP – QFD model. The policy makers of pharmaceutical and chemical organizations can use this model as a part of their strategic planning and decision-making process.

Keywords: Analytical Hierarchy Process (AHP); Quality Function Deployment (QFD); Multi-criteria decision making; technology evaluation; technology assessment; technology management

1. Introduction

Policy makers in manufacturing organizations are often involved in the selection of competing manufacturing technologies and processes. All selection mechanisms somehow reflect the selection of what creates the most net value to the buyer.

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Technology is viewed as one of the major factors that determine the competitiveness of an industry (Huang et al., 2008). As a result, the selection of a proper manufacturing process and the technology behind it generally proves to be a key aspect of a firm's strategic decision-making process. An improper technology selection may adversely affect the manufacturing process of an organization. This may result in reduction of productivity and profitability of the organization. Choosing among competing technologies is driven by the need to fulfill customer requirements in the targeted market segment (Partovi, 2007). There are also many other factors, ranging from the availability of resources to the specific technology constraints that might prevail in an industry that impact the decision. Hence, the selection of technologies is not dependent upon a single criterion, but on a variety of factors. Selection and assessment of technology often involves decision-making tools and techniques that are vital to the growth and profitability of the organization and involves the analysis of a large number of tangible and intangible factors (Georgakellos, 2005). Therefore, using approaches that take into account wide ranging attributes – both subjective and objective - is an important aspect in the selection of an alternative from a set of competing technologies (Atthirawong & MacCarthy, 2002).

The purpose of the paper is to evaluate an integrated multi-criteria approach for the selection of competing manufacturing processes. The integrated analytical approach combines Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD). AHP allows the decision-makers to successfully accommodate both objective and subjective judgments of the evaluators involved in order to make trade-offs and determine priorities among them (Allama et al., 2012). AHP, due to its flexibility and ease of use, can be integrated with other decision-making techniques like QFD, ANP, and so on. This combination allows the consolidation of both qualitative as well as quantitative factors – thereby providing the policy makers with a more accurate and realistic decision (Vaidya & Kumar, 2006; Ho, 2008). In the context of the current research, AHP is used to determine the pair-wise relationship among the customer requirements, and QFD is used to assess the relationship among the customer and technical requirements. Based on the relationship coefficients among the customer and technical requirements, AHP is once again used to determine the best alternative. A more in-depth discussion about the research process is provided later.

The integrated AHP-QFD approach used in this paper has been utilized previously in the literature. However, a review of literature on this technique clearly indicated that this has not been utilized to determine the selection criteria among alternative capital projects in the pharmaceutical drug manufacturing sector. Furthermore, the AHP-QFD technique used in this paper is simple to conduct and attempts to stay away from complicated mathematics, while making sure that the technical and customer requirements are taken care of. Therefore, through this research technique, the authors develop a simple, yet novel technique for selection of alternative techniques for pharmaceutical drug manufacturing and thereby contribute to the body of knowledge.

The current research tries to shed some light on utilization of an integrated AHP-QFD model to determine the preferred choice of alternative in the chemical and pharmaceutical sector. The integrated AHP-QFD methodology, coupled with the illustrative case study in this paper, can serve as valuable tool for managers to make decisions regarding the choice of competing projects in the pharmaceutical domain. AHP is effective for quantifying qualitative knowledge through the idea of multi-criteria decision-making, thus harboring subjective as well as objective factors in the process, thereby allowing intangible dimensions such as subjective preferences and comfort to be measured (Mustafa & Al-Bahar, 1991; Pecchia et al., 2013). On the other hand, QFD is a tool under the umbrella of Total Quality Management (TQM) that incorporates the voice of the customer in the decision-making process (Hauser & Clausing, 1988). Thus, the use of a decision-making model combining AHP with QFD provides management with a more rational basis upon which decisions can be made, while taking into account the quantitative as well as the qualitative factors of decision-making.

The paper begins with a review of the literature on Analytic Hierarchy Process (AHP) and Quality Function Deployment (QFD) along with an overview of the processes compared as a part of the illustrative example. Next, a flowchart depicting the overall research process is presented. This is followed by an illustrative case example used to explain the various stages of the decision process and data analysis along with the final selection decision. Section 5 makes a critique of the integrated AHP-QFD approach, and the article ends discussing the relevance of the integrated model in the domain of operational management and management science, its usefulness to management practitioners and direction for future research.

2. Theoretical background of the concepts

2.1. Overview of AHP

The Analytical Hierarchy Process (AHP), which was developed by T. L. Saaty, was created to deal with models that have intangible criteria or both tangible and intangible criteria (Saaty, 1980, 2011). It is considered one of the most widely used multiple criteria decision-making techniques. AHP is a decision-making process for prioritizing alternatives attributes when multiple criteria are considered as a part of the decision-making process. AHP uses properties of reciprocal matrices to achieve consistency in pair-wise judgments leading to a cardinal ranking of actions, objectives, attributes and criteria relevant to the decision situation (Hughes, 2009). It allows the decision maker to structure the problem through establishing priorities by means of a hierarchic breakdown of the problem, while taking into account the consistencies of the emitted judgments (Melon et al., 2008). The process of AHP starts with the construction of a hierarchy that describes the problem to be tackled. An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation (Dave et al., 2012).

While constructing the hierarchy, the overall objective of the project is always placed at the top of the hierarchical tree and the main attributes a level below it. The sub-attributes are placed on subsequent levels of the hierarchy and the last level consists of the alternatives from which the selection is to be made. After constructing the hierarchy, the next step in developing an AHP model is to derive the weights of the lowest level of attributes through a series of pair–wise comparisons where each attribute of that particular hierarchical level is compared with its sibling with respect to their relative importance to each other. The pair-wise comparisons are generally made relative to their importance/ desirability, and are normally based on a numerical scale. The pair-wise comparisons are denoted in terms of the relative importance of an attribute with respect to the final alternative decisions. Table 1 shows the nine-point AHP scale along with an explanation of each of the scale levels.

Table 1
Scale for pair-wise comparison using AHP

Relative Intensity	Definition	Explanation
1	Equally Preferred	The two attributes in question *(i and j)* are of equal importance
3	Slightly More Preferred	One variable is a little more important than the other
5	Moderately Preferred	One variable is much more important than the other
7	Highly Preferred	One variable is very much more important than the other
9	Extremely Preferred	One variable is extremely more important than the other
Reciprocal (1/3, 1/5, 1/7, 1/9)	If attribute *i* has one of the above numbers assigned to it when compared with attribute *j*, then *j* has the value 1/number assigned to it when compared with *i*. More formally if $n_{ij} = x$ then $n_{ji} = 1/x$, where n_{ji} = The pair-wise comparison between the ith and the jth attribute	

(Adapted from Saaty, 1980; Lang and Merino, 1993)

After the comparisons are made, they are converted into a numeric scale and entered into a matrix. The resulting data is normalized so that it adds up to one. After the comparison has been completed, the results are combined into a composite score that expresses how well each of the alternatives fits the overall objective (focus) of the decision-making process. In this context, it is worthwhile to mention that the AHP has two options of performing an operation – the distributive mode and the ideal mode (Dolan 2000; Liberatore &Nydick, 1993). The ideal mode of synthesis, which is used more frequently than the distributive mode, is followed in this research. After the final composite score has been calculated and the overall value of the alternatives has been deduced, the last step of the AHP process is that of making the actual decision based on the overall values of the alternatives. The alternative yielding the highest AHP value is chosen.

One can conclude from the above that an AHP analysis helps the decision maker to gain valuable insight into the relative merits of the available decision options. The AHP is a structured method that can elicit more information from target respondents (usually experts or decision makers) (Cheng & Lee, 2001). Another important advantage of the AHP is that pair wise decisions can be tested for consistency (through a consistency ratio) to ensure results that are more rational in nature. In addition, several available techniques of sensitivity analysis demonstrate how changes in the pair-wise comparisons of the criteria weights might affect the result.

2.2. Overview of QFD

QFD is defined as "a method for developing a design quality aimed at satisfying the customer and then translating the customer's demands into design targets and major quality assurance points to be used throughout the production phase'' (Akao, 1995). It is a systematic process that is often used to focus the attention of an enterprise towards its customers (Chakraborty & Dey, 2007). The advantage of QFD lies in the fact that it takes into account the "voice of the customers" and tries to integrate it with the planning, design and development process of a particular product or service (Cardoso et al., 2015). QFD helps any product development team to specify the customer requirements and evaluate each proposed product systematically in terms of its impact in meeting those requirements (Bhattacharya et al., 2005; Hauser and Clausing, 1988; Wasserman, 1993).

The basic tool for QFD is the House of Quality (HOQ), which, in simple terms, is a conceptual map that provides the means of inter-functional planning and communication (Hauser and Clausing, 1988). HOQ is a matrix of matrices and the diagram generally looks like a house where the customer requirements and the resulting technical requirements are ranked and prioritized according to their relationship with each other in order to arrive at an optimal system design (Prasad & Chakraborty, 2013; Reid &Hermann, 1989; Hauser & Clausing, 1988; Chakraborty & Dey, 2007). A QFD exercise begins with gathering the customer needs and requirements and subsequently translating them into design/technical specifications. This ultimately allows an organization to make better decisions, thereby streamlining its design and manufacturing process (Bahil & Chapman, 1993). This, in turn, increases the overall growth of an organization and assists it in gaining a competitive advantage in the industry.

In a market driven by customer needs and requirements, the primary task of a QFD team is to gather the critical technical/process parameters for a particular process/technology that are most likely to affect the customer requirements. Determining the prioritized importance of these requirements often forms the next step of the process. The subsequent steps consist of drawing a correlation among the customer requirements and the technical parameters in order to determine (or rank) the important technical parameters for the process. Finally, the operating conditions set the process parameters and control limits in such a way that the product standards and customer requirements are met before ultimately arriving at a preferred technology for the manufacturing process (Chakraborty & Dey, 2007).

Combining the two powerful decision-making techniques in AHP and QFD into an integrated model can prove to be a very important decision tool for an organization. The integrated technique prioritizes customer requirements, while at the same time dealing with the actual performance measurement of a specific technology or process. This, therefore, helps the decision makers to arrive at a more accurate and rational decision regarding the choice of a particular alternative among a set of alternatives. Furthermore, the model incorporates both the technical aspects of a manufacturing process as well as the customer requirements that are essential for the decision-making process. As a result, the integrated technique covers a broader spectrum of evaluation criteria, thereby making the selection process more robust and accurate in nature, as will be illustrated by this research.

2.3. Overview of the chemical processes to be compared

A case study evaluates two competing chemical processes in the domain of drug discovery and development. The first is a conventional heating (conductive heating) method of chemical reaction. This method has proven successful for over 150 years, but has lately been challenged by an emerging technology i.e., the microwave assisted method of organic synthesis (MAOS). Pharmaceutical companies and biotech firms are increasingly exploring this technology and applying it for library synthesis and medicinal chemistry, for lead discovery and optimization, and even for scale-up (Marx, 2004). This is mainly due to its ability to reduce reaction time, which increases the speed of the chemical reaction and the drug discovery process (Kappe & Dallinger, 2006). Reactions that required hours using the conventional method were completed in minutes using MAOS, usually with higher yield and purer products. Microwave chemistry leads to rapid (minutes instead of hours) reactions, higher yield and purer and more environmentally friendly products. Apart from that, microwave chemistry can generate special products that are not easily produced under traditional chemistry procedures.

The conductive method, which has been prevalent in the industry for over a century, has certain advantages over the MAOS, a technology that has challenged its existence over the last two decades or so. The first and foremost advantage that the conductive method has over the MAOS is its ability to conduct large scale reactions. This is primarily due to the fact that although improving rapidly, there is still a dearth of industrial microwave reactors at present. Additionally,
it is not possible to carry out chemical reactions at room temperature under microwave irradiation which is very much possible to do by conventional method, thereby often serving as a stumbling block for MAOS. Finally, a chemical reaction in which one of the reactants is to be added drop wise in the reaction mixture at a certain temperature is not possible with microwave irradiation, where as there is no difficulty carrying out the same reaction by the conventional method.

The benefits of microwave irradiation are finding an increased role in process chemistry, especially in cases where conventional methods require forcing conditions or prolonged reaction times (Wathey et al., 2002). Over the last few years, MAOS has managed to gain a firm foothold in the area of drug discovery and development (Wathey et al., 2002; Kappe, 2003; Collins, 2010). Several pharmaceutical organizations, who were initially skeptical of the MAOS technique, are gradually adapting the technology into their manufacturing logistics. Although microwave synthesis has a high initial capital cost, it allows a high Return on Investment (ROI) in a very short period of time, thus making it even more popular with the pharmaceutical sector (Kappe, 2003). As a result, MAOS serves as a key component of it currently being executed by a plethora of pharmaceutical, agrochemical and biotech companies as a frontline methodology in their chemistry programs (Kappe, 2003; Collins, 2010).

3. The integrated AHP-QFD research model

This paper explores an integrated AHP/QFD model that is used to choose between two competing technology alternatives. Figure 1 provides a basic flowchart of the generalized decision model using the integrated AHP-QFD approach.

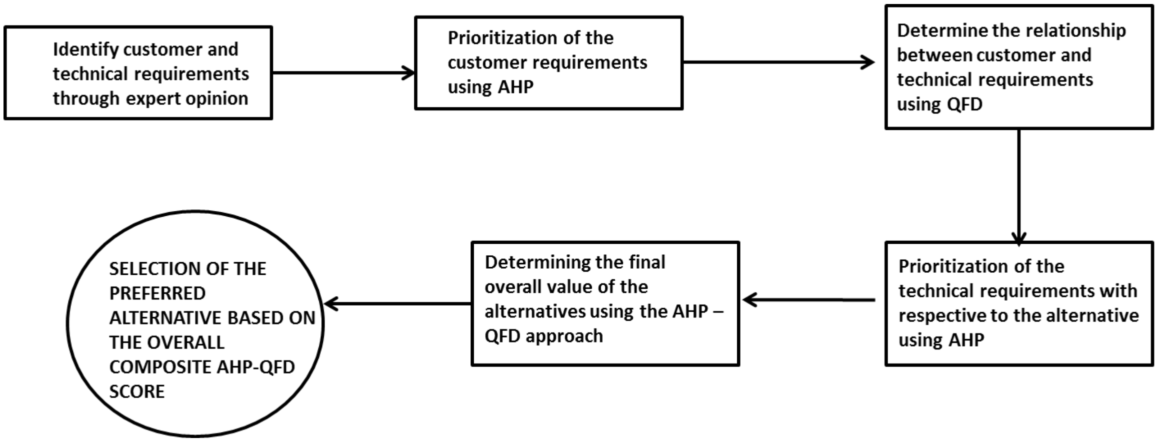

Figure 1. Research model

As seen in Figure 1, AHP is used to prioritize the customer and the technical attributes while QFD is combined with AHP to explore the relationship between the customer demands and the technical attributes. The importance of QFD in this model is based on the fact that it helps to determine the relationship between customer and technical requirements. Therefore, having an integrated evaluative model which combines both AHP and QFD will enable the decision-maker/engineering managers to arrive at a more authentic and robust decision taking into account both customer and technical aspects of the process. The subsequent sections of the paper discuss in detail the above stages along with the techniques of data gathering and analysis that were followed in each of the stages.

4. Data analysis and research results

To validate the integrated AHP/QFD model, a case study in the research consisted of evaluating two alternative drug development procedures – the conventional vis-à-vis the microwave method of drug manufacturing. An integrated multi-criteria technique combining the Analytical Hierarchy Process (AHP) along with Quality Function Deployment (QFD) was used to arrive at a decision regarding the preferred technology. Based on these analyses a decision was made about the competing technologies.

4.1. Identification of customer and technical requirements

Customer and technical requirements were identified through surveys and in-depth discussions with experts in the field of synthetic chemistry and drug development. Even though the literature on synthetic chemistry revealed the presence of a large number of attributes, the empirical evidence indicated that not all of the attributes were of equal importance in the selection process (Ganguly & Merino, 2007). Hence, the first step in identifying the customer and technical requirements was an in-depth interview with subject matter experts. Since one of the selected chemical processes was a part of the illustrative case example, the number of subject matter experts chosen was not a very large pool. A set of twenty five experts were surveyed to obtain the data for the research. The experts surveyed were eminent research scientists in the field of microwave chemistry and drug development who had produced over 500 published journal and conference articles. They also served as consultants for various major pharmaceutical organizations over the last 25 years (Ganguly &Merino, 2007). A survey involving a group of experts was used to narrow down the number of attributes from the initially selected list. The purpose of the survey was to convert the large set of initially listed requirements into a smaller subset comprising only the critical attributes. The survey consisted of a structured questionnaire where the respondents were asked to rate the importance of each of the attributes on a scale of 1 – 5, with 1 being least important and 5 being extremely important. Based on their responses, the results were aggregated and the top five attributes chosen for final analysis. Condensing the set of attributes helps to minimize the large number of attributes which can make it increasingly difficult for the survey respondents to make pair-wise comparisons (Tam & Tummala, 2001). The top five customer requirements and six critical technical requirements that were thought to be most influential in determining the final preferred alternative were identified based on the respondents' feedback. Tables 2 and 3 list the finalized set of customer and technical requirements that were used in the integrated AHP-QFD model along with their operational definition.

Table 2
Customer requirements and their operational definition

	Customer Requirements	Operational Definition
1	Reaction Time	Time taken to complete the chemical reaction
2	Yield	The total yield of the final product
3	Environmental Benefits	The negative effect that the energy and other by-products generated from the chemical reaction has on the environment
4	Cost of the Reaction	The total cost associated with the chemical reaction
5	Revenue Generated	The revenue generated from selling the final manufactured product

Table 3
Technical requirements and their operational definition

	Technical Requirements	Operational Definitions
1	Controlled Reaction Condition	The ability to control and monitor the reaction conditions and environment
2	Minimal Solvent Use	The amount of solvent required to conduct the reaction successfully
3	Minimal Waste Materials	The amount of waste materials in the form of chemicals, solvents and other by-products generated as a part of the reaction process
4	Energy Saving Reaction	The amount of energy that is saved as a result of using a particular manufacturing process
5	Upward Scalability of the reaction	The ability of the reaction to be conducted on a large scale basis from an laboratory basis
6	Reproducibility of the reaction	The ability of the reaction to be reproduced / repeated over and over again with the same level of success

4.2. Prioritization of customer requirements

The first stage of Customer Requirements (CR) prioritization consisted of designing a questionnaire in conformity with the decision hierarchy. The vital customer requirements relevant to the decision-making process (Table 2) were listed to form a matrix for pair-wise comparisons. The pair-wise comparisons were performed with respect to the customer requirements, given the overall objective of the decision-making process. The next step involved inviting experts in the field of drug development and synthetic chemistry to complete the designed questionnaire.

The pair-wise comparison matrix obtained from the set of evaluators was then combined to determine the consensus pair-wise comparison matrix (Saaty, 1980). Expert Choice 2000® (http://www.expertchoice.com/) was the tool used to perform the AHP analysis and the results subsequently recorded. As stated previously, based on the expert panel input, five attributes emerged as the most important. Thus, only 10 judgments [(n (n-1)/2] were required from each of the participants. In the case of the proposed research, the small number of attributes considered kept the analysis and the pair-wise comparison to a manageable proportion. The matrix was subsequently normalized in order to obtain the unique priority weights for each of the attributes (Saaty, 1980; Tam & Tummala, 2001).

Table 4 provides a pair-wise comparison among the selected customer requirements along with their mean normalized weights and the consistency ratio.

Table 4
Pair-wise comparison among the customer requirements and their normalized weights

	RAW WEIGHTS						
Attributes	**Yield**	**Reaction Time**	**Env. Ben.**	**Revenue**	**Cost**	**Normalized Weights of Customer Requirements**	**Consistency Ratio**
Yield	1	5	3	1/7	1/5	**0.107**	**0.14***
Reaction Time	1/5	1	3	1/7	1/5	**0.053**	
Env. Ben.	1/3	1/3	1	1/9	1/7	**0.032**	
Revenue	7	7	9	1	5	**0.564**	
Cost	5	5	7	1/5	1	**0.244**	

** The consistency ratio indicated a slight variation from the acceptable range. The explanation for this is provided later.*

The experts surveyed as a part of the research analysis were asked to evaluate the customer requirements based on the scale provided in Table 1. For example, if one of the customer requirements, for example yield, was somewhat preferred over reaction time, the intersection cell between yield (on the row) and reaction time (in the column) would have a value of 5 while the intersection cell between yield (on the column) and reaction time (on the row) would have a value of 1/5. Furthermore, it should be mentioned here that the above table depicts the pair-wise comparison among the attributes as provided by one of the experts surveyed and is not a composite mean of the complete survey feedback. The feedback received from the other evaluators was analyzed in a similar fashion and the results obtained were used as part of the final research results.

4.3. Construction and analysis of the QFD correlation matrix

The next stage of the research process consisted of developing the QFD correlation matrix, which forms the backbone of the QFD analysis. A correlation matrix was constructed to determine the relative importance of the Technical Requirements (TR). As stated earlier, the critical technical requirements were determined based on the interviews with the experts and through literature reviews. A correlation matrix template was subsequently developed where the survey respondents were asked to map the effect of the listed technical requirements on the customer requirements using a scale of zero to five (0 – 5) where zero signified no correlation and five a very high correlation. The degree of correlation provided by the respondents was used (with the previously determined prioritized customer requirements weights to determine the relative importance of the technical requirements with respect to the customer requirements. This was determined using Equation 1 given below:

$$W_j = \sum_{i=1}^{n} X_{ij} * Y_i \qquad (1)$$

Where,
W_j = Relative importance of the j^{th} technical requirement
X_{ij} = Correlation between the i^{th} customer requirement and j^{th} technical requirement in the QFD matrix and
Y_i = Prioritized weights of the i^{th} customer requirement

Also, since all of the CRs were considered while determining the overall prioritized weight of the TRs, the equation is summed over the entire set of customer requirements, thereby indicating ***i = 1 – n*** in the equation.

The final step in this process was to normalize the degree of importance of the technical requirements determined through Equation 1. Table 5 depicts the correlation matrix and the overall importance of the technical requirements along with their normalized value.

Table 5
The QFD matrix denoting the relative importance of the technical requirements with respect to customer requirements

	Controlled Reaction Condition	**Min. Solvent Use**	**Min. Waste**	**Energy Saving Reaction**	**Upward Scalability**	**Reproducibility**	**Prioritized Weights of Customer Requirements (From Table 4)**
Yield	2	4	4	1	3	3	***0.107***
Reaction Time	5	3	3	3	2	2	***0.053***
Environmental Benefit	3	4	4	4	1	2	***0.032***
Revenue Generated	1	3	2	1	5	5	***0.564***
Cost Incurred	4	4	1	1	3	4	***0.244***
Degree of Importance of the TR (W_j)	**2.115**	**3.383**	**2.087**	**1.202**	**4.011**	**4.287**	**-**
Normalized W_j (k_j)	**0.124**	**0.198**	**0.122**	**0.070**	**0.235**	**0.251**	**-**

Once again it should be mentioned here that the above table only depicts the relative importance of the technical requirements with respect to the customer requirements as provided by one of the experts surveyed and not a composite mean of the complete survey feedback. Since the emphasis was on understanding the degree of association among the customer and technical requirements and not the direction of the relationship, the signs of the correlation coefficient were ignored at this stage.

4.4. Prioritization of the technical requirements with respect to the alternatives

The next stage of the decision process involved ranking two alternative chemical processes based upon the six TRs. A different survey was constructed and the respondents were asked to compare the two alternative chemical processes based upon the TRs that were already enlisted and ranked. Tables 6 – 11 provide the reader with the result of the analysis.

Table 6
Pair-wise comparison among the alternatives with respect to *Controlled Reaction Condition*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conventional	1	1	**0.500**	**0.00**
Microwave	1	1	**0.500**	
Total	-	-	**1.000**	**-**

Table 7
Pair-wise comparison among the alternatives with respect to *Minimum Solvent Use*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conventional	1	1/5	**0.167**	**0.00**
Microwave	5	1	**0.833**	
Total	-	-	**1.000**	**-**

Table 8
Pair-wise comparison among the alternatives with respect to *Minimum Waste Materials*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conventional	1	1/5	**0.167**	**0.00**
Microwave	5	1	**0.833**	
Total	-	-	**1.000**	**-**

Table 9
Pair-wise comparison among the alternatives with respect to *Energy Saving Reaction*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conventional	1	1/7	**0.125**	**0.00**
Microwave	7	1	**0.875**	

Table 10
Pair-wise comparison among the alternatives with respect to *Upward Scalability of the Reaction*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conv. Chem.	1	5	**0.833**	**0.00**
Mic. Chem.	1/5	1	**0.167**	
Total	-	-	**1.000**	**-**

Table 11
Pair-wise cmparison among the alternatives with respect to *Reproducibility of the Reaction*

Attributes	**RAW WEIGHTS**		Mean Normalized Value	C-Ratio
	Conventional	Microwave		
Conventional	1	1	**0.500**	**0.00**
Microwave	1	1	**0.500**	
Total	-	-	**1.000**	**-**

Although mentioned previously, it should be pointed out again that the above set of tables shows the pair wise comparison among the attributes as provided by one of the experts surveyed and not a composite mean of all the survey feedback. The survey feedback from the other respondents was analyzed in similar fashion and the overall composite results from all the surveys were used as the guiding factor for the final decision regarding the process choice.

4.4. Computation of the final value for the alternatives

The final stage of the decision framework consists of computing the overall AHP-QFD values of the alternatives and ranking these alternatives in their order of importance. The final overall value was calculated using Equation 2 given below:

$$A_x = \sum_{j=1}^{n} kj * bij \qquad (2)$$

Where,
A_x = Overall score for the alternative chemical processes
k_j = Normalized weights of the j^{th} technical requirement
b_{ij} = Value of the j^{th} alternative on the i^{th} technical requirements

4.5. Selecting the preferred alternative

The technology with the highest overall value was selected as the preferred choice based on the integrated AHP-QFD model. The final overall value of the alternatives as provided by one of the experts is given in Table 12.

Table 12
Final values of the alternatives

		OVERALL WEIGHTS FOR THE ALTERNATIVES WITH RESPECT TO THE TECHNICAL REQUIREMENTS	
Technical Requirements	**Prioritized Weights for the Technical Requirements**	**Conventional Chemistry**	**Microwave Chemistry**
Controlled Reaction Condition	0.124	0.500	0.500
Minimal Solvent Use	0.198	0.167	0.833
Minimal Waste Materials Generated	0.122	0.167	0.833
Energy Saving Reaction	0.070	0.125	0.875
Upward Scalability of the Reaction Process	0.235	0.833	0.167
Reproducibility of the Reaction	0.251	0.500	0.500
FINAL OVERALL SCORE	**-**	**0.4454**	**0.5545**

As can be seen from Table 12, the final overall value of the microwave method was higher than the conventional heating method for drug development. Hence, it can be concluded that when using the integrated AHP-QFD technique for process selection, the MAOS method is clearly the preferred choice for the decision makers.

As mentioned repeatedly, the values provided so far comprised the feedback from one of the experts. The survey responses from the other experts were analyzed in a similar fashion and the mean of all the overall scores was used to arrive at the conclusion. The mean overall scores along with the standard deviation and range for the two alternatives based on all the responses are shown in Table 13.

Table 13
Mean overall values for the alternatives

	Conventional Method	**Microwave Method**
Mean Overall Values	0.4436	0.5564
Standard Deviation	0.0130	0.0130

Results from Table 13 indicated that the microwave method for chemical process is a better alternative because it had the highest overall value. Furthermore, the low standard deviation values indicated that the experts fairly agreed with each other in spite of having been surveyed separately, thus adding robustness to the research.

4.6. Are the pair-wise inputs consistent?

The consistency ratio analysis indicated a small variation. The mean of all consistency ratios for pair-wise comparison of the customer requirements came out to be 0.15, which was slightly more than the acceptable range (≤ 0.10). The primary reason is that pair-wise comparison among the attributes selected was not transitive. For example, the relative importance of reaction time being greater than the yield and the relative importance of yield being greater than the environmental benefit does not necessarily signify that reaction time will hold a position of more importance than its environmental benefit. As a result, the final AHP judgment values were kept intact and were not revised to lower the consistency ratio to within the permissible range. According to Saaty (2001), evaluators often make tradeoffs that violate transitivity but, overall, are accurate in their judgment since they take into account the relative importance of the criteria themselves. There are times when an evaluator cannot make a clear decision because the tradeoffs among several activities are the same and are not related to some other pair-wise judgment (Saaty, 1980). Also, Tam et al. (2006) states that the root of this problem stems from the 9-point scale of relative importance proposed by Saaty. The scale assumes that the decision-makers understand well the relationship and the magnitude of differences among various decisions under consideration. However, in practice, using such a complicated scale makes it extremely difficult to achieve an absolute consistency in the evaluation process (Tam et al., 2006). They recommend the use of “non-structural fuzzy decision support system” (NSFDSS) as an alternative tool in order to reduce (or even eliminate) the problem of inconsistency, something that should definitely be an important part of future research (Tam et al., 2006).

5. Critique of the integrated AHP-QFD approach

The integrated AHP-QFD approach is a comparatively new technique that can serve as a valuable addition to the toolbox of any decision maker. It is a powerful approach in the selection of alternative manufacturing/ engineering projects. While the case example was directed towards the pharmaceutical sector in the context of this research, this integrated approach can also be applied to a plethora of other engineering decisions. This technique can also be particularly useful in evaluating and assessing a new technology, especially in comparison to an existing technology.

The integrated QFD/AHP approach applies two multiple (group) consensus management techniques of decision-making and allows the policy makers to arrive at more robust decisions. It also allows for organization through integrating both customer and technical requirements, to look at the selection process from both an internal as well as an external point of view. The developed model can help any manufacturing /engineering organization to minimize the risks associated with embracing a new technology over an existing one. Furthermore, this model can aid in a better allocation of an organization’s technological resources along with obtaining a group based decision-making policy – thereby resulting in an effective strategic planning framework for the selection/evaluation of alternative technologies.

Despite the flexibility of the integrated approach, it is not devoid of limitations. The major limitation of this approach is its implicit assumption of transitivity among the pair wise judgments. The AHP implicitly assumes a logical transitivity among the pair wise judgments, which is not always the case in a real-life decision-making process. Thus, the actual value of the Consistency Ratio (CR) in AHP often ends up being higher than the desired value (i.e., ≤ 0.10) since the pair wise judgments of the decision maker are not always transitive in nature for all practical purposes. For example, in the present research, the consistency ratio was slightly greater than 0.10 when performing pairwise comparisons between the customer requirements. Furthermore, the large number of AHP and QFD comparisons that have to be drawn among the attributes often proves to be a tiring and lengthy process, thereby consuming experts’ valuable time.

6. Relevance of the research to decision makers

This research dealt with the problem of choosing between two alternative hi-tech capital projects. The proper selection of a manufacturing process is complicated and requires detailed analysis before committing to huge capital investments. Hence, choosing among competing technologies for any manufacturing process is key to effectively managing technology projects. This is a typical problem for the managerial policy makers and technology managers. The case presented demonstrates to the decision-makers, especially in the pharmaceutical industry, how to use various techniques to choose among alternative technological projects. Even though the case study used in this article involves a chemical process, this technique can also be applied in various other areas pertaining to decision-making and technology management.

The insight of the techniques discussed in this paper can considerably aid the policy makers to gain more knowledge about the techniques and practical applications of decision-making. This, in turn, could lead to a more effective decision-making process and hence a better selection of technological projects. Additionally, using non-economic decision-making tools in tandem with economic tools like sensitivity analysis and after tax analysis provides the decision-makers with the knowledge of how to combine these tools to make a more robust decision regarding the choice of a project. The decision-making techniques as illustrated in this research article can be used either independently or in conjunction with the economic analysis in order to arrive at a more robust and accurate decision, and therefore serve as an important element of the total decision process.

7. Conclusion and future research

As seen from the research results, the AHP-QFD analysis indicates that the chemical process involving the microwave irradiation method should be the preferred alternative as it yielded a higher overall value. The purpose of this paper was an attempt to show the effectiveness of an integrated AHP – QFD model for the selection of capital projects. While the technique of QFD was pivotal in determining the relationship among the customer and the technical requirements, AHP was used to determine the relationship between the variables in the model, especially the customer requirements and alternative selection of the technical requirements. Thus, an effective integration of the two techniques, as shown in the research, allows the decision makers to arrive at a more rational decision while taking into account the idea of multilevel hierarchy. Additionally, the proposed methodology might be particularly well suited to a multi-criteria environment where the data is often unstructured and the information complex – an environment that describes the domain of drug development. In such a situation, a proper evaluation of the requirements, both customer as well as technical, can prove to be very important in the final decision-making process for the appropriate selection of an engineering project. Also, the integrated model analysis used in this research can be applied to almost any other technological decision-making processes. Furthermore, although the proposed illustrative case example discusses only two alternatives, this model can be used for a situation that is concerned with more than two alternatives. Using more than two alternatives does not change the structure of the model, but only introduces one (or more, depending on the situation) extra alternative into the decision-making process.

Future research could be directed towards using the AHP analysis at a more detailed level by constructing another level of hierarchy comprising the sub-factors of the attributes selected for pair-wise comparison. In addition, the technical requirements could be further subdivided in order to arrive at an even more detailed correlation between the customer and the technical requirements. Finally, using the integrated AHP-QFD model in the selection of various engineering and technology projects would definitely aid in enhancing the overall robustness of the model. This would provide the decision makers with a more in-depth result and thus a more accurate conclusion regarding the choice of alternatives.

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