Evaluation and Assessment of Innovative Product Development Practices in an Organization

Thesis

Submitted in the partial fulfillment of the requirements of FDTS

BITS C421T/422T

By

Archit Arora

2008B3A4662P

Under the supervision of

Mr. Kalluri Vinayak

Department of Mechanical Engineering

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

(RAJASTHAN)

DECEMBER 2012

1st Semester, 2012-2013

Certificate

This is to certify that the Thesis entitled, **Evaluation and Assessment of Innovative Product Development Practices in an Organization** and submitted by **Archit Arora** bearing ID.No. **2008B3A4662P** in partial fulfillment of the requirements of BITS C421T/422T Thesis embodies the work done by him under my supervision.

Date: Signature of the supervisor

Mr. Kalluri Vinayak
Lecturer
Mechanical Engineering Department

BITS Pilani (Rajasthan)

Acknowledgments

I wish to express my profound gratitude and indebtedness to **Mr. Kalluri Vinayak,** Lecturer, Mechanical Engineering Department, BITS, Pilani (Rajasthan) for introducing the present topic and for his inspiring guidance, constructive criticism and for his valuable suggestion throughout this project work.

I would also like to thank **Dr. S.K. Verma** for being a mentor as the instructor-in-charge of this course.

ARCHIT ARORA

2008B3A4662P

Abstract

Thesis Title: Evaluation and Assessment of Innovative Product Development Practices in an Organization

Supervisor: Mr. Kalluri Vinayak

Semester: First Session: 2012-2013

Name of Student: Archit Arora

ID NO.: 2008B3A4662P

Department: Mechanical Engineering

Abstract:

The innovative product development process requires an understanding of continuously changing customer wants and needs. Hence, there is a need to study and develop procedures that can help a company or project team gain a profound knowledge of customer requirements and satisfaction, and then develop products with innovative features.

This thesis report has been divided into two parts-Evaluation and Assessment of IPD applied to the model developed by my Thesis supervisor. First part discusses the evaluation of Innovative Product Development (IPD) using Analytic Hierarchy Process (AHP) and Performance Value Analysis (PVA) techniques. Second part discusses the assessment of the IPD using Graph Theoretic (GT) technique.

Table of Contents

Chapter 1

Introduction

Introduction

It is a common notion that competition in industries is becoming increasingly intense. With the trend of business globalization, companies face challenges from both national and international competitors. To counter this threat, many of them focus on searching for sustainable advantages. The survival of a company is heavily dependent on its capacity to identify new customer requirements and to develop and market improved products (goods or services). The delivery of innovative products to the marketplace is, thus, considered as a key element for a company to confront competitive challenges.

Satisfying customer requirements through the use of ordinary products is often not enough to capture and retain market share. Customers' needs and expectations should be met and exceeded through product innovation. However, these needs and expectations become increasingly sophisticated as customers experience new ideas in the world around them every day (Plsek, 1997). The innovative product development process requires an understanding of continuously changing customer wants and needs. Hence, there is a need to study and develop procedures that can help a company or project team gain a profound knowledge of customer requirements and satisfaction, and then develop products with innovative features.

This thesis report has been divided into two parts-Evaluation and Assessment of IPD applied to the model developed by my Thesis supervisor. First part discusses the evaluation of Innovative Product Development (IPD) using Analytic Hierarchy Process (AHP) and Performance Value Analysis (PVA) techniques. Second part discusses the assessment of the IPD using Graph Theoretic (GT) technique.

Chapter 2

2.1 Evaluation of Innovative Product Development Practices using Analytic Hierarchy Process

2.2 Evaluation of Innovative Product Development Practices using Performance Value Analysis

2.1 Evaluation of IPD capability in an organization using Analytic Hierarchy Process: A case study

To demonstrate the applicability of the proposed framework to evaluate the organization's innovative product development performance against the benchmarking organizations, the case study is considered. "ABC Motor Company" is the third largest two wheeler manufacturer in India and is engaged in the business of two wheelers, automobile component manufacturing and retailing of various brands in India. The company manufacturers an entire range of two-wheelers including motorcycles, scooters and mopeds, offering a complete portfolio from the entry level right up to the premium segment. The company also has product offerings for the three-wheeler industry. The Company has manufacturing plants that conform to world-class quality standards and has international presence in more than 50 countries in Asian, African and Latin American Continents and will enter more international markets. In India, the company functions through a strong sales and service network consisting over 490 authorized main dealerships, over 1800 authorized service centers. The company believes that their strength lies in design and development of new products. The company's NPD process focused on delivering total customer satisfaction by anticipating customer need and presenting quality vehicles at the right time and at the right price R& D department focuses on bringing the best of innovation and technology to mainstream. ABC Company's technology features are aimed at providing value to a customer by matching the features to the expectation or price point. After giving attention to customer focus, optimum performance, bikes that are easy to ride, economical to maintain and environment friendly still the company is not able to move ahead from his third position in terms of sales. Hence, the top management of the organization are very much interested in finding out which practices of the company is lagging compared with the first two position companies which are considered to be benchmarking companies. For the present case, it is assumed that ABC Company needs to evaluate in terms of its innovative product development performance with respect to the two benchmarking organizations i.e. "PQR Company" and "XYZ Company". The authors attempt to analyze the above case situation and act as "decision makers" to identify a suitable decision. It should be understood here that the purpose of this case organization is to demonstrate a decision-making process for a situation which is not yet addressed in the literature.

2.1.1 Analytic Hierarchy Process Methodology

Analytic Hierarchy Process (AHP) was developed by Saaty (1980) as a practical approach in solving relatively complex problems. It enables the decision maker to represent the simultaneous interaction of many factors in complex, unstructured situation. Wabalickis (1988) noted that the AHP has been well received by the researchers and it has been applied in the diverse traditional fields such as technology selection, logistics, manufacturing etc. Since the current problem involves more number of quantitative and qualitative factors, AHP was found more suitable for analysis (Anand and Kodali, 2012). Saaty (1980) has discussed about the steps to be followed in developing the AHP model, which has been demonstrated by Anand and Kodali (2012) is adapted to explain the methodology. The steps are given below:

Step 1: Define the problem and determine the objective and alternatives along with the identification of the important elements involved.

The problem identified in our case is the prioritization of innovative product development dimensions of the three companies discussed in the case problem. The alternatives available are, ABC Company, PQR Company and XYZ Company. These alternatives will be evaluated and compared in the light of above determined set of elements (dimensions) and sub-elements. Table 2.1.1 shows the elements and sub-elements that were identified from the literature and validated through empirical study.

Table 2.1.1: Elements and sub-elements of innovative product development process

Element/ Sub-elements	In short
Product Innovation	**PRD**
Newness /Novelty/ Originality / Uniqueness	PRD1
Cost/pricing/Value for money	PRD2
Upgrading features in existing products/Product enhancement	PRD3
Quality	PRD4
Differentiation/Variety	PRD5
Best use of new technology	PRD6
Process Innovation	**PRO**
New production methods	PRO1
Process flexibility	PRO2
Process efficiency	PRO3
Delivery/ Speed of distribution	PRO4
Production cost	PRO5
Market Innovation	**MRK**
Gathering market information / Identification of new market	MRK1
Advertising/Promotion/Marketing campaigns	MRK2
Analyzing competitors	MRK3
Generation of new types of customers/ Entry into new geographical markets	MRK4
Customer focus/ Customer relationship management	MRK5
Service Innovation	**SER**
Service cost reduction	SER1
After sales support services	SER2

Element/ Sub-elements	In short
Service infrastructure	SER3
Service administration	SER4
Behavioral Innovation	**BHV**
Employees individual innovativeness	BHV1
Employees team innovativeness	BHV2
Effective flow of communication	BHV3
Effective interpersonal communication	BHV4
Maintenance of culture to ensure novel solution	BHV5
Managerial Innovation	**MNG**
Administration/ leadership innovation	MNG1
Focus on feasibility studies/ Risk taking attitude of management	MNG2
Management strategy on innovation	MNG3
Support for idea management / Knowledge management	MNG4
Organization’s characteristics	MNG5
Motivation of people to innovate	MNG6
NPD strategy	**STR**
Cycle time reduction	STR1
Competitive advantage	STR2
Reduction in cost	STR3
Fast-follower strategy	STR4
NPD support system	**NPS**
CAD/CAE/Virtual Prototyping	NPS1
Project management	NPS2
Rapid prototyping systems	NPS3
Technology commercialization and testing	NPS4
Product portfolio& structure	**PPS**

Modular	PPS1
Joint ventures	PPS2
Outsourcing	PPS3
Improvements	PPS4
Cost Reduction	PPS5
Additions to existing lines	PPS6
NPD team	**TEM**
Cross-functional teams.	TEM1
Team composition.	TEM2
Simultaneous / Concurrent Engineering	TEM3
NPD tools	**TOL**
Quality function deployment (QFD)	TOL1
Six Sigma / Quality management	TOL2
DFMA / DF’X’	TOL3
Failure mode and effects analysis (FMEA)	TOL4
Product launch	**PRL**
Product launch cycle time	PRL1
Promotion expenditure	PRL2
Launch Strategy for new products	PRL3
Post launch feedback mechanism	PRL4
Pricing policy	PRL5
Concept generation and testing	**CGT**
Innovative planned activities to fill gaps	CGT1
New product department	CGT2
Voice of the customer	CGT3

Step 2: Structure the identified elements in a hierarchy from the top through the intermediate levels to the lowest level. Figure 2.1.1 shows the schematic of AHP model for evaluation of various alternative organizations. In this figure, the objective or problem definition is in the first level, factors (i.e. main-elements or dimensions) are in the second level, sub- elements are in third level, while the alternatives will be the last level.

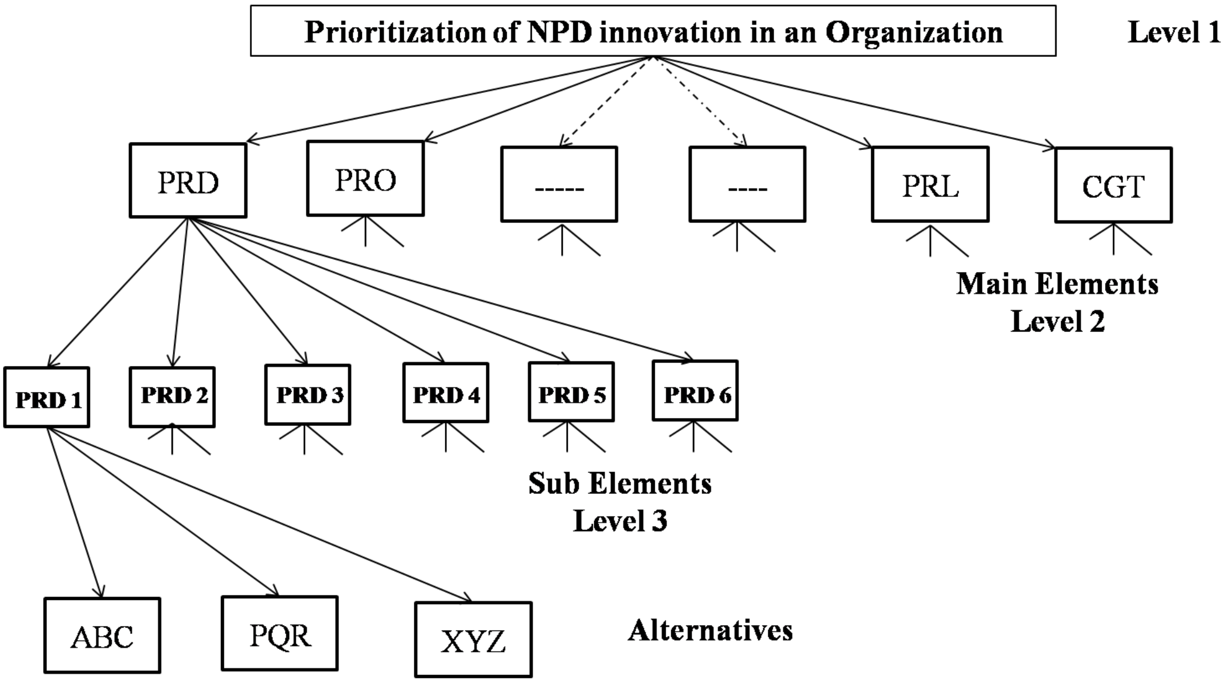

Figure 2.1.1: AHP model for evaluation of various alternative organizations.

Step 3: Construct a set of pair-wise comparison matrices for each of the lower levels. An element in the higher level is said to be a governing element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgments. The pair-wise comparisons are done in terms of which element dominates another. These judgments are then expressed as integers. If element A dominates over element B, then the whole number integer is entered in row A, column B and reciprocal is entered in row B, column A. If the elements being compared are equal, then ‘1’ is assigned to both positions. Thus, there are n (n-1)/2 judgments required to develop a single pair-wise comparison matrix (as reciprocals are automatically assigned in each pair-wise comparisons). For entering the integer values, the scale of relative importance prescribed by Saaty (1980) should be used. Table 4 shows the pair-wise comparison matrix for level 2. In this case, a pair-wise comparison matrix is constructed for the elements. For instance, pair-wise comparison is carried out between the main elements/dimensions ‘NPD Strategy (STR)’ and ‘NPD Team (TEM)’, STR is considered to be more important than TEM. Hence 5 is entered in the row 2, column 4, while 1/5 is entered in row 4, column 2 in Table 2.1.2.

Table 2.1.2: Pair-wise comparison matrix – level 2

	PRD	PRO	MRK	SER	BHV	MNG	STR	NPS	PPS	TEM	TOL	PRL	CGT	PV
PRD	1	2	3	5	7	9	6	2	2	3	1/3	1/2	1/5	0.12
PRO	1/2	1	5	9	8	9	6	2	2	3	1/3	1/2	1/5	0.14
MRK	1/3	1/5	1	2	3	3	6	2	2	3	1/3	1/2	1/5	0.07
SER	1/5	1/9	1/2	1	2	2	5	2	4	2	1/2	1/2	3	0.07
BHV	1/7	1/8	1/3	1/2	1	2	5	2	4	2	1/2	1/2	3	0.07
MNG	1/9	1/9	1/3	1/2	1/2	1	2	3	2	2	2	1	1/3	0.05
STR	1/6	1/6	1/6	1/5	1/5	1/2	1	3	2	2	2	1	1/3	0.05
NPS	1/2	1/2	1/2	1/2	1/2	1/3	1/3	1	2	3	1/3	1/2	1/5	0.04
PPS	1/2	1/2	1/2	1/4	1/4	1/2	1/2	1/2	1	2	1/2	1/2	3	0.04
TEM	1/3	1/3	1/3	1/2	1/2	1/2	1/2	1/3	1/2	1	2	1	1/3	0.04
TOL	3	3	3	2	2	1/2	1/2	3	2	1/2	1	1/2	3	0.10
PRL	2	2	2	2	2	1	1	2	2	1	2	1	1/3	0.08
CGT	5	5	5	1/3	1/3	3	3	5	1/3	3	1/3	3	1	0.14
SUM	13 4/5	15	21 2/3	23 7/9	27 2/7	32 1/3	36 5/6	27 5/6	25 5/6	27 1/2	12 1/6	11	15 1/8	

Step 4: Having done all the pair-wise comparisons and entered the data, the consistency is determined using the Eigen value. To do so, normalize the column of numbers by dividing each entry by the sum of all entries. Then summate each row of the normalized values and take the average. This provides Principal Vector (PV) or Eigen value.

Step 5: The next step is to check the consistency of the judgments of the decision makers. The following steps are utilized to check the consistency of judgments:

- Let the pair-wise comparison matrix be denoted M_1 and principal vector be denoted M_2.
- Then define $M_3 = M_1 * M_2$; and $M_4 = M_3 / M_2$.

- λ_{max} = average of the elements of M_4.
- Consistency Index (CI) = (λ_{max} - N) / N – 1
- Consistency Ratio (CR) = CI / RCI corresponding to N; where

RCI: Random Consistency Index, N: Number of elements.

Random index table (Wabalickis, 1988)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If CR is less than 10%, judgments are considered consistent. And if CR is greater than 10%, the quality of judgments should be improved to have CR less than or equal to 10%.

The CR is found to be less than 10 percent for the pair-wise comparison of main-attributes (dimensions), which is shown in Table 4. Hence the judgments are consistent.

Step 6: Steps 3-5 are performed to have relative importance of each attribute for all levels and clusters in the hierarchy. Table 2.1.3 illustrates the sub-attribute analysis under the attribute 'Product Innovation (PRD)'. It can be found that PRD2 is important compared to the PRD1' and hence a value of "3" is provided. As mentioned above, the PVs and the consistency of the judgments are computed and it was found that the judgments were consistent for all the sub-element analysis. Similar to Table 2.1.3, six more tables were obtained for each main-attribute.

Table 2.1.3: Sub-attribute (element) analysis under the attribute 'Product Innovation (PRD)'– level 3

	PRD 1	PRD 2	PRD 3	PRD 4	PRD 5	PRD 6	PV
PRD 1	**1**	**3**	**2**	**2**	**1**	**3**	**0.251**
PRD 2	**1/3**	**1**	**2**	**1**	**3**	**2**	**0.186**
PRD 3	**1/2**	**1/2**	**1**	**1**	**2**	**2**	**0.148**
PRD 4	**1/2**	**1**	**1**	**1**	**2**	**1**	**0.145**
PRD 5	**1**	**1/3**	**1/2**	**1/2**	**1**	**1**	**0.106**
PRD 6	**1/3**	**1/2**	**1/2**	**1**	**1**	**1**	**0.105**

SUM	4.167	6.667	7.333	6.833	10.5	10.333

The alternative analysis for the lowest level of sub-element is to be carried out in the similar manner as above. Table 2.1.4 illustrates the alternative analysis for the sub-element ‘Analyzing competitors (MRK 3)’. The decision makers assumed that ABC Company’s strength in analyzing the competitors is more compared to the benchmarking companies. Hence, ABC is preferred over PQR and XYZ. In a similar manner, the alternative analysis is carried out for the remaining sub- elements.

Table 2.1.4: Alternative analysis of the sub- element ‘Analyzing competitors (MRK 3)’

	PQR	**ABC**	**XYZ**
PQR	1	3	2
ABC	1/3	1	1
XYZ	1/2	1	1
SUM	1.833	5	4
PV	0.548	0.211	0.241

Step 7: The PVs (or weight values) for each attribute, sub-element and alternative were consolidated. Each value in “weight of sub-element” column (L3-Wt) is multiplied by the respective value of “attribute weight” column (L2-Wt), which is again multiplied by the value for each respective alternative to get the desirability index of the alternative for each sub-element. Finally, the obtained desirability index for each of the sub-elements is summed up to get the overall desirability index for each alternative. The data summary of the complete analysis as well as the sample overall desirability index is shown in Table 2.1.5. The PVs obtained at each level of pair-wise comparison are consolidated to calculate the desirability index of alternatives for each of the sub-elements. In this case, the PV obtained at level 2, i.e. main-attributes analyses (L2-Wt) is multiplied with the PV obtained at level 3, i.e. sub-elements analyses (L3-Wt). The obtained values are again multiplied with the PVs obtained for each alternative at level 4 to obtain the desirability index of alternatives for each sub-elements. Once this desirability index for every sub-element is calculated for each of the alternatives, they are summed up to get the overall desirability index.

Table 2.1.5: Sample Data summary of the complete analysis

Sub elements	Weightages of attributes at level 2 (L2-Wt)	Weightages of attributes at level 3 (L3-Wt)	Weightages of attributes for alternatives at level 4			Desirability index for alternatives		
			PQR	**ABC**	**XYZ**	**PQR**	**ABC**	**XYZ**
SG 2	0.374	0.251	0.595	0.277	0.129	0.056	0.026	0.012
SG 3	0.374	0.186	0.677	0.192	0.131	0.047	0.013	0.009
SG 5	0.374	0.148	0.548	0.211	0.241	0.03	0.012	0.013
SG 6	0.374	0.145	0.62	0.224	0.156	0.034	0.012	0.008
SS 2	0.374	0.106	0.548	0.211	0.241	0.022	0.008	0.01
SS 4	0.374	0.105	0.707	0.201	0.092	0.028	0.008	0.004
SS 6	0.374	0.058	0.62	0.224	0.156	0.013	0.005	0.003
SS 8	0.368	0.235	0.548	0.211	0.241	0.047	0.018	0.021
SS 9	0.368	0.175	0.655	0.158	0.187	0.042	0.01	0.012
PP 1	0.368	0.137	0.62	0.224	0.156	0.031	0.011	0.008
PP 4	0.368	0.134	0.665	0.231	0.104	0.033	0.011	0.005
PP 5	0.368	0.108	0.548	0.241	0.211	0.022	0.01	0.008
PP 7	0.368	0.107	0.655	0.158	0.187	0.026	0.006	0.007
TM 1	0.368	0.054	0.633	0.175	0.192	0.013	0.003	0.004
TM 5	0.368	0.051	0.548	0.211	0.241	0.01	0.004	0.005
TM 7	0.111	0.29	0.548	0.211	0.241	0.018	0.007	0.008
TL 1	0.111	0.198	0.62	0.224	0.156	0.014	0.005	0.003
TL 2	0.111	0.152	0.548	0.211	0.241	0.009	0.004	0.004
TL 3	0.111	0.148	0.548	0.211	0.241	0.009	0.003	0.004
TL 4	0.111	0.112	0.62	0.224	0.156	0.008	0.003	0.002
PL 1	0.111	0.099	0.62	0.224	0.156	0.007	0.002	0.002
PL 2	0.066	0.248	0.62	0.224	0.156	0.01	0.004	0.003
PL 3	0.066	0.199	0.62	0.224	0.156	0.008	0.003	0.002
PL 6	0.066	0.143	0.62	0.224	0.156	0.006	0.002	0.001
PL 8	0.066	0.143	0.62	0.224	0.156	0.006	0.002	0.001
CG 1	0.066	0.105	0.62	0.224	0.156	0.004	0.002	0.001
CG 3	0.066	0.105	0.62	0.224	0.156	0.004	0.002	0.001
CG 5	0.066	0.057	0.548	0.211	0.241	0.002	0.001	0.001
Overall desirability index						**0.607**	**0.215**	**0.177**

2.1.2 Results

Table 2.1.1 to Table 2.1.5 shown in AHP methodology will help the ABC Company to understand the importance of each main-attribute (dimension) and sub-element. For instance, in Table 4, the principal vector describes the importance of each main-attribute with respect to the goal. In this case, the ABC Company is more concerned about the product innovation (PD) and market innovation (MR). Similarly, Table 2.1.3 establishes the relative importance of the sub-elements i.e. the different factors considered within the main-attribute (dimension) – Product Innovation (PRD). In this case, the decision makers judged that the novelty or newness in product (PRD 1) and cost of the product (PRD 2) are more important among other sub-elements.

2.2 Evaluation of Innovative Product Development Practices using Performance Value Analysis

Since there are many main elements (significant category) and sub-elements (performance measures) to be analysed during decision-making, the use of Performance Value Analysis (PVA) was suggested. The PVA model is well received in literature (D'angelo et al., 1996a-b). Various researchers such as Kodali et al. (2004), Kodali and Sangwan (2004), Kodali and Routroy (2006) have used the same for various applications. The algorithm of PVA discussed here is taken from Kodali et al. (2010) and has been applied to the model developed by my Thesis supervisor.

The steps to follow in using the Performance Value Analysis (PVA) are as follows:

Step 1. Define the problem and determine the objective.

In this case, the problem is the prioritization of NPD Best Practices in organization, which can help the case organisation to achieve a significant competitive advantage over other firms, while the objective is to justify the same based on its impact on the performance measures.

Step 2. Identify the alternatives 'a_i' available.

The alternatives are:

- ABC Company,
- XYZ Company and
- PQR Company.

Step 3. Determine the attributes/criteria/performance indicators 'c_j' that govern the problem.

They are obtained from the list parameters identified in Table 2.2.1 below.

Table 2.2.1: List of parameters identified for Prioritization of IPD Practices in Organization

Significant category	Parameters	In Short
Product Innovation (PDI)	Newness /Novelty/ Originality / Uniqueness	PDI1
	Cost/pricing/Value for money	PDI2
	Upgrading features in existing products/Product enhancement	PDI3
	Quality	PDI4
	Differentiation/Variety	PDI5
	Best use of new technology	PDI6
Process Innovation (PRI)	New production methods	PRI1
	Process flexibility	PRI2
	Process efficiency	PRI3
	Delivery/ Speed of distribution	PRI4
	Production cost	PRI5
Market Innovation (MRI)	Gathering market information / Identification of new market	MRI1
	Advertising/Promotion/Marketing campaigns	MRI2
	Analyzing competitors	MRI3
	Generation of new types of customers/ Entry into new geographical markets/Identifying innovative	MRI4
	Customer focus/ Customer relationship management	MRI5
Service Innovation (SRI)	Service cost reduction	SRI1
	After sales support services	SRI2
	Service infrastructure	SRI3
	Service administration	SRI4
Behavioural Innovation (BHI)	Employees individual innovativeness	BHI1
	Employees team innovativeness	BHI2
	Effective flow of communication	BHI3
	Effective interpersonal communication	BHI4
	Maintenance of culture to ensure novel solution	BHI5
Managerial Innovation (MGI)	Administration/ leadership innovation	MGI1
	Focus on feasibility studies/ Risk taking attitude of management	MGI2
	Management strategy on innovation	MGI3
	Support for idea management / Knowledge	MGI4
	Organization’s characteristics	MGI5
	Motivation of people to innovate	MGI6
NPD strategy	Cycle time reduction	NPS1

Significant category	Parameters	In Short
(NPS)	Competitive advantage	NPS2
	Reduction in cost	NPS3
	Fast-follower strategy	NPS4
NPD support system (NSS)	CAD/CAE/Virtual Prototyping	NSS1
	Project management	NSS2
	Rapid prototyping systems	NSS3
	Technology commercialization and testing	NSS4
Product Portfolio & structure (PPS)	Modular	PPS1
	Joint ventures	PPS2
	Outsourcing	PPS3
	Improvements	PPS4
	Cost Reduction	PPS5
	Additions to existing lines	PPS6
NPD team (NPT)	Cross-functional teams	NPT1
	Team composition	NPT2
	Simultaneous / Concurrent Engineering	NPT3
NPD tools (NTL)	Quality function deployment (QFD)	NTL1
	Six Sigma / Quality management	NTL2
	DFMA / DF'X'	NTL3
	Failure mode and effects analysis (FMEA)	NTL4
New Product Launch (NPL)	Product launch cycle time	NPL1
	Promotion expenditure	NPL2
	Launch Strategy for new products	NPL3
	Post launch feedback mechanism	NPL4
	Pricing policy	NPL5
Concept generation and testing (CGT)	Innovative planned activities to fill gaps	CGT1
	New product department	CGT2
	Voice of the customer	CGT3

Step 4. Classify the attributes/criteria/parameters into significant categories.

The parameters were already classified into the following significant categories of Product Innovation (PDI), Process Innovation (PRI), Market Innovation (MRI), Service Innovation (SRI), Behavioural Innovation (BHI), Managerial Innovation (MGI), NPD strategy (NPS), NPD support system (NSS), Product portfolio& structure (PPS), NPD team (NPT), NPD tools (NTL), New Product Launch (NPL), Concept generation and testing (CGT) as shown in Table 2.2.1.

Step 5. Classify the attributes/criteria/parameters into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases).

Table 2.2.2 shows the classification of parameters into direct and indirect categories for the significant category – Cost. It can be found that the up arrow (↑) is used for direct category while a down arrow (↓) is used for indirect category.

Table 2.2.2: Classification of performance measures into direct and indirect categories for the significant category – Product Innovation

Significant category	Parameters	In Short	Max or Min
Product Innovation	Newness /Novelty/ Originality / Uniqueness	PDI1	↑
	Cost/pricing/Value for money	PDI2	↓
	Upgrading features in existing products/Product enhancement	PDI3	↑
	Quality	PDI4	↑
	Differentiation/Variety	PDI5	↑
	Best use of new technology	PDI6	↑

Step 6. Group the attributes/criteria/parameters as quantitative and qualitative measures

Table 2.2.3, shows the classification of quantitative and qualitative measures for the significant category – NPD Strategy. For steps 5 and 6, the parameters were categorised based on the discussions with experts.

Table 2.2.3: Classification of performance measures into qualitative and quantitative categories for the significant category – NPD Strategy

Significant category	Parameters	In Short	Qual or Quan
NPD Strategy (NPS)	Cycle time reduction	NPS1	Quan
	Competitive advantage	NPS2	Quan
	Reduction in cost	NPS3	Quan
	Fast-follower strategy	NPS4	Quan

Step 7. Absolute weight values 'w_j' on a suitable scale (say 1 to 10) is assigned for each attribute/criterion/parameter reflecting the normative judgment of the decision maker.

The experts assigned the weight values individually. For most of the performance measures, the weight values were same and only for few performance measures, significant differences were found between them. In such cases, the same was thoroughly discussed and the weight values were revised. Table 2.2.4 shows the assignment of weight values for the significant category – Process Innovation.

Table 2.2.4: Assignment of weight values for the significant category – Process Innovation

Significant category	Performance Measures	In Short	Weight values for criterion
Process Innovation	New production methods	PRI1	5
	Process flexibility	PRI2	3
	Process efficiency	PRI3	3
	Delivery/ Speed of distribution	PRI4	3
	Production cost	PRI5	4

Step 8. Form the performance matrix, i.e., co-efficient 'e_{ij}' related to the attribute/criterion/parameter 'c_j' (j = 1, 2, …J) and the alternative 'a_i' (i = 1, 2, …I). If it is a qualitative measure, quantify the same using the scale of 1 to

5. In the case of a direct category, 1 refers to low and 5 means high, while it is the vice versa in the case of indirect category (i.e., 5 for low, 1 for high).

Table 2.2.5 shows the formation of performance matrix for the significant category – Product portfolio & structure.

Table 2.2.5: Formation of performance matrix for the significant category – Product portfolio & structure

Significant category	**Parameters**	**In Short**	**Performance matrix (e_{ij})**		
			ABC	**PQR**	**XYZ**
Product portfolio & structure (PPS)	Modular	PPS1	4	5	4
	Joint ventures	PPS2	3	4	2
	Outsourcing	PPS3	4	3	5
	Improvements	PPS4	3	4	2
	Cost Reduction	PPS5	3	2	3
	Additions to existing lines	PPS6	1	5	3

Step 9. Obtain the relative weight values for each attribute/criterion/parameter 'c_j' from absolute weight values 'w_j' as shown in Equation 2.2.1.

$$\overline{W_j} = \frac{w_j}{\sum w_j} \text{, such that } \sum \overline{W_j} = 1 \qquad (2.2.1)$$

Table 2.2.6 shows the relative weight values for the parameters under the significant category – Quality

Table 2.2.6: Relative weight values for the performance measures under the significant category – New Product Launch

Significant category	**Performance Measures**	**In Short**	**Weight values for criterion**	**Relative weight values**
New Product Launch (NPL)	Product launch cycle time	NPL1	5	0.25
	Promotion expenditure	NPL2	4	0.20
	Launch Strategy for new products	NPL3	3	0.15
	Post launch feedback mechanism	NPL4	5	0.25
	Pricing policy	NPL5	3	0.15

Step 10. Form the normalised performance matrix. The values for each attribute/criterion/parameter 'c_j' are obtained based on the following conditions:

- Direct category (when performance increases while measure increases)

$$p_{ij} = \frac{e_{ij}}{\max(e_j)} \qquad (2.2.2)$$

for each alternative 'a_i' related to attribute 'c_j'

- Indirect category (when performance grows while measure decreases)

$$p_{ij} = \frac{\min(e_j)}{e_{ij}} \qquad (2.2.3)$$

for each alternative 'a_i' related to attribute 'c_j'. Table 2.2.7 shows the normalised performance matrix for performance measures under the significant category – Productivity.

Table 2.2.7: Normalised performance matrix for performance measures under the significant category – Product Innovation

Significant category	In Short	Max or Min	Performance matrix (e_{ij})			Normalised performance matrix (P_{ij})		
			ABC	**PQR**	**XYZ**	**ABC**	**PQR**	**XYZ**
Product Innovation	PDI1	↑	3	3	2	1	1	0.66667
	PDI2	↓	4	2	4	0.5	1	0.5
	PDI3	↑	3	5	3	0.6	1	0.6
	PDI4	↑	3	2	4	0.75	0.5	1
	PDI5	↑	4	3	2	1	0.75	0.5
	PDI6	↑	5	3	5	1	0.6	1

Step 11. Obtain partial performance measure 'Z_{ij}' by multiplying relative weight values of attribute/criterion/performance indicator with each of its row members (alternatives), i.e., Partial performance of j^{th} attribute is given as:

$$Z_{ij} = p_{ij} \times \overline{W_j} \qquad \text{where } (i = 1, 2, \ldots I). \qquad (2.2.4)$$

Table 2.8 shows the partial performance measure for performance indicators under the significant category – Market Innovation.

Step 12. Aggregate the partial performance measures for each alternative into an overall measure. Overall measure 'N_i' of alternative 'a_i' is the sum of 'Z_{ij}'

$$N_i = \sum_{j=1}^{J} Z_{ij} \qquad (2.2.5)$$

Step 13. Rank the alternatives 'a_i' in accordance with decreasing value of 'N_i'. Steps 12 and 13 are shown in Table 2.2.9. Table 2.2.9 shows the overall performance measures and ranking of alternatives

Step 14. Perform the significant category analysis.

To obtain the results of this analysis, set the weights of each attribute/criterion/performance indicator to zero, which are different from the significant category being considered and repeat step 7 to step 13. Table 2.2.10 shows the significant category analysis for the category - Managerial Innovation.

Table 2.2.8: Partial performance measure for performance indicators under the significant category – Market Innovation

Significant category	In Short	Max or Min	Qual or Quan	Weight values for criterion	Performance matrix (e_{ij})			Relative weight values	Normalised performance matrix (P_{ij})			Partial performance measures (Z_{ij})		
					ABC	PQR	XYZ		ABC	PQR	XYZ	ABC	PQR	XYZ
Market Innovation	MRI1	↑	Quan	1	3	4	4	0.067	0.75	1	1	0.050	0.067	0.067
	MRI2	↓	Quan	3	4	3	3	0.200	0.75	1	1	0.150	0.200	0.200
	MRI3	↑	Quan	4	5	4	5	0.267	1	0.8	1	0.267	0.213	0.267
	MRI4	↑	Quan	5	4	2	4	0.333	1	0.5	1	0.333	0.167	0.333
	MRI5	↑	Quan	2	3	3	3	0.133	1	1	1	0.133	0.133	0.133

Table 2.2.9: Overall performance measures and ranking of alternatives

	Alternatives		
	ABC	**PQR**	**XYZ**
Overall performance measure	0.933	0.780	1
Rank	2	3	1

Table 2.2.10: Significant category analysis for the category - Managerial Innovation

Significant category	**In Short**	**Max or Min**	**Weight values for criterion**	**Performance matrix (e_{ij})**			**Relative weight values**	**Normalized performance matrix (P_{ij})**			**Partial performance measures (Z_{ij})**		
				ABC	**PQR**	**XYZ**		**ABC**	**PQR**	**XYZ**	**ABC**	**PQR**	**XYZ**
Managerial Innovation	MGI1	↑	2	3	2	3	0.10	1	0.667	1	0.100	0.067	0.100
	MGI2	↓	3	2	3	4	0.15	1	0.667	0.500	0.150	0.100	0.075
	MGI3	↑	4	3	3	5	0.20	0.6	0.600	1	0.120	0.120	0.200
	MGI4	↑	2	4	4	2	0.10	1	1	0.500	0.100	0.100	0.050
	MGI5	↑	5	3	1	1	0.25	1	0.333	0.333	0.250	0.083	0.083
	MGI6	↑	4	4	3	4	0.20	1	0.750	1	0.200	0.150	0.200
				Aggregated partial performance measures for alternatives							**0.92**	**0.62**	**0.708333**

Step 15. Repeat step 14 for all significant categories.

Table 2.2.11 shows the aggregated partial performance measures for alternatives under each significant category. Take the decision based on the overall performance measure calculated above in Table 2.2.9 and the aggregated performance measures of significant categories.

Table 2.2.11: Aggregated partial performance measures for alternatives under each significant category

Significant category	**Aggregated partial performance measures for alternatives**		
	ABC	**PQR**	**XYZ**
PDI	0.8354	0.8187	0.6930
PRI	0.9411	0.7441	0.6421
MRI	0.9333	0.7800	1
SRI	0.7964	0.6892	1
BHI	0.6533	0.8933	0.8266
MGI	0.9200	0.6200	0.7083
NPS	0.9423	0.7692	0.9230
NSS	0.7142	0.7857	0.9523
PPS	0.9111	0.7111	0.6333
NPT	0.3812	0.3583	0.4479
NTL	0.4687	0.4145	0.3479
NPL	0.3775	0.7791	0.8750
CGT	0.8000	0.6148	0.7333

Chapter 3

Assessment of Innovative Product Development Practices using Graph Theoretic Modeling

Assessment of Innovative Product Development Practices using Graph Theoretic Modeling

In this paper Graph Theoretic (GT) Modelling is used to model Innovative Product Development practices in an organization. Since Innovative Product Development has a total of 13 elements divided into New Product Innovation (6 elements) and New Product Development (7 elements). When following algorithm both are taken simultaneously in separate matrices and the results after GT modelling is clubbed to get the final permanent 2 x 2 matrix. The algorithm discussed here has been taken from Kodali et al. (2008) and has been applied to the model developed by my Thesis supervisor.

Phase 1: Development of Digraphs

Step 1. Determine the problem to which the GT modelling can be applied.

In this case, the problem is to identify the best Innovative Product Development (IPD) practices in an organization.

Step 2. Identify the various factors affecting the problem under study and represent them as B^i's.

These IPD elements are divided into two sub-groups namely- New Product innovation having six elements and New Product Development having seven elements shown in Tables 3.1 and 3.2 respectively.

Table 3.1: Consolidated list of elements considered for GT modelling NPI

Taxonomy	Element	In short	Notation
Product Innovation	Newness /Novelty/ Originality / Uniqueness	PDI 1	B_1^1
	Cost/pricing/Value for money	PDI 2	B_2^1
	Upgrading features in existing products/Product	PDI 3	B_3^1

Taxonomy	Element	In short	Notation
	enhancement		
	Quality	PDI 4	B_{4}^{1}
	Differentiation/Variety	PDI 5	B_{5}^{1}
	Best use of new technology	PDI 6	B_{6}^{1}
Process Innovation	New production methods	PRI 1	B_{1}^{2}
	Process flexibility	PRI 2	B_{2}^{2}
	Process efficiency	PRI 3	B_{3}^{2}
	Delivery/ Speed of distribution	PRI 4	B_{4}^{2}
	Production cost	PRI 5	B_{5}^{2}
Market Innovation	Gathering market information / Identification of new market	MRI 1	B_{1}^{3}
	Advertising/Promotion/Marketing campaigns	MRI 2	B_{2}^{3}
	Analyzing competitors	MRI 3	B_{3}^{3}
	Generation of new types of customers/ Entry into new geographical markets/Identifying innovative customers	MRI 4	B_{4}^{3}
	Customer focus/ Customer relationship Management	MRI 5	B_{5}^{3}
Service Innovation	Service cost reduction	SRI 1	B_{1}^{4}
	After sales support services	SRI 2	B_{2}^{4}
	Service infrastructure	SRI 3	B_{3}^{4}
	Service administration	SRI 4	B_{4}^{4}
Behavioral Innovation	Employees individual innovativeness	BHI 1	B_{1}^{5}
	Employees team innovativeness	BHI 2	B_{2}^{5}
	Effective flow of communication	BHI 3	B_{3}^{5}
	Effective interpersonal communication	BHI 4	B_{4}^{5}
	Maintenance of culture to ensure novel solution	BHI 5	B_{5}^{5}
Managerial Innovation	Administration/ leadership innovation	MGI 1	B_{1}^{6}
	Focus on feasibility studies/ Risk taking attitude of	MGI 2	B_{2}^{6}

Taxonomy	Element	In short	Notation
	management		
	Management strategy on innovation	MGI 3	B_3^6
	Support for idea management / Knowledge management	MGI 4	B_4^6
	Organization's characteristics	MGI 5	B_5^6
	Motivation of people to innovate	MGI 6	B_6^6

Note: In this table, each element has been represented as B_i^I, where the subscript 'i' represents the elements that are grouped under a particular taxonomy represented by 'I'.

Table 3.2: Consolidated list of elements considered for GT modelling NPD

NPD strategy	Cycle time reduction	NPS 1	B_1^1
	Competitive advantage	NPS 2	B_2^1
	Reduction in cost	NPS 3	B_3^1
	Fast-follower strategy	NPS 4	B_4^1
NPD support system	CAD/CAE/Virtual Prototyping	NSS 1	B_1^2
	Project management	NSS 2	B_2^2
	Rapid prototyping systems	NSS 3	B_3^2
	Technology commercialization and testing	NSS 4	B_4^2
Product portfolio& structure	Modular	PPS 1	B_1^3
	Joint ventures	PPS 2	B_2^3
	Outsourcing	PPS 3	B_3^3
	Improvements	PPS 4	B_4^3
	Cost Reduction	PPS 5	B_5^3
	Additions to existing lines	PPS 6	B_6^3
NPD team	Cross-functional teams.	NPT 1	B_1^4
	Team composition.	NPT 2	B_2^4
	Simultaneous / Concurrent Engineering	NPT 3	B_3^4
NPD tools	Quality function deployment (QFD)	NTL 1	B_1^5

	Six Sigma / Quality management	NTL 2	B_2^5
	DFMA / DF'X'	NTL 3	B_3^5
	Failure mode and effects analysis (FMEA)	NTL 4	B_4^5
New Product Launch	Product launch cycle time	NPL 1	B_1^6
	Promotion expenditure	NPL 2	B_2^6
	Launch Strategy for new products	NPL 3	B_3^6
	Post launch feedback mechanism	NPL 4	B_4^6
	Pricing policy	NPL 5	B_5^6
Concept generation and testing	Innovative planned activities to fill gaps	CGT 1	B_1^7
	New product department	CGT 2	B_2^7
	Voice of the customer	CGT 3	B_3^7

Step 3. Develop the relationships between the factors logically using a digraph, depending on their interdependencies.

A digraph is used to represent the relationships between the factors (B^i) and their interdependencies (b_{ij}) in terms of nodes and edges. It facilitates a better visualisation of the problem under study and helps in understanding the interactions between the various factors or sub-systems associated with it. 'b_{ij}' indicates the degree of dependence of the 'j'th factor on the 'i'th factor. But, in the digraph (b_{ij}) is represented as a directed edge from node i to node j. The purpose of this digraph is to capture these inheritances and interdependencies graphically among the various companies involved in IPD implementation. Figure 3.1 and 3.2 show the digraphs capturing the inheritances and interdependencies between various companies (B^i's) of the organisation involved in IPD implementation. To develop such relationships, the evaluation team can use their own expertise or they can rely on external consultants and academicians to assist them in developing the digraphs.

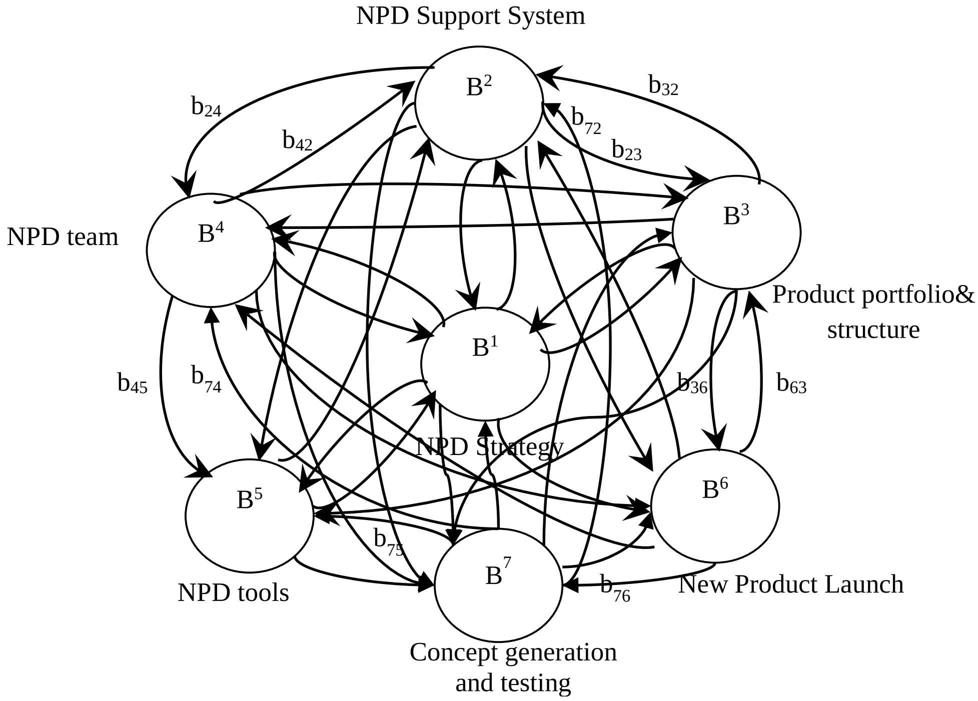

Figure 3.1: Digraph capturing the inheritance and interdependencies between various elements (Bi's) involved in IPD implementation for New Product Development (NPD)

The logic behind the digraph construction is explained as follows:

- A directed edge from B^1 to B^2, B^3, B^4, B^5 and B^6 indicates the interaction of Product Innovation and Process Innovation in NPI. Similarly, in NPD B^1 to B^2, B^3, B^4, B^5, B^6 and B^7 indicates the interaction of NPD Strategy and Support System.
- Similarly, all other interactions can be explained within the particular sub-groups of NPD and NPI but independent of each other when comparing sub-groups.

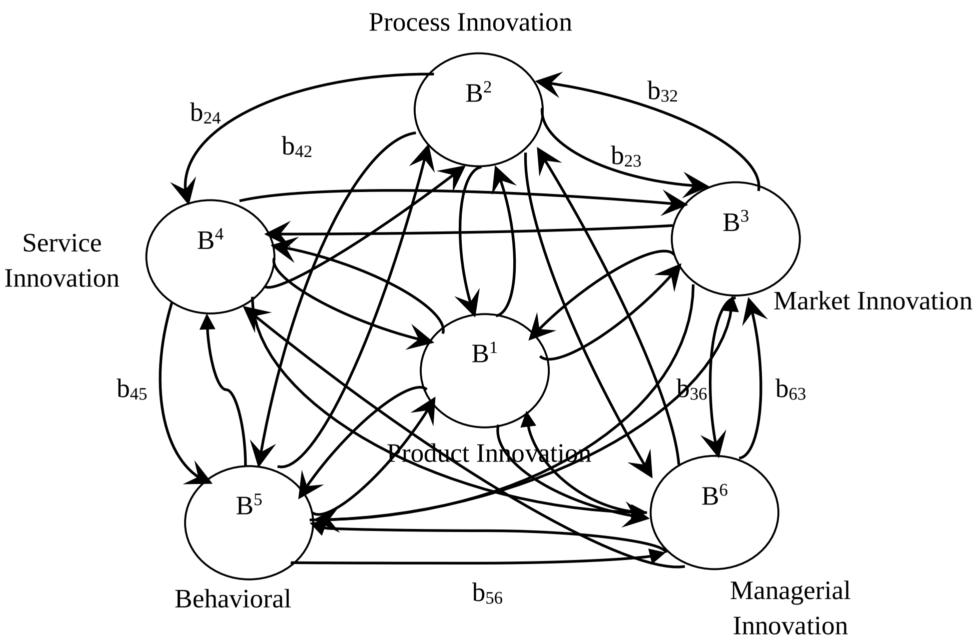

Figure 3.2: Digraph capturing the inheritance and interdependencies between various elements (Bi's) involved in IPD implementation for New Product Innovation (NPI)

- This digraph representation is highly general and can be applied to any type of organisation.

Phase 2: Matrix representation - Derivation of Variable Permanent Matrix (VPM)

Step 4. Represent the digraph in the form of VPM.

The step by step procedure to develop VPM has been discussed in detail by Grover *et al*. (2004, 2006). The VPM at system level is also represented as matrix B or VPM-B. The actual VPM-B for our problem, derived based on the digraph (refer Figure 3.1 & 3.2) is shown below:

$$B = VPM - B = \begin{pmatrix} B_1 & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} \\ b_{21} & B_2 & b_{23} & b_{24} & b_{25} & b_{26} \\ b_{31} & b_{32} & B_3 & b_{34} & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & B_4 & b_{45} & b_{46} \\ b_{51} & b_{52} & b_{53} & b_{54} & B_5 & b_{56} \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & B_6 \end{pmatrix} \qquad (1)$$

$$B = VPM - B = \begin{pmatrix} B_1 & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} & b_{17} \\ b_{21} & B_2 & b_{23} & b_{24} & b_{25} & b_{26} & b_{27} \\ b_{31} & b_{32} & B_3 & b_{34} & b_{35} & b_{36} & b_{37} \\ b_{41} & b_{42} & b_{43} & B_4 & b_{45} & b_{46} & b_{47} \\ b_{51} & b_{52} & b_{53} & b_{54} & B_5 & b_{56} & b_{57} \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & B_6 & b_{67} \\ b_{71} & b_{72} & b_{73} & b_{74} & b_{75} & b_{76} & B_7 \end{pmatrix} \quad (2)$$

The nodes in the digraph represented as B^1 to B^6 occupy the diagonal position in the matrix B, while the remaining off-diagonal positions are filled up based on the relationship between the elements, which is represented by a direct arrow in Figure 3.1 and Figure 3.2. Matrix (1) depicts elements of NPI as listed in Table 3.1 and Matrix (2) depicts elements of NPD as listed in Table 3.2. If an arrow is not present between the elements, then the value corresponding to it in the matrix B will be '0'. The purpose of this VPM is to capture the degree of interdependencies (i.e. relationship or interactions represented by b_{ij}'s) between different elements of NPD & NPI, the degree of inheritances represented by B^i's (i.e., each sub-group contribution) in a mathematical form.

Step 5. The next step is to evaluate the matrix, which involves the calculation of 'permanent' of the matrix.

The permanent equation of matrix (1) or permanent of B is multinomial and is called Variable Permanent Function (VPF-B). It is also represented as per (B) or per B. This permanent function is a standard matrix function which is commonly used and defined in combinatorial mathematics. It is evaluated by standard procedures and is same as the determinant of VPM-B but with all signs positive. The permanent equation for VPM-B or per B (i.e. matrix 1) can be solved using the equation given in Figure 3.3, which represents the general form of a permanent equation for any 6x6 matrix. The value obtained from this equation represents 'Comprehensive Assessment Index (CAI)' - the overall assessment of importance of IPD elements as it has captured both the degree of relationships between various sub-groups. But to solve this equation, the values for the entities in the matrix are needed. The next phase provides details about how to obtain the values for matrix

$$
\begin{aligned}
VPF - B = per\ B = &\prod_{i=1}^{6} B_i + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{ji}) B_k B_l B_m B_n \\
&+ \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{jk} b_{ki} + b_{ik} b_{kj} b_{ji}) B_l B_m B_n \\
&+ \left[\begin{pmatrix} \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{ji})(b_{kl} b_{lk}) B_m B_n \\ + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{jk} b_{kl} b_{li} + b_{il} b_{lk} b_{kj} b_{ji}) B_m B_n \end{pmatrix} \right] \\
&+ \left[\begin{matrix} \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{ji})(b_{kl} b_{lm} b_{mk} + b_{km} b_{ml} b_{lk}) B_n \\ + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{jk} b_{kl} b_{lm} b_{mi} + b_{im} b_{ml} b_{lk} b_{kj} b_{ji}) B_n \end{matrix} \right] \\
&+ \left[\begin{matrix} \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{ji})(b_{kl} b_{lm} b_{mn} b_{nk} + b_{kn} b_{nm} b_{ml} b_{lk}) \\ + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{jk} b_{ki})(b_{lm} b_{mn} b_{nl}) \\ + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{ji})(b_{kl} b_{lk})(b_{mn} b_{nm}) \\ + \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n (b_{ij} b_{jk} b_{kl} b_{lm} b_{mn} b_{ni} + b_{in} b_{nm} b_{ml} b_{lk} b_{kj} b_{ji}) \end{matrix} \right]
\end{aligned}
$$

Figure 3.3: The general form of permanent equation for any 6x6 matrix

Phase 3: Quantification of B^i's and b_{ij}'s of the matrix for the given problem

Step 6. Quantify the B_i's at sub-system level

Each factor B^i in matrix 1 & 2 can be considered as a sub-system with as many sub-factors affecting them. In this case, every element of the sub-groups (B^i's) of each sub-category-NPD and NPI is considered as a sub-system, as they have a significant role to play in IPD. Hence, for the sake of clarity, the following notation is used: each elements has been represented as B_i^I, where the subscript 'i' represents the elements that are grouped under a particular sub-group, while the superscript 'I' represents the sub-group being referred. The same notation is used in Table 3.2 and 3.3. To find out the values of B_i^I's and the interdependency values b_{ij}'s in the VPM-B matrix (matrix 1), the following steps have to be followed:

- The digraph for each sub-system should be drawn as explained in Phase 1. The purpose of the digraph at sub-system level is to capture the degree of relationship between various elements (i.e. interdependencies) identified under a particular sub-group in each sub-category-NPI and NPD in a graphical form.
- Using the steps in phase 2, the VPM for sub-systems (i.e., companies) represented as VPM-B_{SS1}, VPM-B_{SS2}, VPM-B_{SS3}, VPM-B_{SS4}, VPM-B_{SS5}, VPM-B_{SS6} can be derived. These matrices can also be represented as B_{SS1}, B_{SS2} …..B_{SS6}. The purpose of these matrices at sub-system level is to capture the degree of implementation of IPD elements (i.e. inheritances) and the degree of relationship between different IPD elements (i.e. interdependencies) under a particular company in a mathematical form. The value of B_i^I's within the sub-system matrix represents the inheritances, while b_{ij}^I's represent the interdependencies. For instance, a sample VPM-B_{SS1} or B_{SS1} for the company – 'top management' sub-system derived from its corresponding digraph (refer Figure 3.3) is shown below:

$$B_{ss1} \; or \; VPM - B_{ss1} = \begin{pmatrix} B_1{}^1 & b_{12}{}^1 & b_{13}{}^1 & b_{14}{}^1 & b_{15}{}^1 & b_{16}{}^1 \\ b_{21}{}^1 & B_2{}^1 & b_{23}{}^1 & b_{24}{}^1 & b_{25}{}^1 & b_{26}{}^1 \\ b_{31}{}^1 & b_{32}{}^1 & B_3{}^1 & b_{34}{}^1 & b_{35}{}^1 & b_{36}{}^1 \\ b_{41}{}^1 & b_{42}{}^1 & b_{43}{}^1 & B_4{}^1 & b_{45}{}^1 & b_{46}{}^1 \\ b_{51}{}^1 & b_{52}{}^1 & b_{53}{}^1 & b_{54}{}^1 & B_5{}^1 & b_{56}{}^1 \\ b_{61}{}^1 & b_{62}{}^1 & b_{63}{}^1 & b_{64}{}^1 & b_{65}{}^1 & B_6{}^1 \end{pmatrix} \qquad (3)$$

Similar to matrix (3), VPMs for others sub-systems can be developed. From these matrices, the permanent for each of the sub-systems can be calculated using the equation shown in Figure 3.3 after obtaining the values for B_i^I's and b_{ij}^I's.

- As mentioned earlier, the B_i^I values within VPM of sub-systems represent the degree of implementation of the IPD elements by the companies, which can be evaluated using a suitable scale. Table 3.3 suggests a scale to capture the degree of implementation of each IPD element (B_i^I's) under the sub-systems.

Table 3.3: A scale to capture the degree of implementation of each IPD element (B_i's) under the sub-systems (adapted from Saaty, 1980)

S. No.	**Quantitative measure of factors**	**Explanation**
1	Extremely low	When the companies do not know about the IPD element, and it has not been implemented
3	Low	When the companies know about the IPD element, but it has not been implemented
5	Average	When the companies know about the IPD element, but it has been implemented only to certain extent
7	High	When the companies know about the IPD element and it has been implemented properly and well documented
9	Extremely high	When the companies know about the IPD element and it has been implemented properly as a result of which excellent results have been achieved

2, 4, 6, 8	Represent the intermediate values	Used, when compromise is needed between two scales.

This scale is adapted from the Saaty's (1980) relative scale of importance used in the Analytic Hierarchy Process (AHP). A survey could be done using questionnaires asking the participating companies to assign weights to the elements in order of their importance. Similarly, all the IPD elements in the particular category are assessed. A checklist as shown in Table 3.4 and 3.5 can be used for evaluating the degree of importance of IPD elements. A sample VPM-B_{SS2} (i.e.B_{SS2}) is shown in matrix 4 with the values filled in for the diagonal element depicting the level of importance of each IPD element under the category – 'Process Innovation'.

$$B_{ss2} = VPM - B_{ss2} = \begin{pmatrix} 7 & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} \\ b_{21} & 8 & b_{23} & b_{24} & b_{25} & b_{26} \\ b_{31} & b_{32} & 6 & b_{34} & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & 9 & b_{45} & b_{46} \\ b_{51} & b_{52} & b_{53} & b_{54} & 8 & b_{56} \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & 7 \end{pmatrix} \qquad (4)$$

Table 3.4: Checklist for evaluating the degree of importance of NPI elements

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
1.	**Product Innovation**	Newness /Novelty/ Originality / Uniqueness	PDI 1	B_1^1									
2.		Cost/pricing/Value for money	PDI 2	B_2^1									
3.		Upgrading features in existing products/Product enhancement	PDI 3	B_3^1									
4.		Quality	PDI 4	B_4^1									
5.		Differentiation/Variety	PDI 5	B_5^1									
6.		Best use of new technology	PDI 6	B_6^1									
7.	**Process Innovation**	New production methods	PRI 1	B_1^2									
8.		Process flexibility	PRI 2	B_2^2									
9.		Process efficiency	PRI 3	B_3^2									
10.		Delivery/ Speed of distribution	PRI 4	B_4^2									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
11.		Production cost	PRI 5	B_5^2									
12.	**Market Innovation**	Gathering market information / Identification of new market	MRI 1	B_1^3									
13.		Advertising/Promotion/Marketing campaigns	MRI 2	B_2^3									
14.		Analyzing competitors	MRI 3	B_3^3									
15.		Generation of new types of customers/ Entry into new geographical markets/Identifying innovative customers	MRI 4	B_4^3									
16.		Customer focus/ Customer relationship Management	MRI 5	B_5^3									
17.	**Service Innovation**	Service cost reduction	SRI 1	B_1^4									
18.		After sales support services	SRI 2	B_2^4									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
19.		Service infrastructure	SRI 3	B_3^4									
20.		Service administration	SRI 4	B_4^4									
21.	**Behavioral Innovation**	Employees individual innovativeness	BHI 1	B_1^5									
22.		Employees team innovativeness	BHI 2	B_2^5									
23.		Effective flow of communication	BHI 3	B_3^5									
24.		Effective interpersonal communication	BHI 4	B_4^5									
25.		Maintenance of culture to ensure novel solution	BHI 5	B_5^5									
26.	**Managerial Innovation**	Administration/ leadership innovation	MGI 1	B_1^6									
27.		Focus on feasibility studies/ Risk taking attitude of management	MGI 2	B_2^6									
28.		Management strategy on innovation	MGI 3	B_3^6									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
29.		Support for idea management / Knowledge management	MGI 4	B_4^6									
30.		Organization’s characteristics	MGI 5	B_5^6									
31.		Motivation of people to innovate	MGI 6	B_6^6									

Table 3.5: Checklist for evaluating the degree of importance of NPD elements

S. No.	**Taxonomy**	**Element**	**In short**	**Notation**	**Rate the level of importance by placing a tick mark against the following numbers**								
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1.	**NPD strategy**	Cycle time reduction	NPS 1	B_1^1									
2.		Competitive advantage	NPS 2	B_2^1									
3.		Reduction in cost	NPS 3	B_3^1									
4.		Fast-follower strategy	NPS 4	B_4^1									
5.	**NPD support system**	CAD/CAE/Virtual Prototyping	NSS 1	B_1^2									
6.		Project management	NSS 2	B_2^2									
7.		Rapid prototyping systems	NSS 3	B_3^2									
8.		Technology commercialization and testing	NSS 4	B_4^2									
9.	**Product portfolio& structure**	Modular	PPS 1	B_1^3									
10.		Joint ventures	PPS 2	B_2^3									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
11.		Outsourcing	PPS 3	B_3^3									
12.		Improvements	PPS 4	B_4^3									
13.		Cost Reduction	PPS 5	B_5^3									
14.		Additions to existing lines	PPS 6	B_6^3									
15.	**NPD team**	Cross-functional teams.	NPT 1	B_1^4									
16.		Team composition.	NPT 2	B_2^4									
17.		Simultaneous / Concurrent Engineering	NPT 3	B_3^4									
18.	**NPD tools**	Quality function deployment (QFD)	NTL 1	B_1^5									
19.		Six Sigma / Quality management	NTL 2	B_2^5									
20.		DFMA / DF'X'	NTL 3	B_3^5									
21.		Failure mode and effects analysis (FMEA)	NTL 4	B_4^5									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of importance by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
22.	**New Product Launch**	Product launch cycle time	NPL 1	B_1^6									
23.		Promotion expenditure	NPL 2	B_2^6									
24.		Launch Strategy for new products	NPL 3	B_3^6									
25.		Post launch feedback mechanism	NPL 4	B_4^6									
26.		Pricing policy	NPL 5	B_5^6									
27.	**Concept generation and testing**	Innovative planned activities to fill gaps	CGT 1	B_1^7									
28.		New product department	CGT 2	B_2^7									
29.		Voice of the customer	CGT 3	B_3^7									

Step 7. Quantification of b_{ij}^{I}'s at the sub-system level

The value of b_{ij}^{I}'s represents the degree of relationships between two IPD elements, which is assessed using another scale as shown in Table 3.6. Table 3.6 represents the scale to obtain the values of interdependencies (b_{ij}'s) between factors (B^{i}'s).

Table 3.6: A scale to obtain the values of interdependencies (b_{ij}'s) between factors (B^{i}'s)

S. No.	**Quantitative measure of interdependency**	**Assigned value of factor**
1	Very strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

As explained in the previous step, to assess the relationship between different IPD elements, direct observation has to be carried out by the evaluators and in some cases, it may require interviewing the employees, supervisors, etc. to arrive at a particular scale value. A sample VPM- B_{SS3} (i.e. B_{SS3}) for the company – 'Market Innovation' is shown with all the values filled in for both the diagonal and off-diagonal elements depicting the inheritance and the interdependencies between the sub-factors.

$$B_{ss2}\ or\ VPM - B_{ss2} = \begin{pmatrix} 8 & 5 & 5 & 4 & 3 & 2 \\ 4 & 9 & 5 & 4 & 3 & 2 \\ 5 & 5 & 6 & 4 & 3 & 8 \\ 3 & 3 & 5 & 7 & 3 & 2 \\ 4 & 5 & 6 & 6 & 3 & 5 \\ 1 & 3 & 1 & 1 & 1 & 5 \end{pmatrix} \qquad (5)$$

These values indicate that the degree of importance of certain elements is not good, while that of other elements are well-implemented. For instance, in the above matrix (i.e., matrix 5), the element B_2^3 is important and hence a value of '9' is assigned, while in the case of B_6^3, only a value of 5 is assigned, which means that it is not that important. Same is the case with the relationships (i.e., b_{ij}^3). Some relationships are very weak – i.e., implementing one IPD element do not have significant effect on another.

Step 8. From the derived variable permanent matrices VPM-B_{SS1}….. VPM-B_{SS6}, the permanent of the matrices for the sub-systems are calculated using the equation shown in Figure 3.3.

They are represented as Per (B_{SS1}), Per (B_{SS2})….. Per (B_{SS6}). The purpose of this permanent equation is to quantify the elements of every company by integrating the inheritances and interdependencies. It should be noted here that if more number of factors were considered, the permanent equation tends to become so large and it will result in computational complexity. A sample permanent value for VPM-B_{SS4} (i.e., B_{SS4}) representing the quantification of roles and responsibilities of the company – 'Service Innovation' is shown below:

$$\text{Per}\ (B_{SS4}) = 801688$$

The obtained value can also be expressed in logarithmic term as $\log_{10}$ (801688), which will be equal to 5.9. In a similar manner, the permanent values for the remaining sub-system matrices are obtained, which are required to fill in the diagonal elements of matrix 1. To calculate the permanent, the evaluators needs not perform the complex calculation as shown in Figure 3.3. Instead, the values for the matrices can be fed into a small C program, which will directly give the permanent value.

Phase 4: Evaluating the VPM-B matrix

Step 9. To evaluate the value of VPM-B at system levels (i.e. matrix 1 and matrix 2), the off-diagonal values are obtained from the permanent of the sub systems, while the values for the diagonal values are obtained from a suitable table.

Step 10. As said earlier, the values of diagonal elements for matrix 1 are obtained from the 'permanent' calculated for each sub-system, which after representing them in logarithmic terms (log(base 10)) are shown below:

- Per (B_{SS1}) = 405066 or 5.6
- Per (B_{SS2}) = 1285733 or 6.1
- Per (B_{SS3}) = 1223550 or 6.1
- Per (B_{SS4}) = 801688 or 5.9
- Per (B_{SS5}) = 504 or 2.7
- Per (B_{SS6}) = 1112450 or 6.0

Similarly, the values of diagonal elements for matrix 2 are obtained from the 'permanent' calculated for each sub-system, which after representing them in logarithmic terms (log(base 10)) are shown below:

- Per (B_{SS1}) = 506078 or 2.3
- Per (B_{SS2}) = 1189595 or 5.2
- Per (B_{SS3}) = 1042957or 5.1
- Per (B_{SS4}) = 462365 or 6.3
- Per (B_{SS5}) = 354 or 2.5
- Per (B_{SS6}) = 1140734 or 5.8

- Per (B_{SS7}) = 1054235 or 5.3

However, in the diagonal of the matrix, the original permanent values such as 405066, 1285733 etc. are used instead of logarithmic values. The values of off-diagonal elements (b_{ij}'s) for matrix 1 can be obtained from Table 3.6 based on the degree of interdependencies (relationships) among the companies (B_i's). The complete VPM-B matrix for quantifying the importance of NPI and NPD elements in an IPD environment is shown below in Matrices 6 and 7 respectively:

$$B = VPM - B = \begin{pmatrix} 405066 & 5 & 4 & 4 & 4 & 4 \\ 5 & 1285733 & 5 & 4 & 4 & 4 \\ 3 & 5 & 1223550 & 5 & 4 & 4 \\ 3 & 4 & 5 & 801688 & 3 & 4 \\ 4 & 4 & 1 & 1 & 504 & 4 \\ 1 & 5 & 4 & 3 & 1 & 112450 \end{pmatrix} \tag{6}$$

$$B = VPM - B = \begin{pmatrix} 506078 & 4 & 3 & 5 & 3 & 4 & 4 \\ 3 & 1189595 & 4 & 5 & 3 & 4 & 2 \\ 1 & 4 & 1042957 & 2 & 1 & 5 & 5 \\ 4 & 5 & 3 & 462365 & 1 & 2 & 4 \\ 1 & 5 & 4 & 3 & 354 & 4 & 3 \\ 5 & 2 & 3 & 4 & 4 & 1140734 & 3 \\ 5 & 2 & 4 & 3 & 3 & 2 & 1054235 \end{pmatrix} \tag{7}$$

Again, the value of permanent function for the system level matrix (i.e. matrix 6 and 7) is calculated using the equation shown in Figure 3.3.

The obtained value (i.e., Per (B)) represents a quantified value for the total contribution of various companies in implementing the IPD elements by integrating the degree of implementation of IPD elements, the degree of relationships between the companies and the degree of relationship between various IPD elements under each company. In our problem, the permanent of the matrix 6 is found to be Per (B) = 2.86 x 10^{32} and that of matrix 7 is found to be Per (B) = 2.75 x 10^{30} which when converted into logarithmic values for the sake of simplicity is found to be 32.4 and 28.7 respectively. Since the organisation has not completely implemented all the IPD elements within the last one year, they have got the above value as CAI. However, if we compare this value with other organisation which is known for its IPD implementation (say Toyota) or organisation which have not implemented IPD at all, it is possible to compare and analyse where does the organisation stand. The next phase will discuss about the best-case situation and worst-case situation.

Phase 5: Calculation of best-case and worst-case CAI

Step 11. To calculate the range within which the values of CAI can vary, calculate the permanent of VPM-B (i.e., matrix 1) for different case situations.

Step 12. A similar approach was utilised by Grover *et al*. (2006) in which they calculated the CAI for the hypothetical best and worst value of human index. In a similar manner, the CAI is computed for four different case situations, which are discussed below:

- **Practical best-case situation:** This situation can occur only if the organisation under assessment has implemented all the IPD elements properly and successfully. For instance, it can be assumed that such a scenario can be found in Toyota. Since, the concept of IPD was developed by studying the TPS it is valid to assume that every IPD element identified in Table 3.1 and 3.2 would have been implemented completely and successfully in Toyota. Hence, the degree of implementation of IPD elements in TPS will have a maximum value of 9, i.e., the diagonal elements in each sub-system would be 9. In other words, the CAI will be at its best, when the inheritance of all its factors is at its best. In this case, the VPM for B_{SS4} will be re-written as:

$$B_{ss4}\ or\ VPM - B_{ss4} = \begin{pmatrix} 9 & 2 & 3 & 3 & 1 & 2 \\ 4 & 9 & 1 & 3 & 1 & 3 \\ 4 & 2 & 9 & 4 & 3 & 8 \\ 4 & 5 & 3 & 9 & 2 & 3 \\ 3 & 1 & 1 & 2 & 9 & 1 \\ 3 & 4 & 3 & 3 & 1 & 9 \end{pmatrix} \quad (8)$$

In a similar manner, the VPM for other sub-systems are also re-written in such a way that the diagonal elements have the value of '9'. The permanent value for the matrix 8 (Per B_{SS4}) is found to be 2049987. Similarly, the permanent values for other matrices are calculated for the practical best-case situation and are shown in Table 3.7. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI is obtained by calculating the permanent of the matrix 6 and 7 (i.e., VPM-B). In this case, the diagonal elements of matrix 6 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) obtained for the best-case situation and the Per (B) for the VPM-B is found to be 3.73×10^{34}, which when expressed as log (base 10) (i.e., it is written as $\log_{10}(3.73 \times 10^{34})$), is equal to 34.6.

Similarly, when the diagonal elements of matrix 7 is replaced by permanent values of the sub-systems (Per B_{SS1} to Per B_{SS7}) obtained for the best-case situation and the Per (B) for the VPM-B is found to be 2.54×10^{30} which when expressed as log (base 10) (i.e., it is written as $\log_{10}(2.54 \times 10^{30})$), is equal to 31.4.

- **Theoretical best-case situation:** On the other hand, a hypothetical best-case or theoretical best-case situation can be derived by having the maximum values for both inheritances and interdependencies in sub-systems. In other words, as described earlier, a maximum value of 9 can be assigned to the diagonal elements

(B_i^I's) of sub-systems to represent a very high degree of IPD implementation and a maximum value of 5 can be assigned to b_{ij}^I's, representing the highest degree of relationship between different IPD elements. Based on this, the matrix 8 can be re-written as follows:

$$B_{ss4}\ or\ VPM - B_{ss4} = \begin{pmatrix} 9 & 5 & 5 & 5 & 5 & 5 \\ 5 & 9 & 5 & 5 & 5 & 5 \\ 5 & 2 & 9 & 5 & 5 & 5 \\ 5 & 5 & 3 & 9 & 5 & 5 \\ 5 & 5 & 5 & 5 & 9 & 5 \\ 5 & 5 & 5 & 5 & 5 & 9 \end{pmatrix} \quad (9)$$

The permanent value for the matrix 9 (Per B_{SS4}) is found to be 11406466. Similarly, the permanent values for other matrices are calculated and are shown in Table 3.7. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI is obtained by calculating the permanent of the matrix 6 and 7 (i.e., VPM-B). The diagonal elements of matrix 6 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) and diagonals of matrix 7 with permanent values of the sub-systems (per B_{ss1} to B_{ss7}) obtained for the theoretical best-case situation and the Per (B) for the VPM-B is found to be 2.33 x 10^{37}, which can be expressed for the sake of simplicity as $\log_{10}$ (2.33 x 10^{37}), which is equal to 37.3. Similarly, the diagonal elements of matrix 7 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS7}) obtained for the theoretical best-case situation and the Per(B) for the VPM-B is found to be 2.44 x 10^{32}, which can be expressed for the sake of simplicity as $\log_{10}$(2.44 x 10^{32}), which is equal to 33.8.

The obtained value represents the theoretical best-case situation when degree of relationship between IPD elements are at its maximum. But achieving such a state is considered to be ideal situation as the degree of relationship between various elements of IPD cannot be at the maximum.

- **Worst-case situation**: This situation can occur if an organisation has not implemented any of the IPD elements properly and successfully. Hence, the degree of implementation of IPD elements in such an organisation will have a minimum value of 1, i.e., the diagonal elements in each sub-system matrices will be 1. In other words, the CAI will be at its worst, when the inheritance of all its factors is at its worst. In this case, the VPM for B_{SS6} will be re-written as follows:

$$B_{ss6} \; or \; VPM - B_{ss6} = \begin{pmatrix} 1 & 4 & 5 & 3 & 4 & 3 \\ 4 & 1 & 2 & 1 & 4 & 1 \\ 4 & 3 & 1 & 2 & 4 & 1 \\ 3 & 3 & 4 & 1 & 4 & 3 \\ 4 & 4 & 4 & 3 & 1 & 2 \\ 1 & 2 & 1 & 4 & 2 & 1 \end{pmatrix} \qquad (10)$$

In a similar manner, the VPM for other sub-systems are also re-written in such a way that the diagonal elements have the value of '1'. The permanent value for the matrix 10 (Per B_{SS6}) is found to be 77476. Similarly, the permanent values for other matrices are calculated for worst-case situation and are shown in Table 3.8. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI for worst-case situation is obtained by calculating the permanent of the matrix 6 and 7 (i.e., VPM-B). In this case, the diagonal elements of matrix 6 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) obtained for the worst-case situation and the Per(B) for the VPM-B is found to be 1.69 x 10^{23}. The permanent value can be expressed as $\log_{10}$ (1.69 x 10^{23}), which is equal to 23.2. Similarly, the diagonal elements of matrix 7 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS7}) obtained for the worst-case situation and the Per(B) for the VPM-B is found to be 2.13 x 10^{21}. The permanent value can be expressed as $\log_{10}$ (2.13 x 10^{21}), which is equal to 22.3.

- **Ideal worst-case situation:** But in some situation, if an organisation has not implemented any of the IPD elements then the relationship between IPD elements will also be poor. Such a situation may exist in organisation, which still function in a traditional manner. Under such circumstances, minimum values for both the degree of implementation of IPD elements and degree of relationship between IPD elements can be considered. In other words, the values of b_{ij}'s of all the sub-system matrices should have a value of '1', in addition to the diagonal values. For instance, in this case, the matrix 8 will be rewritten as

$$B_{ss6}\ or\ VPM - B_{ss6} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix} \qquad (11)$$

The permanent value of B_{SS6} (i.e., matrix 11) will be 154. In a similar way, the matrices for remaining sub-systems are rewritten and the permanent values for B_{SS1} to B_{SS6} are calculated. These values are shown in Table 3.7. These permanent values of sub-system matrices can be substituted in VPM-B (i.e, matrix 6 and 7) and the permanent for VPM-B can be calculated, representing the CAI for ideal worst-case situation. The CAI for ideal worst case situation is found to be 1.33 x 10^{11}, which can be expressed as $\log_{10}$ (1.33 x 10^{11}), which is equal to 11.1 for the case of matrix 6 i.e. NPI.

The CAI for ideal worst case situation is found to be 1.05 x 10^{9}, which can be expressed as $\log_{10}$ (1.05 x 10^{9}), which is equal to 10.02 for the case of matrix 7 i.e. NPD.

The purpose of calculating the CAI for different case situations is that evaluators can use these values to understand where the organisation stand from the perspective of the roles and responsibilities of their HR during IPD implementation by comparing the CAIs with a similar organisation. For example, we have obtained a CAI value of 2.86×10^{32} or 32.4 for the hypothetical case organisation. Similarly, from Table 3.7, the CAI value for best-case situation is found to be 3.73×10^{34} or 34.6.

Table 3.7: Permanent values for best-case and worst-case situations-NPI

System / Sub-system	**Current value (Normal situation)**	**$\log_{10}$ (Current value) (Normal situation)**	**Maximum value (Theoretical best-case situation)**	**$\log_{10}$ (Maximum value) (Theoretical best-case situation)**	**Maximum value (Practical best-case situation)**	**$\log_{10}$ (Maximum value) (Practical best-case situation)**	**Minimum value (Worst-case situation)**	**$\log_{10}$ (Minimum value) (Worst-case situation)**	**Minimum value (Ideal worst-case situation)**	**$\log_{10}$ (Minimum value) (Ideal worst-case situation)**
Per B_{SS1}	405066	5.6	4058616	6.6	1271547	6.1	12723	4.1	64	1.8
Per B_{SS2}	1285733	6.1	10690316	7.0	2284935	6.4	61023	4.8	252	2.4
Per B_{SS3}	1223550	6.1	8476816	6.9	3380544	6.5	80764	4.9	168	2.2
Per B_{SS4}	801688	5.9	11406466	7.0	2049987	6.3	34879	4.5	312	2.5
Per B_{SS5}	504	2.7	729	2.8	729	2.9	1	0.0	1	0.0
Per B_{SS6}	1112450	6.0	7608166	6.8	2542820	6.4	77476	4.9	154	2.2
Per B	**2.86E+32**	**32.4**	**2.33E+37**	**37.3**	**3.73E+34**	**34.5**	**1.69E+23**	**23.2**	**1.33.E+11**	**11.1**

Table 3.8: Permanent values for best-case and worst-case situations-NPD

System / Sub-system	Current value (Normal situation)	$\log_{10}$ (Current value) (Normal situation)	Maximum value (Theoretical best-case situation)	$\log_{10}$ (Maximum value) (Theoretical best-case situation)	Maximum value (Practical best-case situation)	$\log_{10}$ (Maximum value) (Practical best-case situation)	Minimum value (Worst-case situation)	$\log_{10}$ (Minimum value) (Worst-case situation)	Minimum value (Ideal worst-case situation)	$\log_{10}$ (Minimum value) (Ideal worst-case situation)
Per B_{SS1}	506078	2.3	4923648	6.1	1232649	5.8	45645	5.1	23	1.8
Per B_{SS2}	1189595	5.2	12447378	6.8	2337264	6.2	65455	5.5	232	1.4
Per B_{SS3}	1042957	5.1	234734	7.1	3239234	6.2	54654	5.2	123	1.1
Per B_{SS4}	462365	6.3	12473490	7.3	2349284	6.1	23432	3.5	1	0.0
Per B_{SS5}	354	2.5	492	2.1	248	2.4	12423	2.8	213	1.3
Per B_{SS6}	1140734	5.8	13409537	7.3	4387234	5.8	1	0.0	123	1.0
Per B_{SS7}	1054235	5.3	23542907	8.1	2434222	8.0	24981	3.3	238	1.5
Per B	**2.16E+30**	**31.3**	**2.15E+35**	**35.1**	**3.33E+30**	**30.5**	**1.58E+21**	**20.1**	**1.22.E+10**	**10.1**

Step 13. The permanent values obtained from the two cases are clubbed to form a 2x2 matrix for each of the cases. The matrix for Ideal-worst case situation is shown below:

$$\begin{pmatrix} \mathbf{1.33.E+11} & 0 \\ 0 & \mathbf{1.22.E+10} \end{pmatrix} \qquad (12)$$

Step 14. The permanent values are now calculated for each of these 2x2 matrices.

Resultant table with final permanent values is shown in Table 3.9 below.

Table 3.9: Final Permanent Values

	Theoretical best-case situation	**Practical best-case situation**	**Worst-case situation**	**Worst-case situation**	**Ideal worst-case situation**
Per B	**31.8**	**36.1**	**30.9**	**20.2**	**10.5**

Conclusion

In this thesis report, assessment and evaluation of Innovative Product Development is done. The discussion has been divided into two parts- Evaluation done using AHP and PVA, assessment using Graph Theory. The algorithms for which are discussed here for the model proposed by my Thesis supervisor.

References

[1] Anand, G., and Rambabu Kodali. "A mathematical model for the evaluation of roles and responsibilities of Human Resources in a Lean Manufacturing environment." International Journal of Human Resources Development and Management 10.1 (2010): 63-100.
[2] Gurumurthy, Anand, and Rambabu Kodali. "A multi-criteria decision-making model for the justification of lean manufacturing systems." International Journal of Management Science and Engineering Management 3.4 (2008): 100-118.
[3] Plsek, P.E (1997), Creativity, Innovation, and Quality, ASQC Quality Press, Milwaukee, WI.
[4] Shen, Xiao-Xiang, Kay C. Tan, and Mien Xie. "An integrated approach to innovative product development using Kano's model and QFD." European Journal of Innovation Management 3.2 (2000): 91-99.
[5] Kodali, R. and Routroy, S. (2006) 'Performance value analysis for selection of facilities location in competitive supply chain', International Journal of Management and Decision Making, Vol. 7 No. 5, pp.476-493.
[6] Kodali, R. and Sangwan, K.S. (2004) 'Multi-attribute decision models for justification of cellular manufacturing systems', International Journal of Business Performance Management, Vol. 6 Nos. 3-4, pp.298-320.
[7] Kodali, R., Sangwan, K.S. and Sunnapwar, V.K. (2004) 'Performance value analysis for the justification of world-class manufacturing systems', Journal of Advanced Manufacturing Systems, Vol. 3 No. 1, pp.85-102.
[8] Saaty, T.L. (1980) The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, McGraw Hill, New York.
[9] Grover, S., Agrawal, V.P. and Khan, I.A. (2004) 'A digraph approach to TQM evaluation of an industry', International Journal of Production Research, Vol. 42 No. 19, pp.4031-4053.
[10] Grover, S., Agrawal, V.P. and Khan, I.A. (2006) 'Role of human factors in TQM: a graph theoretic approach', Benchmarking: An International Journal, Vol. 13 No. 4, pp.447-468.
[11] D'angelo, A., Gastaldi, M. and Levialdi, N. (1996a) 'Multi-criteria evaluation model for flexible manufacturing system design', Computer Integrated Manufacturing Systems, Vol. 9 No. 3, pp.171-178.
[12] Anand, G., Rambabu Kodali, and Chandra Sekhar Dhanekula. "An application of analytic network process for selection of a plant location: a case study." International Journal of Services and Operations Management 12.1 (2012): 35-66.
[13] Wabalickis, Roger N. "Justification of FMS with the analytic hierarchy process." Journal of Manufacturing Systems 7.3 (1988): 175-182.