Using the AHP to Determine the Correlation of Product Issues to Profit

Dr. M.H. Muller & Dr A.C. Fairlie-Clarke

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Abstract

The paper discusses a new application of the AHP to a problem where the alternatives are not independent. It is used as an integral part of a method to evaluate the likelihood of successful outcomes from current or proposed product development processes. The AHP is used to determine correlation factors to estimate the impact on profit of the various product issues that must be addressed by a company during the product development process. Due to interactions between the 'alternatives', it was found, as expected, that the AHP could not be used directly to determine these correlation factors. A procedure to overcome this has been developed whereby the correlation factors are determined first by assuming independence between alternatives, and then modifying the factors to take account of any interactions. Test results are promising, and further refinements to improve the method are suggested.

Keywords

Analytic Hierarchy Process, New Product Development, Product Development Process.

Introduction

Successful New Product Development (NPD) has long been, and remains, key for growth and survival of many manufacturing companies. Cooper (1980) notes "New product development stands out as one of the most crucial yet deficient functions of the modern corporation .... more and more firms are taking a critical look at their new product efforts." More recently Hart (1995) observes "Recognition of the importance of new product development to corporate and economic prosperity, coupled with the high risk of failure in such endeavours, has triggered considerable research interest in the dynamics of NPD." Montoya-Weiss and Calantone (1994) show that proficiency of NPD process activities is an important factor for success, while McGrath and Romeri (1994) identify measurement, assessment and evaluation of process performance as being important in ensuring NPD process proficiency.

Fairlie-Clarke and Muller (1998) report on a method to evaluate the potential of a particular Product Development Process (PDP) to produce successful product outcomes (Figure 1). The objective was to develop an evaluation method that would relate to the unique requirements of any company. Statistical methods are obviously not appropriate to analyse unique situations, so the approach adopted was to devise an evaluation scheme to meet the requirements, and then to expose this scheme to criticism and subject it to trials. At the time of writing this paper, sufficient positive feedback has been obtained to support continuation of the work, but more extensive trials will be required to validate the efficacy of the method.

The approach used in the evaluation method is to combine the expert knowledge of company staff about their markets, products, technologies, processes, resources, culture etc. with expert knowledge about management methods and the PDP. A feature of the method is that the evaluation is undertaken by the company itself, and it can address any form of PDP, not just compliance with prescribed procedures. The method requires a company expert (or experts) to identify the issues that primarily determine the success of their products (the determinants of profit (DoP)), and then to relate these issues to the activities that address them. If activities that address the important product issues are performed effectively then there will be a better probability of successful outcomes (Montoya-Weiss and Calantone, 1994). The activities are organised into a number of generic (i.e. related to manufacturing industry in general) elements (GE) of the PDP (e.g. Identify requirements and generate Product Design Specification) in order to provide a structure for the evaluation of activity effectiveness. The effectiveness of each GE in helping to resolve each DoP is assessed by quantifying the quality of execution (i.e. effectiveness) of each constituent activity. Each activity is considered to be characterised by interfaces and resources associated with the activity. Activity effectiveness is determined by assessing the existence and quality of these characteristics and assessing them in the context of current management best practice

Take in Figure 1

It is important to be clear about the distinction between a DoP and the PDP. For example, an important issue in developing a new car may be that the acceleration should be correct for the target market. This is a DoP. It is a function of the PDP to decide what is the correct level of acceleration for a particular car. The DoP are the issues that have to be addressed effectively by the PDP. The ability to make a clear distinction between the DoP, that identify important product issues, and the PDP that resolves those issues, was an important factor tested by the industry trials of the evaluation method.

The purpose of this paper is to describe the use of the AHP to quantify the correlation factors between the various constructs of the evaluation method

Correlation Factors

The correlation factors are weightings that represent the proportional effect that each component has on a parent issue. Figure 2 shows the connections between the components of the method. Thus, the weighting of the effect that each DoP has on determining the potential for profitable outcomes is described as the correlation factor between that DoP and profit, and this must be estimated for every DoP as the first step when using the evaluation method. The assumption is that profit is fully determined by the set of DoP identified by the company for the product under consideration. The potential for profit from a particular PDP is determined by the effectiveness with which each issue identified as a DoP is resolved. This is a function of the quantified effectiveness of each pertinent GE and its relative contribution to realising that DoP (Fairlie-Clarke and Muller, 1998). Thus a further set of correlation factors must be established between the GEs and the DoP which indicate the degree to which the outcome of each DoP is influenced by each set of activities represented by a GE. Also, the quality of each activity characteristic does not contribute equally to the overall effectiveness of the parent activity, and the effectiveness of each constituent activity does not contribute equally to the overall effectiveness of the parent GE. Thus correlation factors must also be estimated to describe these relationships.

Take in Figure 2

The main topic of this paper is the procedure adopted to determine these correlation factors. The procedure must satisfy the following requirements.

1. It must have the capability of eliciting expert judgements from the users of the PDP evaluation method.
2. It must be able to quantify these judgements to determine the relative importance or contribution of components to a common goal.

3. It must accommodate the network system of linked components shown in Figure 2.
4. It must accommodate at least 18 alternatives (or components), this being the number of GEs.
5. It must accommodate the fuzziness inherent in expert judgements.
6. It must account for any interactions amongst the DoP.

The basic requirement is to interpret the users judgements so as to quantify the relative contribution of each component to its parent. The AHP is an available procedure specifically designed to fulfil this function. It was selected for evaluation against the requirements because of its ease of use and because it is readily applicable without recourse to a facilitator (although one has been used during the trials) by using a computer based software package such as Expert Choice (Dyer et al 1988). Further, it is a descriptive theory (Saaty 1990b), which is consistent with the design objective that the PDP evaluation method should not be prescriptive.

The Analytic Hierarchical Process (AHP)

The AHP was developed by Saaty (1990a) who demonstrated the feasibility of expressing, either verbally or numerically, the importance of one element (or alternative) relative to another with respect to a given criterion. Expert judgement concerning alternatives is elicited using a pair-wise comparison method based on the response to a question such as: "In terms of realising the goal, which of the two alternatives is more important, A or B? Quantify the relative importance of A over B (or vice versa)." The expert first has to judge which alternative is the more important or makes the greater contribution, and then quantify the degree of importance/contribution. Each pair of alternatives is considered in turn using the numerical scale or linguistic responses given by Saaty (Table I). The judgements are recorded in a matrix, which describes a set of equations that can be solved for the principal right eigen vector. This vector gives the normalised weights for all of the alternatives, which are used as factors to indicate the degree of correlation between individual component effects and their parent.

Take in Table I

In the computation of the weights, the numerical scale is applied directly as a ratio of importance. Experience has confirmed that a scale of nine units is reasonable and reflects the degree to which humans can quantify relationships among elements (Saaty 1990b).

Saaty (1990a) establishes four axioms that must be true of any system under consideration.

1. Reciprocal Comparison. The decision maker must be able to make comparisons and state the strength of preferences. A reciprocal comparison must be the direct inverse of the initial comparison.
2. Homogeneity. The preferences are represented by means of a bounded scale (e.g. Table I).
3. Independence. Criteria are assumed independent of the properties of the alternatives. i.e. a comparison between one pair of elements is not affected by the properties of any other element.
4. Expectations. For the purpose of making a decision, the system structure is assumed to be complete i.e. all possible alternatives are represented.

In terms of the commonly used semantics, the AHP is described as the pair-wise comparison of a number of alternatives in order to grade the alternatives. However, in this application it is not strictly alternatives that are considered but rather components, all of which contribute to the performance of the parent. It is the relative level of contribution that must be determined.

Review of the AHP against the Requirements

Use of the AHP to obtain component weightings is well established. Two of the AHP validation experiments described by Dyer and Forman (1991) provide examples. In the first, respondents were asked to make judgements about the relative sizes of five geometrical shapes using pair-wise comparison with the verbal criteria given in Table I, but with importance replaced by ratio of size. Analysis of the results using the numerical scale in Table I shows that verbal judgements can provide quite accurate estimates of the actual numerical ratios. The second experiment was based on judgements of perceived light intensity. The power of the AHP was demonstrated by successfully predicting the inverse square law from verbal judgements of intensity levels. Other relevant work which supports the choice of the AHP for this application includes Forman (1992), who describes the use of the AHP to determine factors of certainty for expert system rules, and Dobias (1990), who produces weightings of the relative importance of design criteria for new product development. Requirements 1 to 4 are readily satisfied by the AHP. The issue of fuzziness is addressed by Zahedi (1986), Ruoning and Xiaoyan (1992) and Weck et al (1997), who all show that some degree of fuzziness can be incorporated into the AHP. Also, Tsaur et al (1997) describe a procedure that permits the user to define fuzzy numbers for each verbal judgement and then execute the analysis using these fuzzy numbers. Thus, the literature shows that requirement 5 can be satisfied.

However, requirement 6 is not satisfied because it violates Saaty's third axiom. Interactions exist between DoP, the effect of which must be quantified. It was considered that the advantages of the AHP’s were such that it was worth some effort to find a way of handling the interactions in conjunction with the AHP.

DoP Interactions

A scenario can exist where the impact on profit of one DoP may be dependent on first effectively realising one or more related DoP. For example, the DoP for an electric toaster may include 'selling price', 'aesthetics' and 'features'. However, the benefit of selling at an appropriate price is only achieved if the toaster has the specific features and aesthetic appeal expected by customers prepared to pay that price. If these features and aesthetic appeal are not realised to the correct level by the PDP, then the impact of selling price on profit is negated. Thus it can be seen that the impact of one DoP may not be independent of others.

In order to retain the numerical basis of the evaluation method it is necessary to quantify these interactions. This is done by taking each DoP in turn and estimating, through judgements made by the user in response to an appropriate question, the strength of the interaction effect (SI) on the 'subject' DoP from each of the other 'interacting' DoP. If there is no interaction then SI = 0, and if there is complete interaction, such that no benefit would be gained from the subject DoP if the interacting DoP was not realised effectively, then SI = 1.0. The limits of 0 and 1.0 are used to maintain numerical consistency with other aspects of the evaluation method. The strength of interaction from each DoP is assumed to be independent and can be estimated directly by the user of the evaluation method. Alternatively, the AHP can be applied again to assist the user. Pair-wise comparisons are executed in response to the question: "which of the following two DoP [from the interacting set] has the greater negative effect, if not realised effectively, on the subject DoP? Use Saaty’s scale to quantify the relative effect." The weights obtained from the AHP provide the relative values of the SI, normalised to sum to 1.0. The absolute values of SI_{ij}, which give the strength of interaction of the ith. interacting DoP on the jth. subject DoP, are obtained by the user placing an absolute value, on the scale from 0 to 1.0, against the highest weight obtained from the AHP, and then applying the same conversion factor to the remaining weights. A consequence of this is that the cumulative impact is not well represented by the sum of the individual strengths of interaction, which may easily exceed 1.0. A procedure is required that will estimate the cumulative impact of several interacting DoP. This must apply the full impact of a single interacting DoP, but progressively reduce the impact of additional interacting DoP so that the total cumulative strength of interaction does not exceed 1.0, or some lesser value ($SImax_j$) that the user may assign if it is felt that some benefit will still derive from the subject DoP, even if all interacting DoP act to negate the benefit. It is logical and necessary that all SI_{ij} should be less than or equal to $SImax_j$. The procedure that has been developed involves the effectiveness measure (η) of the DoP, and the impact of effectiveness must therefore be considered before the procedure is presented.

Impact of Interactions on Correlation Factors

A particular feature of DoP interactions is that they only have an impact when DoP are realised with an effectiveness of less than 100%. Such DoP are described as 'incomplete'. Saaty's third axiom can therefore be satisfied if all the DoP in an interacting set are assumed to be realised with an effectiveness of 100% (i.e. to be complete). The use of the AHP to correlate DoP to profit under this constraint was tested successfully in industry. Weightings were obtained using the AHP, and the industrial practitioners were then given the opportunity to review their judgements if they considered the resulting correlation factors to be inappropriate. In the rare instances where consistency ratios (Saaty 1990b) were greater than 0.1 practitioners were asked to reconsider their judgements, but were allowed to retain their original judgements if they still felt them to be appropriate (an approach that is supported by Saaty (1990a) and Dyer and Foreman (1991)). Some initial tests were also conducted to see whether the AHP could be applied in the presence of interactions. These are described in the section 'Approach 1'. However, it became apparent that this required an unreasonable degree of mental agility, and it was therefore necessary to develop and test a specific procedure to account for DoP interactions. This procedure is discussed in the section 'Approach 2'.

<u>Approach 1. Modification of the Pair-Wise Comparison Question</u>

The objective of this modification was to quantify the effect of interactions amongst a set of DoP. It was thought that DoP interaction effects could be quantified with the aid of a matrix of correlation factors generated by repeating the full set of pair-wise comparisons in turn assuming that just one interacting DoP was incomplete at a time. Thus a set of normalised weights that reflect each DoP's impact on profit could be derived given that one of the DoP was incomplete. The number of sets of normalised weights for each DoP would be equal to the number of incomplete interacting DoP. These would then be combined to yield a single set of correlation factors reflecting the expert's judgement about the impact of each DoP on profit, in the context of all incomplete interacting DoP.

Clearly, the first step was to ensure that an industrial expert could relate to a modified knowledge elicitation procedure i.e. adding an extra proviso to the standard AHP question. The question was re-phrased to read: "Relative to the goal of maximising the profit potential of the product, which of the following DoP is more important, A or B given that C is incomplete? Use Saaty's scale to quantify the relative importance."

The expert experienced difficulty in answering this form of question. Although he was able to complete the pair-wise comparison matrix, he found it virtually impossible to consider the 'ranking' question with the proviso of incomplete DoP, and when the incomplete DoP had a strong correlation to profit, he found it meaningless to try to compare two less strongly correlated features .

It was concluded that it was not practical to include interaction effects within pair-wise comparison judgements, and that an alternative approach was required.

Approach 2: Decoupling the DoP Interactions

It has already been established a) that interacting DoP can be de-coupled by assuming that the PDP is 100% effective in realising appropriate outcomes (i.e. all DoP are complete), and b) that industry experts are comfortable using the AHP to estimate the correlation factors under this constraint. This provides the basis for Approach 2 in which the 'complete' correlation to profit of each subject DoP is modified to take account of all incomplete interacting DoP.

The modification to the correlation factor is determined by the degree of impact (DI_{ij}) that each incomplete interacting DoP (suffix i) has on the potential for profit that stems from realising the subject DoP (suffix j) 100% effectively. Each DI depends on the strength of the interaction (SI_{ij}) and on the effectiveness (η_i) with which the interacting DoP is realised. Each interacting DoP with $\eta_i < 1.0$ will compound the cumulative negative effect on the potential benefit to profit of realising the subject DoP. The subject DoP's correlation factor to profit (w_j), calculated by assuming that all the DoP are complete, is adjusted by this cumulative interaction effect before its effectiveness η_j is applied.

A DoP that is realised with 100% effectiveness ($\eta_i = 1.0$) has no interaction effect on any other DoP. DI_{ij} is therefore zero for all j (i.e. for all subject DoP). It follows therefore that the degree of impact of an interacting DoP on the subject DoP is only high when its strength of interaction is high *and* it is realised with a low effectiveness. If the strength of interaction is low, or if the effectiveness is high, then the degree of impact will low. The set of possibilities is illustrated in Table II. These are boundary conditions that represent high/low cases only.

Take in Table II

By equating high to the numeral 1.0, and low to the numeral 0, the results in Table II can be represented graphically as the vertex points of two intersecting planes in a three dimensional space, as shown in Figure 3. The four points can define two alternative pairs of planes. The first pair is shown hatched, while the second pair is shown by heavy lines and takes the form of two faces of a pyramid. These alternative planes provide two linear boundaries to the space that probably contains the best estimate of DI as a function of SI and η. At this early stage in the development of the method it was decided to use the linear function defined by one pair of planes, and intuitively the hatched planes are more appropriate since they indicate that there is no significant interaction effect provided that the effectiveness of the process is reasonably good. The value of DI can be obtained from Figure 3 as the intersection of the normal through the point (SI,η) with the planes. This can be expressed algebraically to provide a simple algorithm for the degree of impact.

$$DI_{ij} = SI_{ij} - \eta_i \quad \text{for } SI_{ij} > \eta_i$$

and

$$DI_{ij} = 0 \quad \text{for } SI_{ij} \leq \eta_i$$

Take in Figure 3

In the absence of interactions, the sum of the correlation factors relating DoP to profit ($\sum(w_j)$) is equal to 1.0, and the simplest expression for potential to maximise profit is given by $PMP = \sum(w_j.\eta_j)$. The sum of the modified correlation factors ($\sum(w'_j)$), with interaction effects taken into account, is less than 1.0 if any interacting DoP has $DI_{ij} > 0$. This results in a loss in potential to maximise profit, which is now given by PMP` = $\sum(w'_j.\eta_j)$.

In the absence of evidence to the contrary, the algorithm to modify the correlation factor is based on linear relationships. It is a subject for future research to determine these relationships more exactly. On this basis, the modification to the correlation factor w_j due to the ith. interacting DoP is given by $w'_j = w_j\,(1\text{-}DI_{ij})$. Thus a high DI will have a large negative effect on the potential of the subject DoP to maximise profit. The modification to w_j due to the accumulated effect of several interacting DoP is obtained by applying each successive DI_{ij} to the progressively reducing difference between the accumulating DI and $SImax_j$. By this means the accumulated total degree of impact DIt_j becomes asymptotic to $SImax_j$ if there are a large number of interacting DoP. This gives:

$$w'_j = w_j.(1.0 - DIt_j)$$

Where

$$DIt_j = SImax_j\left(1.0 - \prod_{i=1}^{n}\left(1.0 - \frac{DI_{ij}}{SImax_j}\right)\right)$$

Example

Table III gives some typical values from the evaluation of the PDP for an electric toaster. The correlation to profit of the DoP 'price' is judged to be dependent on two interacting DoP (aesthetics and features). The effect of the interaction is to reduce the potential to maximise profit (PMP) from 0.58 (i.e.$\Sigma\eta$.w) to the calculated value of 0.448 (i.e. $\Sigma\eta$.w`).

Take In Table III

Threshold Effectiveness Values

A further issue was raised during the tests in industry of the method to account for DoP interactions. It was observed that there would be little point in producing a product unless certain DoP were satisfactorily realised by the PDP. For example, a mechanical handling device that did not meet minimum statutory safety requirements would be a non-starter. The evaluation method is only meaningful if the PDP has the potential to deliver viable (i.e fit for purpose) products.

For a ‘safety’ DoP, an effective PDP must not only correctly identify the appropriate level of safety but must also ensure that the product meets this requirement. As the PDP becomes less effective there is less assurance that the optimum requirement will be met, even though the product may still be viable. A PDP that does not address safety at all (i.e. $\eta = 0$) is clearly not viable. There must therefore be at least a notional threshold value of effectiveness (η_{th}) below which the PDP is not viable, and therefore has no potential for successful outcomes. Thus the first step for a company must be to ensure that they have a viable PDP, and only then can they use the evaluation method to benchmark the process.

Clearly then, minimum targets must be achieved for some critical DoP. However it is a fundamental tenet of the evaluation method that DoP do not set target values. Rather it is the function of the PDP to set these values when realising the DoP. The evaluation method should not be dependent on what these values are *per se*. Thus the method requires the user to identify threshold values of effectiveness without first assigning target specification values. It was accepted that some crude judgements would have to be made, but they are necessary to avoid spurious results from the evaluation method by ensuring that a zero potential to maximise profit will be returned if the effectiveness value of any critical DoP lies below its threshold.

During tests in industry it was discovered that it could be difficult to make an absolute estimate of low levels of effectiveness, and that it could also be useful to use threshold values of effectiveness with non-critical DoP. In this case the effectiveness of any DoP that was evaluated as being below the threshold would be recorded as zero, and its degree of impact (DI) would then be equal to the full strength of the interaction (SI) and used as such to modify the subject DoP correlation factors.

Industry Tests

The evaluation method has been evaluated at various stages of development with eight collaborating manufacturing companies, and the complete method tested with three of these companies. In each test, a researcher acted as facilitator to assist the company expert with interpretation of the judgements to be made. The facilitator presented the rationale underlying the AHP and the method for handling interactions. He put forward the alternatives about which the practitioner had to make judgements, recorded the users judgements and inputted the data to calculate the correlation factors (Saaty 1990a, Dyer and Forman 1991) and the interaction effects. The DoP were identified first, and then the sets of interacting DoP were identified by asking the expert "In order to gain the benefit of getting this issue (subject DoP) right, what other issues (interacting DoP) must be got right as well?". The next step was to estimate the strengths of interaction. The GE were then reviewed to determine whether they were all applicable to the PDP under evaluation, and the development activities were listed under the GE. Finally the effectiveness of every activity was estimated.

The first company identified a high level of interaction between DoP, and also set the threshold values of GE effectiveness at a high level. The consequence of this was to reduce the PMP to zero. This arose, to some extent, because of the blocking of judgements due to limited time, and because of an inadequate explanation of the nature of interactions. These issues were rectified prior to the following trials.

Tables IV and V show the results for the second company where the method was applied as described in the paper. No threshold values were set since all DoP were judged to be realised at a high level of effectiveness and the interactions had no influence on the resulting PMP. The PMP was very high and reflects the success of the product produced using the evaluated process. For the purposes of illustrating the method, the effectiveness values in Table V have been reduced a little to show the impact that interactions might have on a basically successful process. This gives a complete PMP of 0.817, which reduces to 0.705 when the effect of interactions is included.

The expert in the third company did not feel able to make close estimates of the strengths of interaction in the time available, so the procedure was modified to simply identify the existence of interactions, and then to apply DI = 0 if the effectiveness of the interacting DoP was above the threshold value and DI = 1.0 if it was below. It was judged that none of the DoP was critical. Tables VI and VII show these results, and the impact of not achieving threshold levels of effectiveness is clearly shown by the low PMP.

The company experts were satisfied that although their judgements were subjective, and even crude in some cases, the procedure did allow them to represent their knowledge of their product and their PDP, and that the results of the evaluation provided a fair reflection of the capability of the evaluated process. The judgements they were asked to make were felt to be insightful and to focus their attention on some issues that were largely handled by default. It needs to be recognised that these findings may be coloured by the fact that the primary purpose of the trials was to test the evaluation method rather than to evaluate the company's PDP. However, the findings are encouraging and warrant further trials with a statistically valid sample of companies.

Discussion

The paper has shown that the AHP can be applied to quantify many subjective judgements that must be made to evaluate the PDP in a manufacturing company, and in particular to determine the correlation of important product issues (DoP) with the likelihood of successful product outcomes. It is shown that interactions can exist between the DoP, and this violates Saaty's third axiom for the AHP. Tests show that it is indeed very difficult to apply the AHP if interactions exist, but a procedure has been developed whereby the correlation factors are first estimated using the AHP with the assumption of no interactions, and are then modified to reflect any interaction effects.

Results of trials in three manufacturing companies show that the AHP is effective in this application. The company experts involved were satisfied that it provided a realistic quantification of their subjective judgements about their products and their PDP. Further work is required to refine the evaluation method to enable company experts to express their knowledge and judgement with increasing accuracy and to interpret the results so as to enable improvements to the PDP. At this stage, many relationships have been assumed to follow a simple linear form, but as more field data is generated it will be possible to refine these relationship to provide increasingly accurate and useful feedback to company management.

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NUMERICAL SCALE	VERBAL SCALE	EXPLANATION
1.0	Equal importance of both elements.	Two elements contribute equally.
3.0	Moderate importance of one element over another.	Experience and judgement favour one element over another.
5.0	Strong importance of one element over another.	An element is strongly favoured.
7.0	Very strong importance of one element over another.	An element is very strongly dominant.
9.0	Extreme importance of one element over another.	An element is favoured by about an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Intermediate value between two adjacent judgements.	Used for compromise between two judgements.
Increments of 0.1	Intermediate values in increments of 0.1	Use for even finer graduations of judgements.

Table I: The Pair-Wise Comparison Scale (Saaty 1990).

Effectiveness (η)	Strength of Interaction (SI)	Degree of Impact (DI)	Vertex Co-ordinates
high	high	low	1;1;0
low	high	high	0;1;1
high	low	low	1;0;0
low	low	low	0;0;0

Table II: Relationship between Effectiveness, Strength of Interaction, and Degree of Impact.

n	Subject DoP	w	η	SI			DI			DIt	w'	η.w'
				1	2	3	1	2	3			
1	Price	.45	.8	-	.5	.7	-	.1	.3	.367	.285	.228
2	Aesthetic	.3	.4	0	-	0	0	-	0	0	.3	.12
3	Features	.25	.4	0	0	-	0	0	-	0	.25	.1
											PMP` = .448	

Table III: Example of the Evaluation Analysis (SI_{max_1} = 0.9)

		Interacting DoP					
n	**Subject DoP**	**1**	**2**	**3**	**4**	**5**	**6**
1	Aesthetics	-	0.5	0.9	0.1	0.7	0.1
2	Technical compatibility	0.7	-	0.9	0.1	0.7	0.1
3	Performance	0.7	0.3	-	0.1	0.9	0.1
4	Reliability	0.5	0.3	0.9	-	0.7	0.1
5	Perceived value	0.7	0.3	0.9	0.1	-	0.1
6	Launch date	0.5	0.3	0.9	0.1	0.7	-

Table IV: DoP Strength of Interaction (SI) Values (2nd company)

n	**Subject DoP**	**w**	**η**	**η.w**	**DIt**	**w'**	**η.w'**
1	Aesthetics	0.15	0.95	0.142	0.1	0.135	0.128
2	Technical compatibility	0.1	0.98	0.098	0.1	0.09	0.088
3	Performance	0.36	0.8	0.288	0.2	0.288	0.23
4	Reliability	0.03	0.95	0.029	0.1	0.027	0.026
5	Perceived value	0.31	0.7	0.217	0.1	0.279	0.195
6	Launch date	0.05	0.85	0.043	0.1	0.045	0.038
				PMP = 0.817			**PMP' = 0.705**

Table V: Estimated and Modified Subject DoP Correlation Factors (2nd company)

n	Subject DoP	Interacting DoP 1	2	3	4	5	6	7
1	PC card standard	-					x	x
2	Store/power performance		-					x
3	Environment performance		x	-				x
4	MTBF		x		-			x
5	Aesthetics					-		
6	Plug and play	x					-	
7	Product road map	x	x	x	x	x	x	-

Table VI: DoP Interaction Matrix (3rd company)

n	Subject DoP	w	η_{th}	η	η.w	DI_t	w'	η.w'
1	PC card standard	0.16	0.8	0.9	0.144	0	0.16	0.144
2	Store/power perform.	0.3	0.8	low	0	0	0	0
3	Environment perform.	0.21	0.6	low	0	1.0	0	0
4	MTBF	0.15	0.6	low	0	1.0	0	0
5	Aesthetics	0.04	0.6	0.75	0.03	0	0.04	0.03
6	Plug and play	0.1	0.8	0.85	0.085	0	0.1	0.085
7	Product road map	0.04	0.6	0.7	0.028	1.0	0	0
					PMP = 0.287			**PMP' = 0.259**

Table VII: Estimated and Modified Subject DoP Correlation Factors (3rd company)

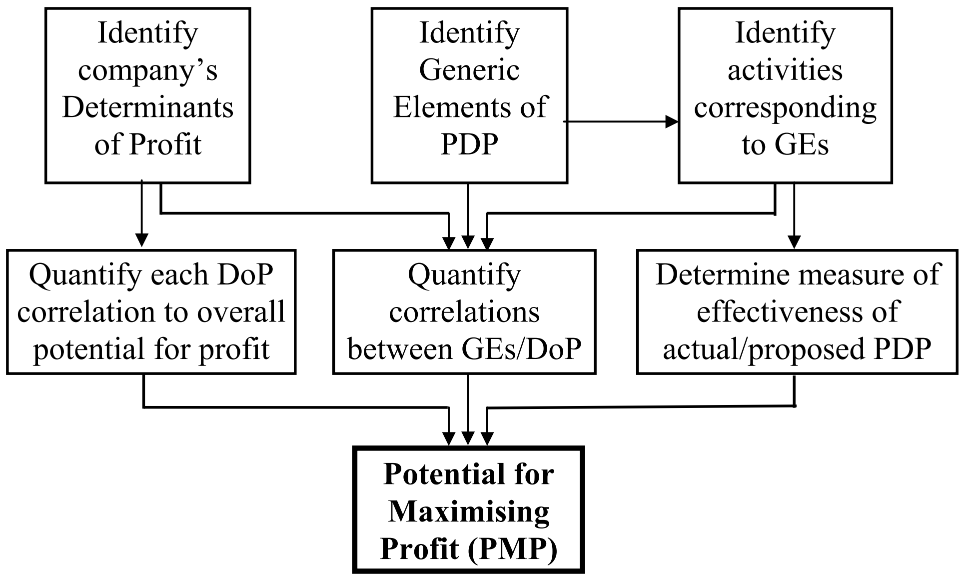

Figure 1: Product Development Process Evaluation

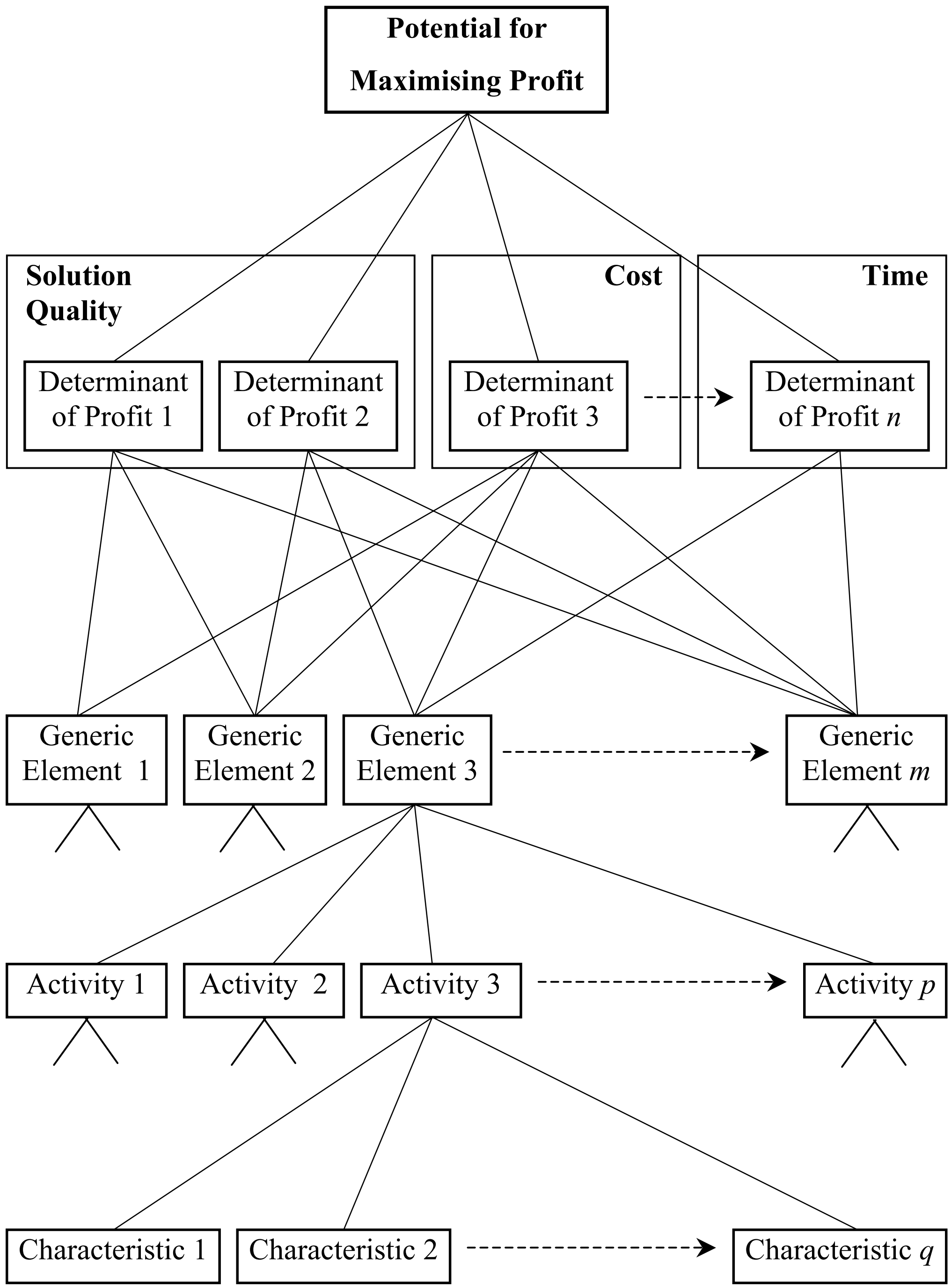

Figure 2: Correlation Network

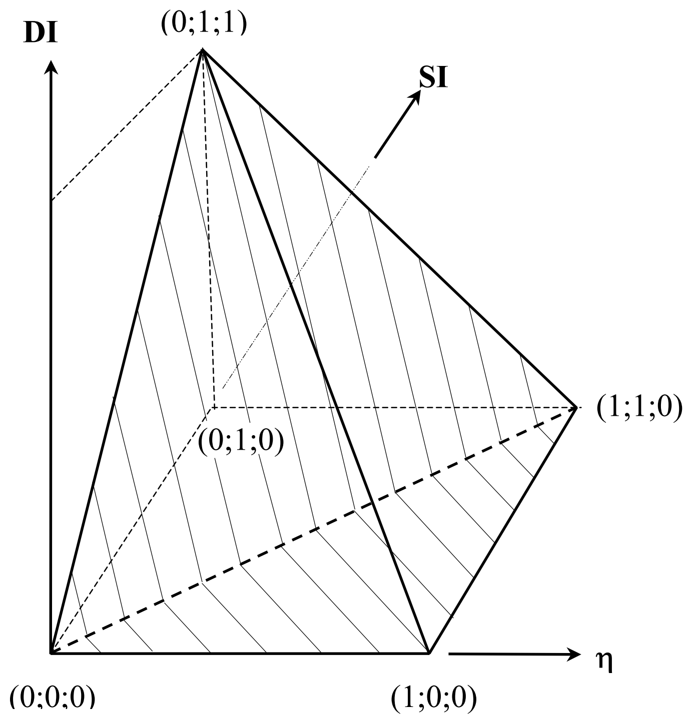

Figure 3: Relationship Between Strength of Interaction (SI), Realised Effectiveness (η) and Calculated Degree of Impact (DI)