# AN ANALYTIC APPROACH FOR SIX SIGMA PROJECT SELECTION IN THE LOGISTICS INDUSTRY

(LOJİSTİK SEKTÖRÜNDE ALTI SİGMA PROJELERİNİN SEÇİMİ İÇİN ANALİTİK BİR MODEL ÖNERİMİ)

by

**Demet ÖZTÜRKCAN, B.S.**

**Thesis**

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

**MASTER OF SCIENCE**

in

**INDUSTRIAL ENGINEERING**

in the

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Demet ÖZTÜRKCAN
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| | |
|---|---|
| AHP | : Analytic Hierarchy Process |
| ANOVA | : Analysis of Variance |
| ANP | : Analytic Network Process |
| B | : Benefits |
| BE | : Business Excellence |
| BO | : Budget Overrun |
| BOCR | : Benefits, Opportunities, Costs, Risks |
| C | : Costs |
| CI | : Cost of Implementation |
| CT | : Cost of Training |
| CL | : Customer Loyalty |
| COPQ | : Cost of Poor Quality |
| CS | : Customer Satisfaction |
| D | : Dispatcher in DEMATEL |
| DEMATEL | : Decision Making Trial and Evaluation Laboratory |
| DMAIC | : Define Measure Analyze Improve Control phases of Six Sigma |
| DPMO | : Defects per Million Opportunities |
| EC | : Employees' Competencies |
| FMEA | : Failure Modes & Effects Analysis |
| FP | : Financial Performance |
| GP | : Goal Programming |
| HR | : Cost of Human Resources |
| LG | : Learning and Growth |
| MCDM | : Multi Criteria Decision Making |
| MS | : Increased Market Share |
| O | : Opportunities |
| OE | : Operational Excellence |
| PE | : Process Excellence |

| | |
|---|---|
| PJ | : Project Related Risks |
| PPI | : Pareto Priority Index |
| PR | : Productivity |
| R | : Receiver in DEMATEL |
| R | : Risks |
| R&D | : Research and Development |
| RG | : Revenue Growth |
| SMART | : Specific Measurable Achievable Realistic Time-bound |
| SME | : Small or Medium sized Enterprises |
| TD | : Time Delay |
| ZOGP | : Zero-One Goal Programming |

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# ABSTRACT

Six Sigma is regarded as a well-structured methodology for improving the quality of processes and products. It helps achieve the company's strategic goal through the effective use of project based approach. As Six Sigma is a project driven methodology, it is essential to prioritize projects which provide maximum financial benefits to the organization. Generating and prioritizing the critical Six Sigma projects, however, are real challenges in practice. This study aims to develop a novel approach based on a combined Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP) and Zero-One Goal Programming (ZOGP) techniques to help companies determine critical Six Sigma projects and identify the priority of these projects especially in logistics companies. First of all the Six Sigma project evaluation dimension and components are determined. DEMATEL approach is then applied to construct interrelations among criteria. The weights of criteria are obtained through ANP. Lastly, ANP is integrated with a ZOGP model to obtain optimum alternative with desired organizational benefits by utilizing limited resources. An empirical case study from logistics industry is used to explore the effectiveness of the proposed approach.

# RÉSUMÉ

Le Six Sigma est considéré comme une méthodologie bien structurée pour améliorer la qualité des processus et des produits. Il aide à atteindre l'objectif stratégique de la compagnie par l'utilisation efficace de l'approche du projet. Comme le Six Sigma est une méthodologie du projet, il est essentiel de donner la priorité aux projets qui procurent les avantages financiers maxima à l'organisation. Produire et mettre en ordre d'importance les projets critiques de Six Sigma sont de vrais défis dans la pratique. Cette étude vise à développer une approche originale basée sur les techniques de Laboratoire combiné de prise de décision et d'évaluation (DEMATEL), le processus analytique de réseau (ANP) et Zero-One Goal Programming (ZOGP) pour aider les compagnies à déterminer les projets critiques de Six Sigma et à définir la priorité de ces projets particulièrement dans les compagnies de logistique. Tout d'abord la dimension d'évaluation et les composants du projet sont déterminés. L'approche de DEMATEL est alors appliquée pour déterminer les interdépendances entre les critères. Les poids des critères sont obtenus par ANP. Enfin, ANP est intégré avec le modèle ZOGP pour obtenir l'alternative optima avec les avantages désirés en utilisant les ressources limitées. Une étude de cas empirique de l'industrie de logistique est employée pour évaluer l'efficacité de l'approche proposée.

**ÖZET**

Altı Sigma yöntemi süreç ve ürünlerin kalitesini iyileştirmede uygulanan, düzenli yapılandırılmış bir teknik olarak kabul edilmektedir. Proje temelli uygulaması ile şirketlere, stratejik hedeflerine ulaşmalarında yardımcı olan etkin bir yaklaşımdır. Altı Sigma uygulaması proje temelli olduğu için, projelerin şirketlere finansal faydayı en büyükleyecek şekilde sıralandırılmasında etkin olmaktadır. Bununla birlikte Altı Sigma projelerinin uygulama aşamasında, projelerin oluşturulması, önceliklendirilmesi ve seçilmesi başlı başına önem arz etmektedir. Bu çalışma özellikle lojistik şirketlerinde, kritik Altı Sigma projelerinin tanımlanması, önem sırasına göre düzenlenmesi ve seçilmesinde yardımcı olacak çok ölçütlü karar verme yöntemleri olan karar verme ve değerlendirme laboratuarı (*DEMATEL-Decision Making Trial and Evaluation Laboratory)*, analitik serim süreci (*ANP-Analytic Network Process)* ve sıfır-bir tam sayılı programlama (*ZOGP-Zero-One Goal Programming)* tekniklerinin birleştirilmesiyle oluşturulan yeni bir yaklaşım önermektedir. Çalışmanın ilk aşamasında, Altı Sigma projelerinin değerlendirilmesinde kullanılan önemli elemanlar ve kriterler belirlenmiştir. Belirlenen kriterler arasında var olan karşılıklı ilişki ve kriterlerin birbiri üzerindeki etkisi DEMATEL yöntemi ile modellenmiştir. Kriterlerin ağırlıkları ANP yöntemi ile hesaplanmıştır. Son olarak, ANP yöntemi ile elde edilen kriter ağırlıkları sınırlı kaynakların göz önüne alındığı ZOGP modeli içerisinde kullanılarak şirket faydasına en uygun proje alternatifinin seçilmesi hedeflenmiştir. Önerilen yaklaşımın etkinliği, bir lojistik firmasından elde edilen güncel verilerle denenerek geçerliliği sınanmıştır.

# I. INTRODUCTION

Six Sigma is one of the powerful business strategies that improves quality initiatives in many industries around the world. It is a company-wide systematic approach to achieve continuous process improvements. Not only a technique but also as a philosophy, performing at Six Sigma means producing only 3.4 defects out of every million opportunities for a business process [1]. There has been a significant increase and development of Six Sigma technology and methodology in organizations [2, 3]. Especially in the last decade, as a change and improvement strategy, Six Sigma has received considerable attention in global companies to generate maximum business benefit and competitive advantage [4, 5]. This strategic approach consists of five basic phases: define measure, analyze, improve and control which can also be symbolized by initials, as D-M-A-I-C.

In selecting the most suitable project, define phase is the critical step in identification of the problem [6, 7, 8, 9]. Likely benefits and possible contributors are defined [10]. Focussing on the customer needs, Six Sigma projects are formed, the requirements and current performance are measured, the criteria and key variables that affect the customer satisfaction are analyzed, the process is improved, by monitoring and checking the systems the process is controlled [1, 10].

Selecting of the right Six Sigma project is one of the most sensitive elements in the deployment of Six Sigma [1, 7, 11, 12]. For this reason, in this study we applied an integrated decision framework based on Decision Making Trial and Evaluation Laboratory (DEMATEL) [13], Analytic Network Process (ANP) [14] and Zero-One Goal Programming (ZOGP) [15] for selecting the most appropriate Six Sigma project alternative.

As a matter of fact, there are numerous applications of DEMATEL and ANP recently used together to supplement and/or support the outcomes of each other in cases such as airline safety measurement [16], location selection [17], identification of key development areas [18], corporate social responsibility programs [19], solid waste management [20], choosing knowledge management strategies [21], and selecting management systems [22].

In addition to this, ANP and ZOGP are also adopted together to complement the outcomes of one another in cases such as interdependent information system project selection [23], product planning in quality function deployment [24], selection of a reverse logistics project for end-of-life computers [25], revitalization strategies in historic transport [26] and selecting management systems for sustainable development in SMEs [22] which this study is lead in light of the work.

DEMATEL method is a potent method that helps in gathering group knowledge for forming a structural model, as well as visualizing the causal relationship of sub-systems through a causal diagram [27]. ANP was developed by Saaty [14] to overcome the problem of dependence and feedback among criteria or alternatives [16]. ZOGP is a good approach to handle a Multi Criteria Decision Making (MCDM) problem regarding both the objectives and resource constraints of a company. Here, DEMATEL is used to detect complex relationships and build relation structure among criteria for selecting Six Sigma projects. Additionally, ANP is adopted to deal with the problem of the sub-systems interdependence and feedback; set priorities among goal, strategy and criteria; and finally ZOGP is applied to evaluate the weighted criteria considering the limitations to determine the most appropriate project alternative.

The rest of this master thesis is organized as follows. In Section 2, the Six Sigma main concept is introduced. In Section 3, Six Sigma project evaluation and the developed model is presented. In Section 4, the techniques applied in evaluation of the Six Sigma projects are explained. In Section 5, an empirical case study from logistics industry is given to prove the effectiveness of the proposed approach. In conclusion, the findings of this research are discussed.

## 2. SIX SIGMA METHODOLOGY

The origin of Six Sigma comes from statistics and statisticians [28]. From the statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% where sigma is a term used to represent the variation about the process average [29].

Motorola and General Electric are considered to be pioneers of the Six Sigma approach, which is aimed at assessing and improving product and service quality [30]. Reputed examples of Six Sigma companies include Honeywell, Polaroid, Sony, Honda and Ford. The Six Sigma approach was first applied in manufacturing operations and rapidly expanded to different functional areas such as marketing, engineering, purchasing, servicing, administrative support and lately supply chain and logistics.

### 2.1. SIX SIGMA MAIN CONCEPTS

The Six Sigma method is a project-driven management approach to improve the organization's products, services and processes by continually reducing defects in the organization. It is a business strategy that focuses on improving customer requirements understanding, business systems, productivity and financial performance [28]. Among the many business improvement approaches available, Six Sigma approach has been recognized as one of the most effective methods [5].

Stroud and Sutterfield [31] indicate that, the basic principles of the Six Sigma approach, which is ultimately a managerial decision-making tool, include:

- Aligning key business processes and customer requirements with the organization's strategic goals,
- Instituting a standard measurement system to be used throughout the organization,
- Providing extensive Six Sigma and project management training,

- Deploying appropriately trained teams to improve quality and profitability while reducing time and waste, and
- Setting extended improvement goals.

The basic approach of Six Sigma is composed of five main phases: Define, Measure, Analyze, Improve and Control which is also symbolized by initial letters DMAIC in literature. As Define phase is the first step of the whole methodology, it focuses on the opportunities for development, improving business processes, identifying key customer needs and preparation to be an efficient project team [12, 32]. This initial phase is the main point in defining the project alternatives.

The secondary phase Measure involves identifying relevant criteria to meet the customer needs, develop operational performance and optimize inventory to determine existing process performance and desired process performance [8, 33]. The third action of the technique, Analyze deals with determining the cause and solution of the problem and finding statistically verified variations in the process [2, 3].

Following that, Improve phase covers the evaluation of the development solutions adapting the organization to the changes and selecting the new or revised improvement process to be implemented [11]. The final step, Control emphasizes the importance of planning and implementation in the company to determine if corrective action is needed [34, 35]. The general Six Sigma process is presented in Figure 2.1.

Based on the phases of Six Sigma, Define phase is the initial step in considering the project alternatives and Improve phase is the step in selecting the most appropriate project regarding company goals and resource constraints. Understanding the key features, obstacles and shortcomings of Six Sigma provides opportunities to practitioners for better select and implement Six Sigma projects [28]. It allows them to better support their organizations' strategic direction and increasing needs for coaching, mentoring and training.

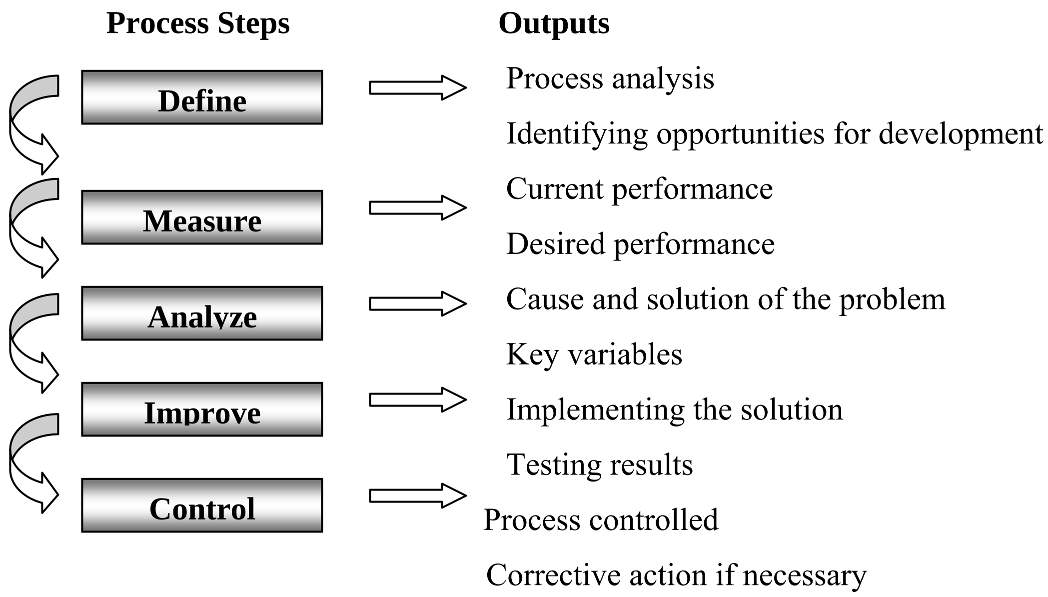


Figure 2.1. The Six Sigma process and the key outputs.

During Six Sigma implementation, projects are generally employed by specially trained Black Belts and Green Belts with technical expertise in project management and statistical experimentation methods to tackle process related problems [8, 36]. The belts are expected to hold the technical and managerial skills, capability to understand and implement tools, techniques and methodologies and be able to coach the organization [7]. In application, if the project is initiated in one department a Green Belt can take charge, if it is run in several departments a Black Belt and/or Master Black Belt is assigned to coordinate in integrity [6]. Black Belts and Green Belts are supported by Yellow Belts, mostly operators who have relevant hands-on experience.

The duration of each Six Sigma project may range 4 to 6 months [9]. The training involves a particular period of time, for the Black Belt this period is about for months, whereas the Green Belt training sessions take two months time [9].

Six Sigma is a well structured methodology that can help a company achieve expected goal through continuous project improvement. The main benefit of a Six Sigma program is the elimination of subjectivity in decision making, by creating a system where everyone in the organization collects, analyzes and displays data in a consistent way [4]. Companies who apply Six Sigma gain a significant improvement in the quality of processes and products regarding both the business strategy and the customer requirements [3]. The prioritized projects by Six Sigma provide maximum financial benefits to the organization [8]. With Six Sigma methodology, the benefits of an organization include not only higher levels of quality bus also lower levels of costs, higher customer loyalty, greater market share, better financial performance and profitability of business [30].

Moreover, service oriented companies adopting Six Sigma have efficient and reliable internal operations, reduced number of non-value added operations through systematic elimination, leading to faster delivery of service, more predictable and consistent level of service by monitoring process variances [8]. Six Sigma application in the company improves cross-functional teamwork across the entire organisation and transform organisational culture from being reactive to proactive mindset [12]. Considering the realized benefits of Six Sigma program, many organizations have sustained their competitive advantage by integrating their knowledge of process with statistics, engineering and project management [28].

## 2.2. SIX SIGMA APPLICATIONS IN TURKEY

Embraced and implemented by some of the biggest corporations in the world, 6 Sigma is a highly disciplined business management strategy that seeks to remove the causes of defects and errors in manufacturing and business processes, and to continuously improve productivity, profitability and customer satisfaction. The Six Sigma methodology was introduced by Motorola, Inc. who has reported over US$17 billion in savings from Six Sigma as of 2006. In addition to Motorola, companies that adopted Six Sigma methodologies early on and continue to practice them today include Honeywell International and General Electric. Lately, the methodology is implemented and applied in many Turkish companies too.

One of the leading appliers of Six Sigma program in the country is TEI-Tusaş Engine Industries (http://www.tei.com.tr). TEI has been applying Six Sigma to fully adopt quality management systems per international/customer/regulatory authority standards. The company has advanced its delivery on time strategy with competitive pricing with Six Sigma implementation by continuously improving products and services, processes and quality management system.

Arçelik A.Ş. (http://www.arcelik.com.tr), one of the leaders in the Turkish white goods industry, has taken the first initiative to apply Six Sigma in production and technology processes in 1998 and extended to other processes as well as since 2002. In Arçelik A.Ş., Six Sigma projects are determined and implemented with coordination of Six Sigma leaders. Six Sigma applications used at Arçelik A.Ş. involve improving processes, making processes transparent and manageable, establishing a decision making mechanism based on data, achieving a constantly profit increasing platform, combining organization and process objectives, achieving customer oriented approach and encouraging innovation.

Vodafone Turkey, a telecommunication operator is also applying Six Sigma in process design, process management and process improvement as management strategy since 2007. With the help of the Six Sigma program, Vodafone Turkey focuses on prioritization of the projects, develops customer satisfaction, improves team work in the entire company and gains a competitive advantage in the telecommunication market.

Eczacıbaşı Vitra, one of the leading companies in building products, applies Six Sigma in effective data gathering and analysis, aiming process excellence by eliminating non-value added operations, focusing on customer needs and developing internal team work in the company. Benefiting of the Six Sigma program, Eczacıbaşı Vitra has minimized the defects in the production process and gained a degree of ranking the fifth company in the world in building products market.

Ford Otosan, a shareholder of Ford Motor Company in Turkey, also uses Six Sigma methodology in its service units. The company mainly applied the customer focused strategy of Six Sigma, fastening service processes' development, decreasing costs of poor quality and minimizing product defects. This directly reflected a 10%-40% cost effective advantage for the company profit.

Bosch Bursa Diesel Plant (http://www.bosch.com.tr) is a successful applier of the Six Sigma methodology in Turkey. It is among the four plants of Bursa and produces automotive technologies. With Six Sigma the company ensured the continuous improvement of all its internal processes keeping its customers satisfied and quality standards high.

Borusan Holding (www.borusan.com.tr), steel pipe and flat steel manufacturer, automotive and heavy construction equipment distributor, embarked its Six Sigma journey as part of a broader corporate transformation strategy aimed at reinventing itself to perform in an increasingly competitive economy in 2002. The program has been credited with generating over $38 Million in financial benefits based on the completion of over 200 projects realized by a Six Sigma community of more than 1000 employees.

KalDer (the Turkish Society for Quality) (www.kalder.org) has cooperated with ASQ (American Society for Quality) in introducing and spreading Six Sigma program to the Turkish companies. Today, Six Sigma is applied in many companies of various sectors such as manufacturing, service, telecommunication, oil refining, automotive, white goods, supply chain, construction etc.

## 3. SIX SIGMA PROJECT EVALUATION AND SELECTION

Project selection refers to identifying some alternative projects in order to maximize the net benefit to the organization and allocating resources only among those alternatives, within the given constraints on resources [37]. Selecting the optimal solution in an organization is a difficult task since there are multiple factors such as project risk, organization goals, limited resources etc. in the candidate project alternatives.

For many companies, the question is not whether or not to implement Six Sigma, but how to implement a successful Six Sigma project. The selection of the most appropriate projects is probably the most difficult aspect of Six Sigma [2]. Six Sigma projects have to be carefully reviewed, planned and selected to maximize the benefits of implementation. The project has to be feasible, organizationally and financially beneficial and customer oriented. The project has to be reviewed periodically to evaluate the status of the project as well as the performance of Six Sigma tools and techniques being implemented [28].

Considering the appropriate selection, projects should be linked to the strategic needs and priorities of the organization [34]. According to Antony *et al.* [12] the selection of the right project is a vital factor for gaining early and long-term acceptance of the Six Sigma program among the managers and the employees in any organization. The projects must be chosen in accordance with the organization's goals and strategies [7]. Leading the needs of the company and the customers, a suitable project is chosen to be applied aiming to improve the performance and reach an optimum solution.

### 3.1. PROJECT EVALUATION AND SELECTION LITERATURE SURVEY

Effective project selection is based on identifying the projects that best match the current needs, capabilities and objectives of organizations [2]. The existing methodologies for project selection range from multiple criteria decision making techniques to scoring and ranking methods. Lee and Kim [23] used ANP approach within a ZOGP model to suggest an improved information system project selection methodology which reflects interdependencies among evaluation criteria and candidate projects. Ravi *et al.*, [25] applied a combination of ANP and ZOGP to deal with selection of reverse logistics projects for end-of-life computers. In the study ANP is used determine the degree of interdependence among criteria and candidate projects while ZOGP permits the consideration of resource limitations and other constraints arriving at the solution. Meade and Presley [38] similarly used ANP and developed a generic model which includes in its decision levels the actors involved in the decision, the stages of research, categories of metrics, and individual metrics to support the selection of projects in a R&D environment. Liang and Li [39] used ANP for enterprise information system project selection with regard to BOCR which contributes to the study of ANP application in project selection. Wey [40] proposed a unique model integrating multi objective optimization, Monte Carlo simulation and the ANP for urban renewal projects selection with uncertainty considerations. Kim and Emery [41] utilized ZOGP in project selection and resource planning, presenting and a model that determines most advantageous project to pursue in light of limited resources including capital, personnel and machinery by utilizing a quantitative methodology .

According to the studies made in literature since 2000, it is observed that various researchers came out with a list of criteria in selection of Six Sigma Projects. Customer satisfaction is seen to be one of the major decision making approaches and it is proposed by Pyzdek [3, 42], Anderson-Cook *et al*. [32], Banuelas [35, 43], Antony *et al*. [12], Kumar *et al*. [33], etc. Risk criterion is suggested by Pande e*t al.* [2] and Antony [8; 44]. Revenue growth is advised by Breyfogle [45], Goldstein [46], Nonthaleerak and Hendry [9]. Learning and growth is another option recommended by Snee and Rodenbaugh [11] and Banuelas *et al*. [35]. Project duration is also implied in studies of Harry and Schroeder [30] and Kumar *et al*. [33]. In addition to this, cost involved in running the project is another significant decision point supported by Pande *et al*. [2] and Antony *et al*. [12] in selecting Six Sigma projects. The detailed literature survey of the criteria in selection of Six Sigma projects is presented in Table 3.1.

Table 3.1. Six Sigma project selection criteria.

| CRITERIA | MAIN SOURCES |
|---|---|
| Voice of the customer, customer satisfaction, customer needs | [1, 2, 3, 6, 8, 12, 30, 32, 33, 35, 42, 44, 45, 47, 48, 49, 50, 51]. |
| Voice of the business, goals in strategic terms, core competence | [2, 3, 7, 8, 12, 30, 33, 34, 35, 42, 43, 44, 45]. |
| Voice of the process | [8, 11, 12, 47]. |
| Voice of the stakeholders, top management commitment | [2, 8, 35, 47]. |
| Project impact in financial terms | [2, 3, 8, 9, 12, 30, 32, 33, 34, 35, 42, 44, 45, 46, 51]. |
| Cost involved in running the project | [8, 12, 33, 44]. |
| Level of expertise required for project, number of BB and GB | [2, 8, 11, 12, 33, 52, 53]. |
| Risk involved in the project | [2, 8, 12, 44]. |
| Project impact on the cost of poor quality (COPQ) | [8, 12, 30, 33, 36]. |
| Feasibility criteria, probability of success, measurable | [2, 3, 8, 30, 34, 35, 42, 45, 46, 51]. |
| Organization impact criteria, increase in sigma level | [2, 11, 33]. |
| Defects per million opportunities (DPMO), quality | [8, 30, 33, 36, 47, 52]. |
| Cycle time, duration of the projects considered | [8, 30, 33]. |
| Capacity and resources required | [8, 30]. |
| Internal performance, voice of the employees | [7, 8, 35, 51]. |
| Learning and growth | [2, 11, 30, 35, 44]. |
| SMART (specific, measurable, achievable, realistic, time-bound) | [8, 53]. |
| Voice of the suppliers | [52]. |

There are numerous techniques applied in evaluating Six Sigma methodology. According to De Koning and De Mast [47], the Six Sigma program offers a wide range of tools and techniques, which might be statistical or non-statistical, that are intended to assist the project leader. Those methods even can be utilized in different phases of the Six Sigma projects. The successful implementation of Six Sigma requires stringent application of tools and techniques at different stages of the methodology [8].

The tools and techniques applied in the evaluation of six sigma phases can be classified as statistical tools like Sampling [32, 47], Analysis of Variance (ANOVA) [54], Statistical Process Control [9, 10, 12, 32, 47, 54], Regression Analysis [8, 10, 29], Correlation Studies [8, 29, 54] etc., quality tools like Quality Function Deployment [2, 3, 8, 12, 29, 32, 35, 42, 47, 54, 55], Quality Costing [8, 29], or MCDM methods especially Analytic Hierarchy Process (AHP) [3, 42, 54, 56]. Based on the literature survey, the techniques applied in Six Sigma evaluation is given in Table 3.2 and a general view of the proposed evaluation framework is given in Figure 3.1.

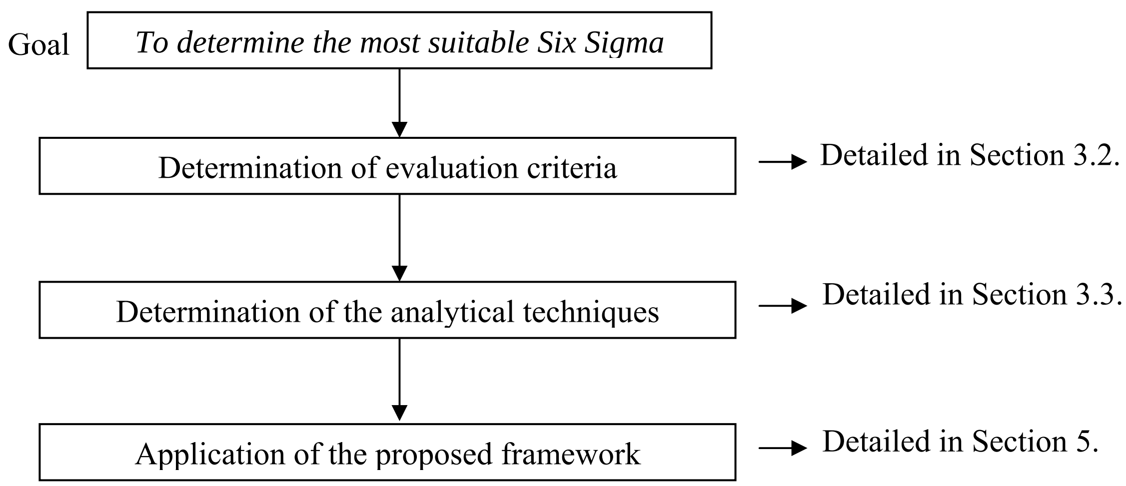


Figure 3.1. A general view of the proposed evaluation framework.

Table 3.2.a. Tools and techniques for Six Sigma evaluation.

| TOOLS | MAIN SOURCES |
|---|---|
| Process mapping | [8, 12, 43, 47, 54]. |
| Brainstorming | [8, 10, 12, 32, 47, 54]. |
| Root cause analysis | [8, 12, 57]. |
| Run charts | [10, 12, 29, 58]. |
| Benchmarking | [1, 8, 12, 35, 47, 54]. |
| Pareto analysis | [1, 8, 10, 12, 29, 32, 35, 43, 47, 54]. |
| Change management tools | [12]. |
| Kano model | [8, 10, 12, 35, 47]. |
| Statistical process control | [9, 10, 12, 32, 47, 54]. |
| Quality function deployment | [2, 3, 8, 12, 29, 32, 35, 42, 47, 54, 55]. |
| Design of experiments | [10, 12, 29, 47]. |
| Process capability analysis | [8, 12, 32, 43, 47, 57]. |
| Poka-Yoke | [12, 29, 55]. |
| Gap model, gap analysis | [12, 43]. |
| Pareto priority index (PPI) | [3, 35, 42]. |
| AHP | [3, 42, 54, 56]. |
| Theory of constraints | [3, 35, 42]. |
| Project assessment matrix | [45]. |
| Project selection matrix | [59]. |
| Project ranking matrix | [52]. |
| Reviewing data on potential projects against specific criteria | [60]. |
| Data envelopment analysis | [33]. |
| Check sheet | [32, 47]. |
| Data collection plan, form, sheet | [10, 47, 57]. |
| Bar chart, pie chart | [32, 47]. |

Table 3.2.b. Tools and techniques for Six Sigma evaluation.

| TOOLS | MAIN SOURCES |
|---|---|
| Box plot | [10, 32, 47]. |
| Line chart | [32, 47]. |
| Histogram | [8, 10, 32, 47, 58]. |
| Sampling | [32, 47]. |
| Customer interview, Survey, Focus group | [32, 35, 47]. |
| CTQ tree, tree diagram | [10, 32, 43, 47, 54]. |
| Affinity diagram | [8, 10, 32, 47]. |
| Data mining | [47]. |
| Cause and effect matrix | [8, 10, 29, 35, 43, 47, 54, 55, 58]. |
| Transmission of variance analysis | [32, 43, 47]. |
| Gantt chart | [8, 10, 32, 47]. |
| Failure modes & effects analysis (FMEA) | [29, 32, 47, 54, 58]. |
| Simulation | [32]. |
| Value stream mapping | [35, 54]. |
| Balance scorecard | [35]. |
| Cost-Benefit analysis | [8, 35]. |
| Regression analysis | [8, 10, 29]. |
| Correlation studies | [8, 29, 54]. |
| Taguchi methods | [29]. |
| Hypothesis testing | [8, 10, 29]. |
| Control charts | [8, 10, 29, 58]. |
| Quality costing | [8, 29]. |
| ANOVA | [54]. |
| Consensus | [10]. |

### 3.2. SIX SIGMA PROJECT EVALUATION AND SELECTION CRITERIA

After making a very detailed literature survey as given in Section 3.1, it is analyzed that authors have constituted numerous dimensions in selecting the right Six Sigma project. In this study, we categorized those criteria under 3 strategies (business excellence, revenue growth, and productivity), 4 factors (benefits, opportunities, risks, costs) and a total number of 14 sub-factors.

As a strategy, business excellence (BE) is the systematic improvement of business performance based on the principles of customer focus, stakeholder value, and process management [7, 43, 48]. Key practices in business excellence applied across functional areas in an enterprise include continuous and breakthrough improvement, preventative management and management by facts [3]. Some of the tools used are the balanced scorecard, the Six Sigma statistical tools, process management, and project management [44].

The following strategy, revenue growth (RG) is the increase in value of the goods and services produced by a company. As a result of Six Sigma program application, consistent revenue growth, as well as income growth, is considered essential for a company [46, 51]. The raise in financial income is accepted as the basic indicator of a company's business activities. This helps to give analysts, investors and participants an idea of how much a company's sales are increasing over time. Third strategy, productivity (PR) is one of the main processes of a company managed by Six Sigma program. PR is the amount of output produced relative to the amount of resources (time and money) that go into the production. Productivity increases when the quantity of output increases relative to the quantity of input with the help of Six Sigma methodology [33]. Companies can increase productivity in a variety of ways. Six Sigma is one of the techniques applied for productivity and quality in terms of sustainable efficiency [2, 34].

Benefits (B) can be one of the factors that affect Six Sigma project selection and it is analyzed in four sub-factors: process excellence (PE), customer satisfaction (CS), financial performance (FP) and learning and growth (LG). PE can simply regard to the methodical development of business process which is one of the main targets of the Six Sigma projects [12, 47]. PE requires the ensemble of activities of planning and monitoring the performance of a process which can be possible with an accurate process management. It is a systematic approach in the Six Sigma projects to help any organization optimize its underlying processes to achieve more efficient results [11]. CS is a measure of how products and services supplied by a company meet or surpass customer expectation. As a major objective of Six Sigma program, it is seen a key differentiator and increasingly has become a primary element of business strategy [6, 30, 32]. In terms of retaining existing customers and targeting non-customers, measuring CS provides an indication of how successful the company is at providing product and/or services [8, 43].

As a following sub-factor, FP is one of the most important aspects of business management in an organization [46]. It is a subjective measure of how well a firm can use assets from its primary mode of business and generate revenues over a given period of time. FP generally involves balancing risk and profitability, while attempting to maximize an entity's wealth and the value of its stock which is one of the major criteria applying Six Sigma methodology [3, 45].

The final sub-factor of Benefits is LG. It is a perspective that includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement. LG refers to implementation of Six Sigma process in company and adaptation of employees and knowledge-workers [35, 44]. In any case, LG constitute the essential foundation for successful Six Sigma projects of any knowledge-worker organization [2, 11].

Opportunities (O) is another factor including the sub-factors operational excellence (OE), increased market share (MS), customer loyalty (CL) and employees' competencies (EC). OE is a philosophy of leadership and teamwork resulting in continuous improvement throughout the organization by focusing on the needs of the customer, empowering employees, and identifying wasteful activities from its process which is one of the strategies of the Six Sigma application [52]. It defines a safe, healthy, environmental, reliable, efficient and a systematic approach of management to achieve world-class performance [30]. It involves analyzing the flow of materials and managing product development, operations and information in terms of suppliers, customers and employees [36, 52].

MS is one of the most important objectives of a company aiming to increase the percentage or the proportion of the total available market that is being serviced by a company. It can be expressed as a company's sales revenue divided by the total sales revenue available in that market. It is the clearest indication of how well a company is doing in the marketplace compared to its competitors.

The following sub-factor, CL describes the tendency of a customer to choose one business or product over another for a particular need. It is a model in Six Sigma program which company resources are employed so as to increase the loyalty of customers and other stakeholders in the expectation that corporate objectives will be met or surpassed [49]. The ultimate goal of CL programs is satisfied customers who will return to purchase again and persuade others to use that company's products and services which is a basic output of the Six Sigma methodology [48, 50].

EC is the last sub-factor analyzed under the Opportunities factor. It is the ability of employees' to perform a specific task, action or function successfully and it is one of the major intentions of implementing Six Sigma in an organization [51]. By visualizing the strengths and weaknesses of each team member and worker leads to refine their skills for their highest level of performance [7]. This approach can be optimized by well-written job descriptions taking into account the employees' education and experiences.

The following factor Risks (R) consists of the sub-factors budget overrun (BO), time delay (TD) and project related risks (PJ). Under the factor of risks, BO can be defined as excess of actual budget which plays a very important role for decision making in any project applied Six Sigma [2]. Through the financial year turn if the expected revenues and expenses instead of coming close diverge wildly from the budget, this sends an out of control signal and as a result comes out with a suffering share price [61].

TD is the shift of time to a forward date which directly affects the budget and the business process [30]. It is a risk that requires a corrective action, taken care of earlier than the final point without impacting the Six Sigma project schedule [8]. PJ can be any risk that would affect the ongoing Six Sigma project negatively [44]. Political situation, laws & regulations, permits & approvals, working conditions, financial status, competence of project team, approval methodology & timing, technical know-how, staffing, suppliers, etc. can be some of the key reasons of any project. The Six Sigma is directly related with risk involved in the project [2, 12].

Last factor stated is costs (C) and it is examined in three different sub-factors as cost of implementation (CI), cost of training (CT) and cost of human resources (HR). CI is the cost needed in realization of the Six Sigma project in the company. The implementation cost for a successful Six Sigma initiative can be considerable and failure to select an alternative may further translate into loss of expected returns [61]. It is already a proven fact that the benefits obtained from Six Sigma implementation outweigh the investment costs [62].

CT is the cost utilized in instructional Six Sigma process for employees and workers of the company. The duration of each Six Sigma project may range 4 to 6 months [9]. The training involves a particular period of time, for the Black Belt this period is about for months, whereas the Green Belt training sessions take two months time [9]. Regarding the type of project, CT is directly related with the duration scheduled.

HR refers to the total charge used in orientation of Six Sigma project phases for employees and workers. The number of managers running the Six Sigma program and the number of departments the project is initiated help to embody the cost involved for staffing [7]. Degree of managerial skills and authorization, whether a Green Belt, Black Belt or a Master Black Belt also plays a significant role in budgeting the human resources [6]. The general evaluation model of Six Sigma project selection is given in Figure 3.2.

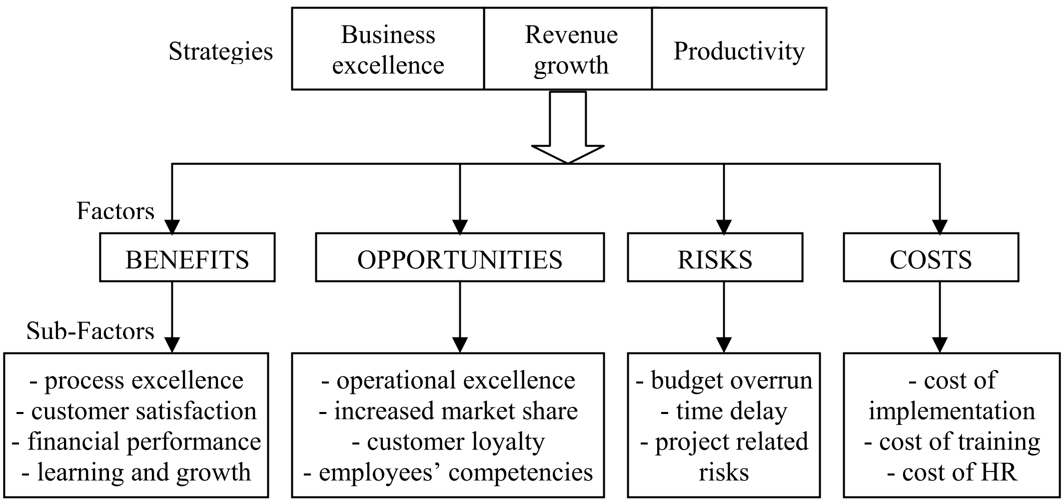


Figure 3.2. Six Sigma project evaluation criteria.

## 3.3. OVERVIEW OF THE PROPOSED EVALUATION FRAMEWORK

Project selection process is made up of several steps. The critical points are to define criteria by analyzing the studies in literature and doing market research regarding the goals, strategies and financial benefits for the company, to set up a team of competitive managers for a consensus evaluation, to apply analytical tools to testify and validate the evaluation criteria and finally to choose the best project alternative for the organization. In project selection, the problem should be stated clearly and decomposed into a rational system like a network.

Since project selection involves a variety of alternatives, it also involves a variety of criteria. To solve multi criteria problems, there exist various techniques and approaches in literature. In this study, to select the most appropriate Six Sigma project MCDM techniques are utilized. MCDM methods assist in reaching critical decisions that cannot be made straightforwardly [63]. One of the widely used MCDM methods is AHP. Saaty [64] developed AHP method to solve the problems of MCDM in 1980. Since

AHP method cannot handle interdependence in evaluation criteria, ANP was developed [65]. It is a nonlinear structure, while AHP is hierarchical and linear with a goal at the top level and the alternatives in the bottom level [27]. Since project selection involves considering various states and options, it is reasonable to utilize ANP which extends the AHP method [66]. Additionally, DEMATEL method is also used in MCDM field to construct interrelations between criteria [67].

The effectiveness of decision making depends on the ability of decision-makers to analyze the complex cause-effect relationships [68]. In recent years, DEMATEL and ANP tools have been successfully used in some areas especially including project selection. Both methods are based on a pairwise comparison foundation and allow including the influence of intangibles. According to Wu [21], DEMATEL is a wise option to calculate inner dependencies since it can produce more valuable information for making decisions. Following this statement, in this study we preferred to use the same approach applying DEMATEL to obtain relations of influence between sub-factors in a pairwise manner when inner dependency occur within an evaluation cluster.

The DEMATEL method is the initial tool utilized in identifying the interactions among evaluation criteria to construct a network structure with interdependent relationships. DEMATEL is beneficial to detect complex relationships [16]. It is also advantageous in gathering group knowledge for forming a structural model to visualize the cause-effect relationships of sub-criteria [37, 41]. It is utilized to help management decision makers in judging, ranking and classifying the inner dependency among strategies and sub-factors.

Following that, for obtaining the relative influence between factors and sub-factors, the experts were asked through a series of pairwise comparisons. The results gathered and the inner dependences occurred within an evaluation cluster obtained by DEMATEL method are both carried and placed in the supermatrix. The inner dependency is structured and symbolized on the model by looped arcs. Additionally, according to the total-relation matrix the impact-diagraph map is formed. Further calculations are made to obtain the best project alternative using the ANP methodology.

Secondly, ANP approach is used to decide the relative weights of the criteria. ANP is one of the MCDM techniques that improves the visibility of decision making processes and generates the priorities between the decision alternatives [22]. The ANP method is useful in transforming qualitative judgments into quantitative values which is appropriate in selection projects. The calculations of the supermatrix can be easily solved by using the professional software named Super Decisions 1.6.0 [69]. Another advantage of ANP is that the weights obtained through its application can be integrated with ZOGP.

Finally, ZOGP is applied with the evaluated data obtained by ANP. For project selection, the ZOGP model is advantageous in handling multiple conflicting objectives [24]. Since the application presented in this thesis is a real life case study, it concerns resource and other selection limitations such as time, budget and necessary investment etc. It is seen that, ANP and ZOGP model gives an effective solution providing more realistic result [25, 26]. The ZOGP model is solved by LINGO 9.0 software [70].

Integrating the data obtained with the utilized analytical tools, this thesis presents a combined DEMATEL, ANP and ZOGP approach to choose Six Sigma projects in a logistics company. The methods DEMATEL, ANP and ZOGP used in Six Sigma project selection framework are summarized in the following section.

# 4. TECHNIQUES APPLIED IN SIX SIGMA PROJECT SELECTION

The techniques determined for the proposed methodology are detailed in this section in order of application with updated literature surveys.

## 4.1. THE DEMATEL METHOD

In this section, firstly the literature survey on DEMATEL is given; then the methodology is presented.

### 4.1.1. The DEMATEL Literature Survey

The DEMATEL method originated for a Science and Human Affairs Program by the Geneva Research Centre of the Battelle Memorial Institute [13, 71]. It is a comprehensive method for building and analyzing a structural model involving causal relationships between complex factors [72]. It is especially practical and useful for visualising the structure of complicated causal relationships with matrices or diagraphs [21]. The matrices or diagraphs portray a contextual relation between the elements of the system [73].

According to the above information, the major application of DEMATEL is to investigate the influential status and strength between the factors and transform them into an explicit structural mode of a system [68, 74, 75]. The DEMATEL method has been successfully applied in many fields such as R&D project selection [68]; real estate agent service quality expectation [20]; evaluation of service solutions in service engineering [76]; introduction of a new product [72, 77]; airline safety measurement [16, 78]; job performance structuring [79]; solid waste management [73, 80]; evaluation and selection of knowledge management strategies [21]; human factors engineering [81]; developing global managers' competencies [27]; evaluation of e-learning programs [75]; hotel service quality [82], safety and security systems analysis [83, 84]; regional development [18]; strategic planning [85, 86]; location selection [17] etc. The detailed survey is given in Table 4.1.

Table 4.1.a. DEMATEL method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [16] | Airline safety measurement using a hybrid model / Measuring airline safety system levels | DEMATEL & ANP, MCDM | DEMATEL is beneficial to detect complex relationships and build relation structure among criteria. |
| [17] | Using a strategic approach to analysis the location selection for high-tech firms in Taiwan / Location selection | DEMATEL & ANP | Methods are utilized to show relationships and to explain the value and benefits of criteria. |
| [18] | Identification of key development areas for the Opole Region / Identification for regional development | DEMATEL & MCDM, AHP, ANP | No explication for justification. |
| [19] | Corporate social responsibility programs choice and costs assessment in the airline industry – a hybrid model / Developing a technique for operationalizing CSR programs | DEMATEL & ANP, ZOGP, Activity-based costing | No explication for justification. |
| [20] | A causal and effect decision making model of service quality expectation using grey-fuzzy DEMATEL approach / Real estate agent service quality expectation | DEMATEL & Fuzzy set theory, Grey theory | The advantage of the grey-fuzzy DEMATEL approach is the evaluation of ranking uncertain problems. |
| [21] | Choosing knowledge management strategies by using a combined ANP and DEMATEL approach / Evaluation and selection of KM strategies | DEMATEL & ANP, MCDM, Knowledge management | It is favorable to use the DEMATEL to handle the problem of inner dependences. |
| [22] | Selecting management systems for sustainable development in SMEs: a novel hybrid model based on DEMATEL, ANP and ZOGP / Selecting management systems | DEMATEL & ANP, ZOGP | DEMATEL is used to construct interrelations among criteria, and with ANP weights are obtained, then ANP is integrated with a ZOGP model. |

Table 4.1.b. DEMATEL method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [27] | Developing global managers' competencies using the fuzzy DEMATEL method / Developing global managers' competencies | DEMATEL & Fuzzy logic | No explication for justification. |
| [68] | A causal analytical method for group decision-making under fuzzy environment / R&D project selection | DEMATEL & Fuzzy theory | Fuzzy DEMATEL method is proposed to separate the involved criteria of a system into the cause-effect relationship groups. |
| [72] | A study of the system's hierarchical structure through integration of DEMATEL and ISM / Introduction of a new product in a company | DEMATEL & ISM (Interpretive structural modeling) | DEMATEL is advantageous in gathering group knowledge for forming a structural model to visualize the causal relationships of sub-systems. |
| [73] | Application of fuzzy DEMATEL to develop a cause and effect model of municipal solid waste management in Metro Manila / Solid waste management | DEMATEL & Fuzzy logic, Defuzzification | The main advantages of DEMATEL are involving indirect relations into a compromised cause and effect model in this study. |
| [75] | Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL / Evaluation of e-learning programs | DEMATEL & Factor analysis, Fuzzy integral, MCDM | No explication for justification. |
| [76] | A service evaluation method using mathematical methodologies / Evaluation of service solutions in service engineering | DEMATEL & QFD | DEMATEL is chosen to make quantitative analysis possible considering indirect interactions. |
| [77] | Identifying the cause and effect factors of agile NPD process with fuzzy DEMATEL method: the case of Iranian companies / New product development | DEMATEL & Fuzzy logic | Fuzzy DEMATEL is proposed to divide the factors into cause and effect groups. |

Table 4.1.c. DEMATEL method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [78] | Building an effective safety management systems for airlines / Safety management systems in aviation industry | DEMATEL & Fuzzy logic | No explication for justification. |
| [79] | Analyzing job performance structural model using decision making trial and evaluation laboratory technique / Job performance structuring | DEMATEL | The major contribution of DEMATEL is to help management decision makers in selecting and judging the important factors among all factors. |
| [80] | Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila / Solid waste management | DEMATEL & ANP | It is favorable to use the DEMATEL to handle the problem of inner dependences, since it can provide more valuable information for decision-making. |
| [81] | Designing methods of human interface for supervisory control systems / Human factors engineering | DEMATEL | No explication for justification. |
| [83] | The analysis of the mutual influence between the work safety process areas of construction company / Work safety process | DEMATEL | No explication for justification. |
| [84] | Extraction and systems analysis of factors that prevent safety and security by structural models / Safety and security systems analysis | DEMATEL | No explication for justification. |
| [85] | Knowledge management strategic planning / Strategic planning | DEMATEL & KM | DEMATEL method is applied to gather collective knowledge to capture the causal relationships between criteria. |
| [86] | Multi-criterion evaluation of development strategy components in the presence of intangibles and uncertainty / Strategy development | DEMATEL & MCDA | DEMATEL is utilized to obtain both ranking and classification of considered alternatives and suitable to data processing. |

Table 4.1.d. DEMATEL method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [87] | Application of DEMATEL in discussion of key competency of talents in manufacturing industries / Competency analysis in manufacturing industries | DEMATEL | The major reason is that DEMATEL is a rigorous tool able to illustrate complicated structures. |
| [88] | Causal relationship analysis based on DEMATEL technique for innovative policies in SMEs / Identification of policy instruments for SMEs | DEMATEL | The purpose of the DEMATEL enquiry in this paper is the analysis components structures of each factor, direct and indirect relationships between policy instruments. |
| [89] | Cognition map of experiential marketing strategy for hot spring hotels in Taiwan using DEMATEL method / Segmentation of criteria for marketing strategy | DEMATEL | The proposed method is applied to successfully divide a set of complex factors into a cause group and effect group and produce a visible diagram. |
| [90] | Member selection of telework teams: a network fuzzy management / Member selection | DEMATEL & AHP, Fuzzy management experiment, Fuzzy comprehensive evaluation | With the help of DEMATEL method some improvements are made to the AHP designing with a fuzzy management experiment of selection. |
| [91] | Reconfiguring the innovation policy portfolios for Taiwan's SIP mall industry / Reconfiguring innovation portfolios | DEMATEL & Grey relational analysis, Delphi method | Requirements are derived by Delphi and identified using DEMATEL. |
| [92] | Reprioritization of failures in a system failure mode and effects analysis by DEMATEL / Reprioritization of failures | DEMATEL & Failure mode and effect analysis (FMEA) | DEMATEL method can be an efficient, complementary and confident approach in a FMEA. |

### 4.1.2. The DEMATEL in Application

This research explains the definition and steps of DEMATEL with reference to studies of relative scholars [16, 21, 22, 80, 87, 93] are as follows:

Step 1: Generating the direct-relation matrix

Measuring the relationship between criteria requires a comparison scale designed as four levels: no influence (0), low influence (1), medium influence (2), high influence (3), very high influence (4). A team of experts is asked to make pairwise comparisons in terms of influence and direction between criteria. The results of these evaluations form a *n x n* matrix called direct-relation matrix ***A***, in which $\boldsymbol{a_{ij}}$ is denoted as the degree to which the criterion *i* affects the criterion *j*.

Step 2: Normalizing the direct-relation matrix

On the basis of the direct-relation matrix ***A***, the normalized direct-relation matrix ***M*** can be obtained through formulas (4.1) and (4.2):

$$\boldsymbol{M} = \mathrm{k} \cdot \boldsymbol{A} \tag{4.1}$$

$$\mathrm{k} = \mathrm{Min}\left( \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} |a_{ij}|}, \frac{1}{\max\limits_{1 \le j \le n} \sum_{i=1}^{n} |a_{ij}|} \right), \tag{4.2}$$

$$i, j \in \{1,2,3,\ldots,n\}$$

Step 3: Obtaining the total-relation matrix

Once the normalized direct relation-matrix ***M*** has been obtained, the total relation matrix ***S*** can be derived by using formula (4.3), where the ***I*** is denoted as the identity matrix.

$$\mathbf{S} = \mathbf{M} + \mathbf{M}^2 + \mathbf{M}^3 + \ldots = \sum_{i=1}^{\infty} M^i$$

$$= \boldsymbol{M} \left(I - M\right)^{-1} \tag{4.3}$$

Step 4: Compute dispatcher group and receiver group

Using the values of ***D* – *R*** and ***D* + *R*** where R is the sum of columns and also D is the sum of rows in matrix S as shown in formulas (4.4), (4.5) and (4.6). Criteria having positive values of ***D* – *R*** have higher influence on one another and are assumed to have a higher priority and are called dispatcher; others having negative values of ***D* – *R*** receiving more influence from another are assumed to have a lower priority and are called receiver. On the other hand, the value of ***D* + *R*** indicates degree of relation between each criterion with others and criteria having more values of ***D* + *R*** have more relationship with another and those having little values of ***D* + *R*** have less of a relationship with others.

$$\boldsymbol{S} = \left\lfloor s_{ij} \right\rfloor_{mxn} \quad , \quad i, j \in \{1,2,3,\ldots,n\} \tag{4.4}$$

$$\boldsymbol{D} = \sum_{j=1}^{n} s_{ij} \tag{4.5}$$

$$\boldsymbol{R} = \sum_{i=1}^{n} s_{ij} \tag{4.6}$$

Step 5: Set threshold value and obtain the impact-diagraph-map

The impact-diagraph-map also known as causal diagram can be acquired by mapping the dataset of the (***D* + *R*, *D* – *R***), where the horizontal axis ***D* + *R*** and the vertical axis ***D* – *R*,** providing valuable insight for making decisions. To obtain an appropriate diagram, decision-maker must set a threshold value for the influence level. Only some aspects, whose influence level in matrix ***S*** is higher than the threshold value, can be chosen and converted into the impact-diagraph-map. If the threshold value is too low, the map will be too complex to show the necessary information for decision-making. If the threshold value is too high, many aspects will be presented as independent aspects without showing the relationships with other aspects.

Step 6: Obtaining the inner dependence matrix

In this step, the sum of each column in total-relation matrix is equal to 1 by the normalization method, and then the inner dependence matrix can be acquired.

## 4.2. THE ANP METHOD

Based on the recent studies on ANP, a literature survey is presented. Following that, the ANP methodology is given.

### 4.2.1. The ANP Literature Survey

When project problems are evaluated, a group of opinions needs to be collected to know the interdependence relationship among criteria which can be analyzed as a MCDM problem. To improve the quality of decision-making, a methodology is required for business development projects under uncertain conditions. AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogenous elements with respect to a common criteria or attribute [94]. AHP is first developed to help establishing decision models through qualitative and quantitative processes [66]. AHP qualitatively helps to decompose a decision problem from the top goal to a set of attributes, sub-attributes; criteria, sub-criteria; activities, sub-activities, etc. [95]. Quantitatively it uses pairwise comparisons to assign weights to the elements at all levels [95].

ANP goes beyond linear relationships and allows interrelationships among elements. Instead of a hierarchy, it is a network that replaces single direction relationships with dependence and feedback. The main object is to determine the overall influence of all the elements [96]. Saaty [66] developed a 9-point priority measurement scale, with a score of one representing equal importance of the two compared elements and nine being overwhelming dominance of one element (row element) over another element (column element). When overwhelming dominance of a column element exists over a row element, a score of 1/9 is given [80].

The network relationship of ANP method does not only present the relationship between factors, but also calculate the relative weightings (eigenvectors) of each factor [22]. The results of these computations form a supermatrix. A supermatrix is a partitioned matrix where each matrix segment represents a relationship between two nodes (components or clusters) in a system [23]. A generalized form of a supermatrix introduced by Saaty in 1996 to deal with interdependence characteristics among elements and components is given in Figure 4.1. In the figure, the components of a decision system is shown as $C_k$, $k$=1,…,$n$, and each component $k$ has $m_k$ elements, denoted by $e_{k1}, e_{k},\ldots, e_{kmk}$.

$$
\begin{array}{ccc}
 & & \begin{array}{ccccccccccc} & C_1 & & & C_2 & & \cdots & & Cm & \\ e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{m1} & \cdots & e_{mn_m} \end{array} \\
 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} C_1 & \\
W = & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \\ \vdots \end{array} C_2 & \begin{pmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{pmatrix} \\
 & \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} C_m &
\end{array}
$$

Figure 4.1. Supermatrix form in ANP.

In Figure 4.2. the structure and corresponding supermatrix in a network is given. A node represents a component (or cluster) with elements inside it; a straight line or an arc denotes the interactions between two components; and a loop indicates the inner dependence of elements within a component [22]. When the elements of a component "Goal" depend on another component "Criteria", this relation is represented with an arrow from component "Goal" to "Criteria".

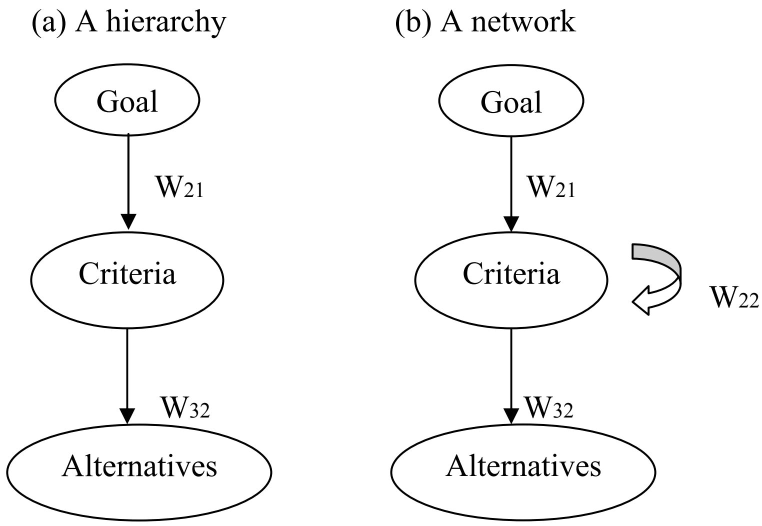


Figure 4.2. Goal to Criteria (a) linear hierarchy and (b) nonlinear network [32].

In Figure 4.3, the corresponding supermatrix of the hierarchy with three levels of clusters is given, where $W_{21}$ is a vector representing the impact of the "Goal" on the "Criteria", $W_{32}$ is a matrix representing the impact "Criteria" on each element of the "Alternatives" and $W_{22}$ showing the interdependency and the supermatrix of the elements in a component or between two components [22, 32]. Any zero in the supermatrix can be notably replaced by a matrix if there is an interrelationship of the elements in a component or between two components.

(a) (b)

$$W_k = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix} \qquad W_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix}$$

Figure 4.3. Vector, (a) linear hierarchy and (b) nonlinear network.

With pairwise comparison matrix of the row components with respect to the column component, an eigenvector is obtained. This process gives rise to an eigenvector for each column block. For each column block, the first entry of the respective eigenvector is multiplied by all the elements in the first block of that column, the second by all the elements in the second block of that column and so on [14]. In this way, the block in each column of the supermatrix is waited, known as the weighted supermatrix. To achieve importance weight convergence, the weighted supermatrix is raised to the power of $2k+1$, where $k$ is an arbitrarily large number [14]. This new matrix is called the limit supermatrix. If the limit supermatrix covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized supermatrix [26]. The alternative with the largest overall priority should be selected.

In recent years, the ANP method has been widely and successfully applied in various project selection cases such as information system project selection [23, 39, 97]; urban renewal project selection [40]; project selection [98]; R&D project selection [38]; reverse logistics project selection [25]; logistics service provider [99]; partner selection [100], etc. Using ANP to project selection involves a decision model that specifies relationships among elements within a hierarchical structure [98]. The detailed survey is given in Table 4.2.

Table 4.2.a. The ANP method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [21] | Choosing knowledge management strategies by using a combined ANP and DEMATEL approach | ANP & Knowledge management (KM), DEMATEL, MCDM | Combined ANP and DEMATEL approaches are used to select a favorable KM strategy. |
| [22] | Selecting management systems for sustainable development in SMEs: a novel hybrid model based on DEMATEL, ANP and ZOGP | ANP & DEMATEL, ZOGP | DEMATEL is applied to construct interrelations among criteria and weights are obtained through ANP, then integrated with ZOGP to obtain optimal alternatives. |
| [23] | Using analytic network process and goal programming for interdependent information system project selection | ANP & ZOGP | Interdependencies among evaluation criteria and candidate projects using ANP within a ZOGP model. |
| [26] | Using ANP priorities with goal programming for revitalization strategies in historic transport: a case study of the Alishan forest railway | ANP & Fuzzy Delphi, ZOGP, BOCR analysis | Fuzzy Delphi and ANP methods are used to formulate goal programming. |
| [37] | Analytic network process-based model for selecting an optimal product design solution with zero-one goal programming | ANP & Fuzzy Delphi method (FDM), Zero-one goal programming (ZOGP) | The information obtained from the FDM and ANP is used to formulate a goal programming. |
| [66] | Applying the analytic process to disclose knowledge assets value creation dynamics | ANP | No explication for justification. |
| [80] | Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila | ANP & MCDM, DEMATEL | DEMATEL is used to construct interrelations between criteria whose weights are then obtained through ANP measuring dependency. |
| [96] | An analytic network network process approach for locating undesirable facilities: an example from Turkey | ANP | No explication for justification. |

Table 4.2.b. The ANP method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [97] | An integrated approach for interdependent information system project selection / an example | ANP & Delphi, Zero-One Goal Programming | Delphi method and ANP is used to formulate a goal programming. |
| [99] | Selection of logistics service provider: an ANP approach | ANP | No explication for justification. |
| [101] | A framework for group decision support systems / an application in the evaluation of information technology for logistics firms | ANP & Delphi and Maximise Agreement Heuristic (MAH) methods | To integrate ANP, Delphi and MAH in order to perform quantitative and qualitative analysis to achieve the overall consensus. |
| [102] | A hybrid MCDM model for strategic vendor selection / an example | ANP & MCDM, TOPSIS and NGT (nominal group technique) | No explication for justification. |
| [103] | A hybrid MCDM model for personnel selection in manufacturing systems | ANP & TOPSIS and MCDM | No explication for justification. |
| [104] | A network approach for modeling and design of agile supply chains using a flexibility construct | ANP & Sensitivity Analysis, Knowledge Management | No explication for justification. |
| [105] | A soft computing method for multi-criteria decision making with dependence and feedback | ANP & AHP, FDM (fuzzy decision maps), FCM (fuzzy cognitive maps) | No explication for justification. |
| [106] | A strategic decision framework for green supply chain management / an example | ANP & AHP | No explication for justification. |
| [107] | Aggregate analysis of manufacturing systems using system dynamics and ANP | ANP & System Dynamics, Causal Loop Diagram | ANP is applied to complement the SD based aggregate analysis. |
| [108] | An analytic network process model for municipal solid waste disposal options | ANP | No explication for justification. |

Table 4.2.c. The ANP method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [109] | An analytic network-process approach to concept evaluation in a new product development environment | ANP | No explication for justification. |
| [110] | An analytical network process-based framework for successful total quality management (TQM) / an assessment | ANP & Multiple criteria analysis, Decision analysis | No explication for justification. |
| [111] | An ANP-based technology network for identification of core technologies / a case of telecommunication technologies | ANP | No explication for justification. |
| [112] | An application of ANP with benefits, opportunities, costs and risks in supplier selection / a case study in a diesel engine manufacturing firm | ANP & BOCR, MCDM | No explication for justification. |
| [113] | An application of the ANP to the advertising media budget allocation decision | ANP | No explication for justification. |
| [114] | An expert system approach to assess service performance of travel intermediary | ANP | No explication for justification. |
| [115] | An integrated multiobjective decision making process for supplier selection and order allocation | ANP & MOMILP (multi-objective mixed integer linear programming) | No explication for justification. |
| [116] | An integrated multi-objective decision-making process for multi-period lot-sizing with supplier selection | ANP & Multi-objective mixed integer linear programming, Tchebycheff procedure | No explication for justification. |
| [117] | An integrated multi-objective decision-making process for supplier selection with bundling problem | ANP & MIP (mixed integer programming), Delphi method | ANP-MIP analysis is adopted adopted for supplier selection with bundling problem. |

Table 4.2.d. The ANP method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [118] | Analytic network process decision-making to assess slicing machine | ANP & EWMA (exponential weighted moving average) control chart, Process Capability indices (PCI) | EWMA and PCI demonstrated the effectiveness of the proposed ANP method. |
| [119] | Analytic network process in supplier selection: a case study in an electronic firm | ANP & MCDM | No explication for justification. |
| [120] | Analytic network process for software selection in product development / a case study | ANP | No explication for justification. |
| [121] | Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach | ANP & Balanced scorecard, MCDM | No explication for justification. |
| [122] | Analyzing organizational project alternatives for agile manufacturing processes: an analytic network approach | ANP | No explication for justification. |
| [123] | ANP-GP approach for product variety design | ANP & Goal Programming | ANP results are integrated with the cost limitations to construct the GP models. |
| [124] | Application of ANP in process models: an example of strategic partnering | ANP & MCDM, Process models | No explication for justification. |
| [125] | Applying ANP approach to partner selection for strategic alliance | ANP & Markov chain | The concept of Markov chain is applied to the super matrix of ANP. |
| [126] | Contractor selection using the analytic network process | ANP & AHP, MCDM | Results of the normalized relative weights of the candidates obtained from ANP and AHP are compared. |
| [127] | COTS evaluation using modified TOPSIS and ANP | ANP & MCDM, TOPSIS | Weights of criteria are determined by ANP and proceeded with TOPSIS ranking approach. |

Table 4.2.e. The ANP method literature survey.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [128] | Evaluating componentized enterprise information technologies: a multiattribute modeling approach | ANP & AHP | No explication for justification. |
| [129] | Selection of third-party logistics (3PL): a hybrid approach using interpretive structural modeling (ISM) and ANP | ANP | Managerial insights developed through the use of ISM and ANP-based complementary approaches uncover the scope for improvements. |
| [130] | Strategic analysis of logistics and supply chain management systems using the ANP | ANP | No explication for justification. |
| [131] | The study of applying ANP model to assess dispatching rules for wafer fabrication | ANP | No explication for justification. |

### 4.2.2. The ANP in Application

The definition and steps of ANP with reference to studies of relative scholars [21, 22, 98, 131, 132] are as follows:

Step 1: Developing the decision model structure

The research problem should be stated clearly and decomposed into a rational system like a network. The structure is obtained by decision makers through brainstorming, literature survey or other appropriate methods.

Step 2: Conducting pairwise comparisons on the clusters

Experts are asked to make pairwise comparisons with Saaty's (1980) 9-point priority measurement scale ranging from 1 (equal) to 9 (extreme) where two components are compared in terms of how they contribute to their particular upper level criterion. By doing that, the relative weightings and eigenvectors are obtained.

Step 3: Supermatrix formation and transformation

Supermatrix is a partitioned matrix composed of local priority vectors entered in the appropriate columns of a matrix, where each matrix segment represents a relationship between two nodes (components or clusters). The supermatrix must be transformed first to make it stochastic, meaning each matrix column sums to unity, also known as weighted supermatrix and then must be raised to limiting powers until the weights have been converged and remain stable. This new matrix is called the limit supermatrix. The final priorities of all matrix elements can be obtained by normalizing each supermatrix block.

Step 4: Selecting the best alternative

When the supermatrix covers the whole network, the final priorities of elements are found in the corresponding columns in the limit supermatrix. The alternative with the largest overall priority should be the one selected.

### 4.3. THE ZOGP METHOD

According to the literature studies, it is seen that there is an increase in the application of ZOGP recently. Following the literature survey of ZOGP, the methodology is presented in this section.

#### 4.3.1. The ZOGP Literature Survey

Goal programming (GP) is a well-known and widely used multiple-objective programming technique first introduced by Charnes and Cooper in 1955 [15, 133]. Unlike linear programming, the GP model does not optimize (maximize/minimize) the objectives directly. Instead, it attempts to minimize the deviations between the desired goals which must be prioritized in a hierarchy of importance and the realized results [22].

ZOGP permits the consideration of multiple goals regarding resource limitations and other selection limitations that must be rigidly observed in the selection problems [37]. This property of ZOGP enables the appliers to incorporate multiple goals, such as the planning and design fees, available cost budget, project duration, necessary initial investment etc.

The ZOGP combined with ANP method has been successfully applied in many fields. Wei and Chang [37] used a combined ANP and ZOGP model as an aid in product design selection problems; Liu and Hsiao [123] also used ANP and GP instead of AHP-GP since it reduces the cost demonstrating the potential benefit of the proposed method for product variety design; Chang *et al*. [26] used ANP, Fuzzy Delphi method and ZOGP together for revitalization strategies in transport to provide more realistic solutions; Tsai and Chou [22] utilized ANP, DEMATEL and ZOGP in selecting management systems for sustainable development in SMEs; Cekyay *et al.* [134] applied Fuzzy ANP with ZOGP in information system project selection; Lee and Kim [23, 97] proposed an integrated approach ANP and ZOGP for interdependent information system project selection to permit the consideration of resource and other selection limitations; Karsak *et al.* [24] used weighted ZOGP as a decision tool since it can handle multiple objectives in product planning in quality function deployment; Ravi *et al.* [25] applied ZOGP and ANP together in selection of a reverse logistics project to get better solution with inclusion of obligatory and flexible goals; Tsai and Hsu [19] applied ANP, DEMATEL and ZOGP for corporate social responsibility programs choice and costs assessment in the airline industry; Wei and Chang [37] used an analytic network based model with ZOGP for selecting an optimal product design solution; Wey and Wu [135] applied ANP, Fuzzy Delphi and ZOGP in resource allocation in transportation. The detailed survey is given in Table 4.3.

Table 4.3.a. The ZOGP technique in literature.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [19] | Corporate social responsibility programs choice and costs assessment in the airline industry-a hybrid model / an illustrative example | ZOGP & ANP, DEMATEL | No explication for justification. |
| [22] | Selecting management systems for sustainable development in SMEs: A novel hybrid model based on DEMATEL, ANP, and ZOGP / an application | ZOGP & ANP, DEMATEL | Using the ZOGP model can help the organization without exceeding their both the budget and the allocated time frame. |
| [23] | Using analytic network process and goal programming for interdependent information system project selection / an illustrative application | ZOGP & ANP | ZOGP permits the consideration of resource limitations and other selection limitations. |
| [24] | Product planning in quality function deployment using a combined analytic network process and goal programming approach / a numerical example | ZOGP & ANP | Using weighted ZOGP is preferred as a decision tool since it can handle multiple objectives and seeks to minimize the total deviation. |
| [25] | Selection of a reverse logistics project for end-of-life computers: ANP and goal programming approach / an illustrative application | ZOGP & ANP, MCDM | It is seen that ANP-ZOGP model gives better solution with inclusion of obligatory and flexible goals. |
| [26] | Using ANP priorities with goal programming for revitalization strategies in historic transport / a case study in transportation | ZOGP & ANP, Fuzzy Delphi Method, BOCR Analysis | Integrated ANP and ZOGP model is an effective solution aid which provides more realistic solutions. |

Table 4.3.b. The ZOGP technique in literature.

| Main Sources | Subject / Area | Technique Applied & Supplementary Method | Justification |
|---|---|---|---|
| [37] | Analytic network process-based model for selecting an optimal product design solution with zero-one goal programming / an empirical example in product design | ZOGP & ANP, Fuzzy Delphi Method | A combined ANP and ZOGP model is specifically used as an aid in product design selection problems. |
| [97] | An integrated approach for interdependent information system project selection / an illustrative application | ZOGP & ANP, Delphi | For project selection, the GP formulation allows for the incorporation of multiple conflicting objectives and resources limitation. |
| [123] | ANP-GP approach for product variety design / a case study in product design | ZOGP & ANP | Instead of AHP-GP, applying ANP-GP approach reduces the cost demonstrating the potential benefit of the proposed method. |
| [134] | IS Project Selection based on Fuzzy-ANP and ZOGP / a numerical example | ZOGP & FANP | No explication for justification. |
| [135] | Using ANP priorities with goal programming in resource allocation in transportation / an empirical example | ZOGP & ANP, Fuzzy Delphi | No explication for justification. |

### 4.3.2. The ZOGP Formulation

The model assigns optimal values to a group of variables in situations involving multiple goals and constraints [133]. It permits the consideration of resource limitations that must be observed in project selection [23]. The model is described as follows [23]:

Minimize $Z = P_k(w_j^{ANP} d_i^+, w_j^{ANP} d_i^-)$

Subject to: $a_{ij} x_j + d_i^- - d_i^+ = b_i$

for $i = 1,2,\ldots,m$, $j = 1,2,\ldots,n$,

$x_j + d_i^- = 1$

for $i = m + 1, m + 2,\ldots,m + n$, $j = 1,2,\ldots,n$,

$d_i^+ \geq 0, d_i^- \geq 0$ for $\forall_i$

$x_j = 0$ or $1$ for $\forall_i$

Where Z denotes the sum of the deviation from $m$ goals considered; $n$ is the pool of projects from which the optimal set is selected; $P_k$ represents a preemptive priority ($P_1 > P_2 > P_3 >>> P_k$) for goal $k$; $d_i^+$ and $d_i^-$ are the positive or negative deviation variables for the selection criterion (resource) $i$; $w_j^{ANP}$ represents the ANP mathematical weight on the $j$th project; $a_{ij}$ parameter $j$ of selection resource $i$; $b_i$ denotes the available resource or limitation factors that must be considered in the selection decision, and $x_j$ represents the binary variable [23].

The ZOGP model bases the selection of the projects $x_j$ on the ANP determined weights of $w_j^{ANP}$ for corresponding $d_i^+$ [22]. The larger the $w_j^{ANP}$, the more likely the corresponding project will be selected [23].

# 5. CASE STUDY

In this section, a case study is presented to validate the proposed approach's applicability for decision makers who involve in the Six Sigma project selection process in a company.

## 5.1. CASE COMPANY

This case study was realized in a leading logistics company in Turkey. In terms of privacy, the name of the company can not be declared. The ABC Logistics, located in Istanbul, provides services in all logistics activities and it has branches in Ankara, Izmir, Adana and Bursa. The company is centered around two strategic business units: Third Party Logistic Services and Port Management. It carries out Third Party Integrated Logistics Services as a growing regional power in Ukraine, Rumania, Russia, Hungary, CIS countries, North Africa, Syria, Iraq and Lebanon, as well as the Benelux countries. The company provides freight and transportation management, project cargo management, supply chain management, and storage and distribution management services mainly to the automotive, FMCG, petrochemicals, durable goods, steel and steel products sectors, continuing the tradition for excellence and reliability.

The company has been applying Six Sigma throughout the group since 2002. Six Sigma methodology not only boosts financial growth and profitability in the group companies, it is also the driving force behind a significant cultural transformation. Six Sigma projects are carried out by trained Green Belts who work part-time on the project, as well as by the company employees at every level, under the full-time supervision and guidance of expert Black Belts. In gathering the data, the experts of the company, 2 Black Belts and 1 Green Belt assigned for Six Sigma methodology were asked to reply survey questions in this study. Based on their proficiency in Six Sigma, the consensus decision making approach is applied in the case study.

## 5.2. THE EVALUATION FRAMEWORK

Application of the proposed evaluation framework is given in Figure 5.1.

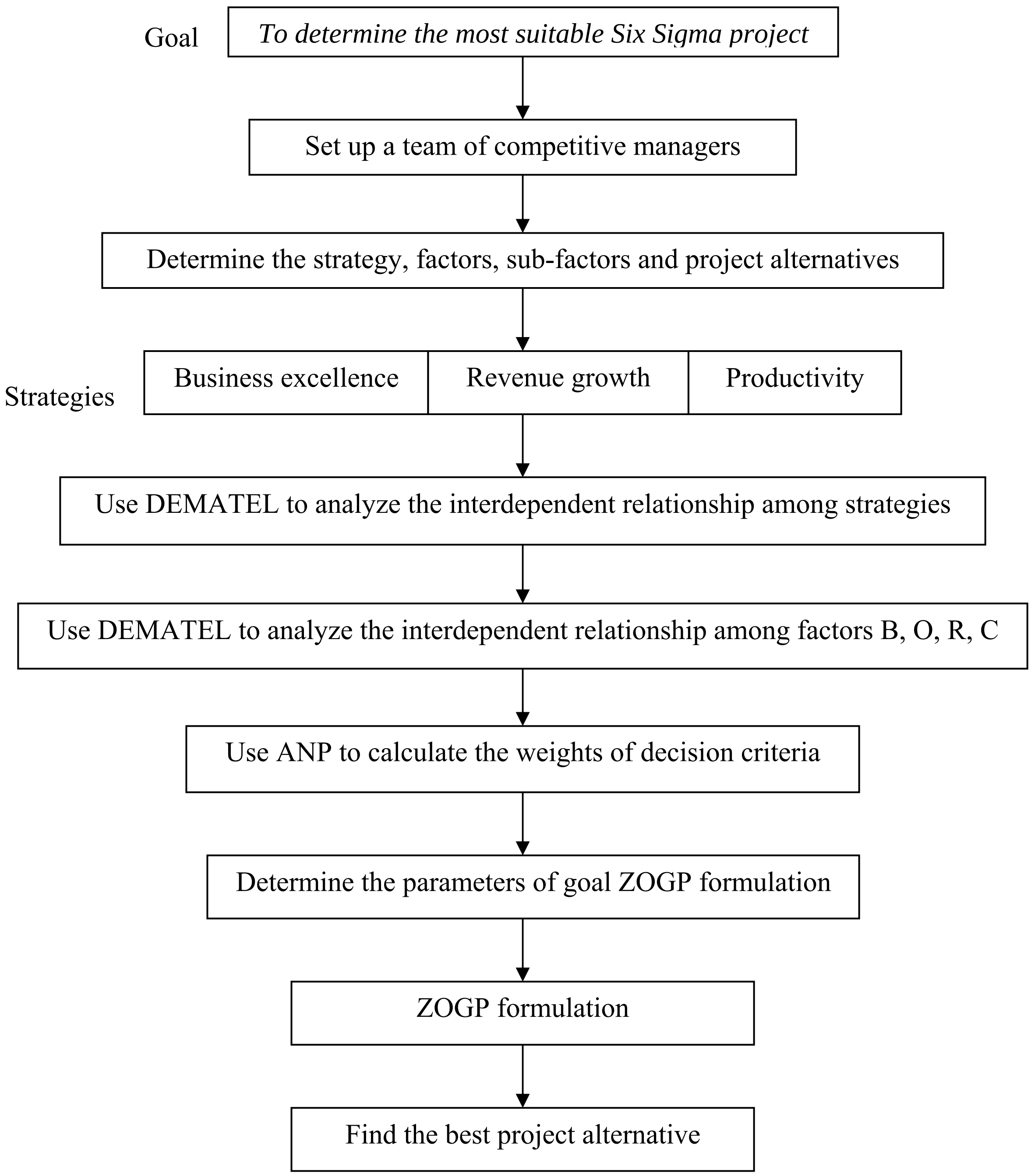


Figure 5.1. Application of the proposed evaluation framework.

In this study, based on project selection we evaluate three Six Sigma project alternatives named as Project A (improving the business processes), Project B (improving customer relations) and Project C (optimizing inventory).

Improving the business processes can implicate any kind of development in the route such as improving first time delivery rates, developing operational routines, educating employees and workers, minimizing time shifts etc. Improving customer relations deals with all terms concerning customers, especially increasing customer satisfaction, making forward surveys on customer needs and expectations, offerings to keep customer loyalty and so on. Optimizing inventory is directly related with the service levels and arranging demands, forecasting accuracy lead to better inventory flows, preventing overstocks and this eventually helps controlling corporate budget, increasing financial performance, market share and cash flow.

### 5.3. THE APPLICATION OF DEMATEL

After defining the decision strategies, factors and sub-factors, the team of ABC Company's Six Sigma experts make pairwise comparisons according to the 4-leveled scale of DEMATEL. Firstly, the inner dependence among strategies composed of business excellence, revenue growth and productivity is calculated. Following the previously presented steps of DEMATEL, the initial direct-relation matrix for strategies as given in Table 5.1 is produced. Based on the direct-relation matrix, the normalized direct-relation matrix for strategies is obtained by using formulas (4.1) and (4.2) as shown in Table 5.2:

Table 5.1. The initial direct-relation matrix for strategies.

| | BE | RG | PR |
|---|---|---|---|
| BE | 0 | 2 | 4 |
| RG | 3 | 0 | 3 |
| PR | 2 | 4 | 0 |

Table 5.2. The normalized direct-relation matrix for strategies.

| | BE | RG | PR |
|---|---|---|---|
| BE | 0 | 0,286 | 0,572 |
| RG | 0,429 | 0 | 0,429 |
| PR | 0,286 | 0,572 | 0 |

Utilizing the formula (4.3), the total-relation matrix for strategies is constituted as given in Table 5.3. Then, using formulas (4.4), (4.5) and (4.6) the impact-diagraph map for strategies is acquired by mapping the dataset of (D + R, D – R) given in Figure 5.2. The assigned threshold value for strategies is accepted to be 1,85. The value under the threshold value gains too many factors and complex relationships in the system. It is seen that business excellence is the dispatcher and revenue growth and productivity are the receivers. According to the graph, business excellence has a high impact on revenue growth and productivity in Six Sigma strategy. Obviously, the convergence of D + R values of strategies' elements shows the degree of relation and proves strong inner dependence.

Table 5.3. The total-relation matrix for strategies.

| | BE | RG | PR | D | D+R | D-R |
|---|---|---|---|---|---|---|
| BE | 1,577 | 2,094 | 2,372 | 6,042 | 11,317 | 0,768 |
| RG | 1,884 | 1,856 | 2,303 | 6,042 | 12,224 | -0,140 |
| PR | 1,814 | 2,232 | 1,996 | 6,042 | 12,712 | -0,628 |
| R | 5,275 | 6,182 | 6,670 | | | |

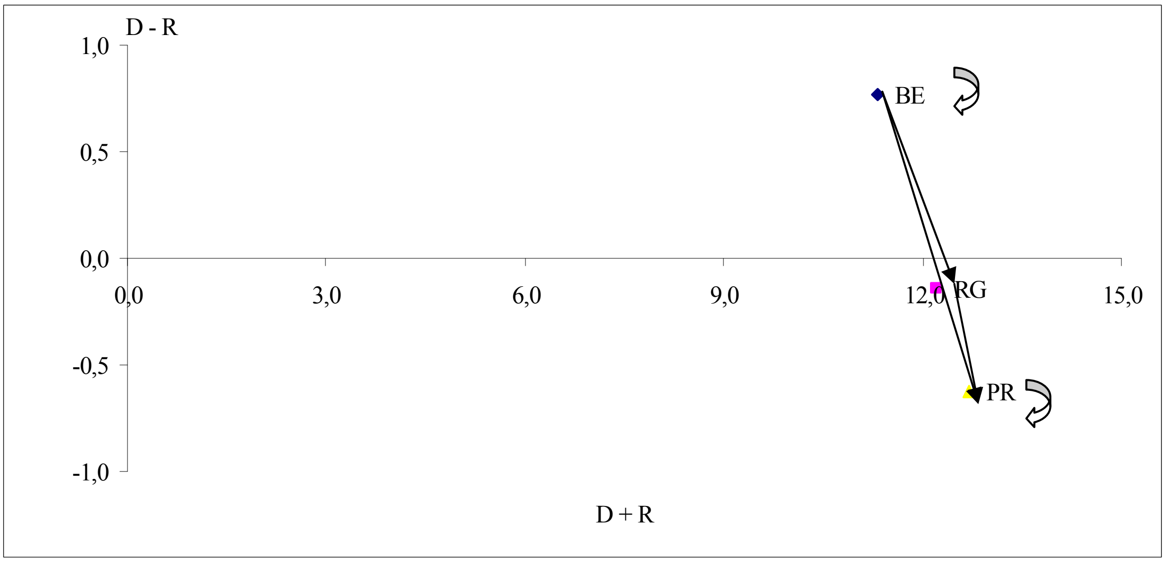


Figure 5.2. The impact-diagraph-map of total relation for strategies.

Secondly, the inner dependency between factors is measured. Based on the pairwise comparisons made for process excellence, customer satisfaction, financial performance and learning and growth sub-factors, the initial direct-relation matrix for benefits as shown in Table 5.4, is produced. Derived from the direct-relation matrix, the normalized direct-relation matrix for benefits is obtained by using formulas (4.1) and (4.2) as given in Table 5.5.

Table 5.4. The initial direct-relation matrix for benefits.

| | PE | CS | FP | LG |
|---|---|---|---|---|
| PE | 0 | 2 | 3 | 2 |
| CS | 0 | 0 | 4 | 1 |
| FP | 3 | 2 | 0 | 3 |
| LG | 4 | 2 | 3 | 0 |

Table 5.5. The normalized direct-relation matrix for benefits.

| | PE | CS | FP | LG |
|---|---|---|---|---|
| PE | 0 | 0,2 | 0,3 | 0,2 |
| CS | 0 | 0 | 0,4 | 0,1 |
| FP | 0,3 | 0,2 | 0 | 0,3 |
| LG | 0,4 | 0,2 | 0,3 | 0 |

Utilizing the formula (4.3), the total-relation matrix for benefits is constituted as given in Table 5.6. Then, using formulas (4.4), (4.5) and (4.6) the impact-diagraph map for benefits is acquired by mapping the dataset of (D + R, D – R) given in Figure 5.3. The assigned threshold value for benefits is accepted to be 0,5.

Table 5.6. The total-relation matrix for benefits.

| | PE | CS | FP | LG | D | D+R | D-R |
|---|---|---|---|---|---|---|---|
| PE | 0,519 | 0,607 | 0,888 | 0,631 | 2,645 | 5,346 | -0,056 |
| CS | 0,423 | 0,336 | 0,798 | 0,458 | 2,014 | 4,328 | -0,300 |
| FP | 0,822 | 0,662 | 0,737 | 0,752 | 2,972 | 6,431 | -0,487 |
| LG | 0,938 | 0,709 | 1,036 | 0,569 | 3,252 | 5,662 | 0,843 |
| R | 2,701 | 2,314 | 3,459 | 2,409 | | | |

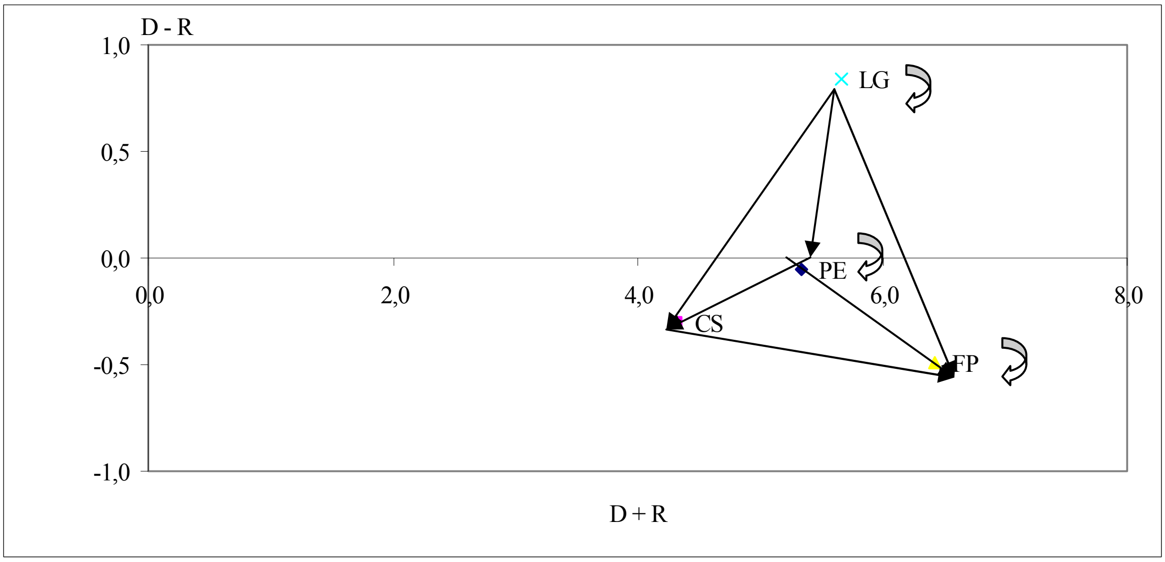


Figure 5.3. The impact-diagraph-map of total relation for benefits.

It can be analyzed that under the factor of benefits, learning and growth has a higher impact than customer satisfaction and process excellence in applying the Six Sigma application. Learning and growth is the dispatcher whereas process excellence, customer satisfaction and financial performance are the receivers. Additionally, the close D + R values of benefit sub-factors confirm strong inner dependency between each other. Orderly, the inner dependency between the other factors opportunities, risks and costs are measured by applying exactly the same transaction processes given above. Based on the pairwise comparisons made for sub-factors of opportunities, the direct-relation matrix as given in Table 5.7, the normalized direct-relation matrix as shown in Table 5.8 and the total-relation matrix given in Table 5.9 are formed. The assigned threshold value for opportunities is accepted to be 0,45. Placing the numerical values on the impact-diagraph-map for opportunities helps to visualize the inner dependencies clearer as shown in Figure 5.4. According to Figure 5.4, it is clear that employees' competency has a high impact on operational excellence, increased market share and customer loyalty. The close values of D+R for opportunities prove high inner dependency between each other.

Table 5.7. The initial direct-relation matrix for opportunities.

| | OE | MS | CL | EC |
|---|---|---|---|---|
| OE | 0 | 3 | 2 | 2 |
| MS | 2 | 0 | 3 | 1 |
| CL | 2 | 4 | 0 | 1 |
| EC | 4 | 3 | 3 | 0 |

Table 5.8. The normalized-relation matrix for opportunities.

| | OE | MS | CL | EC |
|---|---|---|---|---|
| OE | 0 | 0,3 | 0,2 | 0,2 |
| MS | 0,2 | 0 | 0,3 | 0,1 |
| CL | 0,2 | 0,4 | 0 | 0,1 |
| EC | 0,4 | 0,3 | 0,3 | 0 |

Table 5.9. The total-relation matrix for opportunities.

| | OE | MS | CL | EC | D | D+R | D-R |
|---|---|---|---|---|---|---|---|
| OE | 0,492 | 0,861 | 0,693 | 0,454 | 2,500 | 5,163 | -0,162 |
| MS | 0,583 | 0,550 | 0,684 | 0,340 | 2,157 | 5,548 | -1,235 |
| CL | 0,628 | 0,900 | 0,505 | 0,366 | 2,399 | 5,215 | -0,417 |
| EC | 0,960 | 1,080 | 0,934 | 0,393 | 3,367 | 4,920 | 1,814 |
| R | 2,663 | 3,391 | 2,816 | 1,553 | | | |

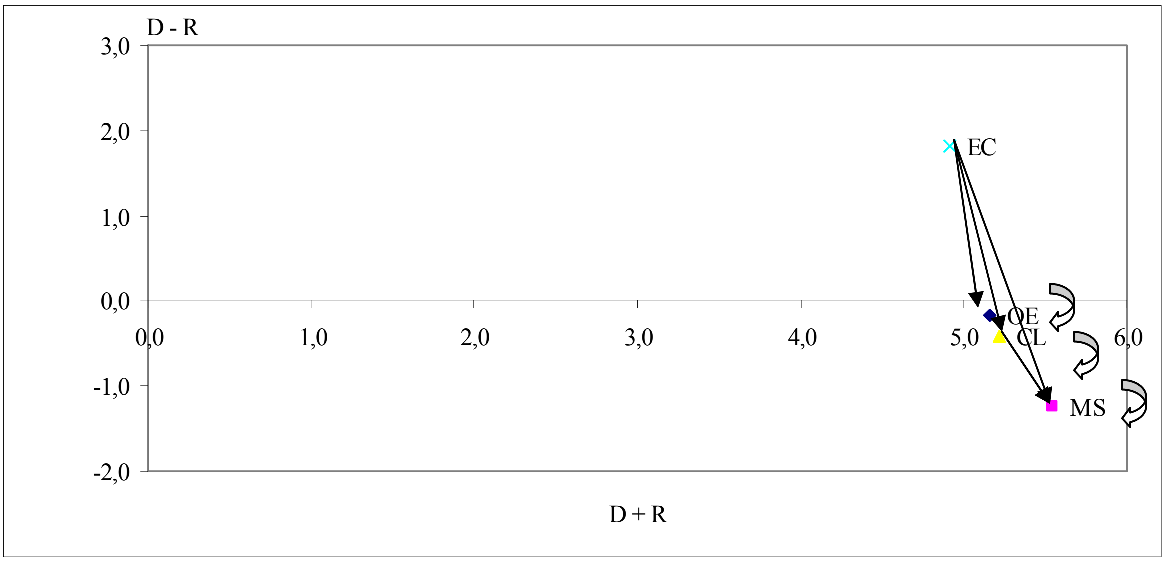


Figure 5.4. The impact-diagraph-map of total relation for opportunities.

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The following factor risks, is examined in three sub-factors budget overrun, time delay and project related risks. After running the similar operations step by step given formerly, derived from the pairwise comparisons made the direct-relation matrix given in Table 5.10, the normalized direct-relation matrix given in Table 5.11 and the total-relation matrix given in Table 5.12 for risks factor are obtained. The assigned threshold value for risks is agreed to be 2,8. Placing the numerical values on the impact-diagraph-map for risks as shown in Figure 5.5 assists to envision the inner dependencies.

Table 5.10. The initial direct-relation matrix for risks.

| | BO | TD | PJ |
|---|---|---|---|
| BO | 0 | 4 | 3 |
| TD | 4 | 0 | 2 |
| PJ | 3 | 3 | 0 |

Table 5.11. The normalized direct-relation matrix for risks.

| | BO | TD | PJ |
|---|---|---|---|
| BO | 0 | 0,572 | 0,429 |
| TD | 0,572 | 0 | 0,286 |
| PJ | 0,429 | 0,429 | 0 |

Table 5.12. The total-relation matrix for risks.

| | BO | TD | PJ | D | D+R | D-R |
|---|---|---|---|---|---|---|
| BO | 3,602 | 3,966 | 3,109 | 10,677 | 21,461 | -0,107 |
| TD | 3,644 | 3,280 | 2,788 | 9,712 | 20,496 | -1,072 |
| PJ | 3,538 | 3,538 | 2,529 | 9,605 | 18,031 | 1,179 |
| R | 10,784 | 10,784 | 8,426 | | | |

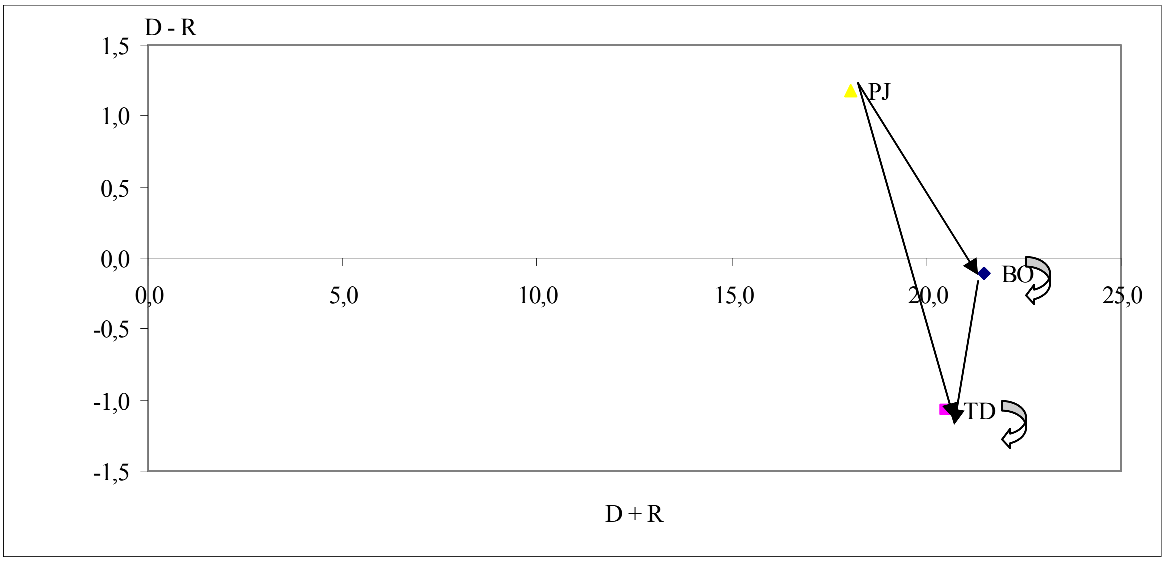


Figure 5.5. The impact-diagraph-map of total relation for risks.

It can be observed that under the factor of risks, project related risks sub-factor has a higher impact than budget overrun and time delay in applying Six Sigma. Project related risks prove to be the dispatcher; budget overrun and time delay are the receivers. Moreover, the close D+R values for risks sub-factors verify the high inner dependency between each other.

The final factor costs, is also analyzed in three sub-factors given as cost of implementation, cost of training and cost of human resources. Operating the formulas (4.1) - (4.6) on the pairwise comparisons made for costs factor, the direct-relation matrix given in Table 5.13, the normalized direct-relation matrix given in Table 5.14 and the total-relation matrix given in Table 5.15 are formed.

Table 5.13. The initial direct-relation matrix for costs.

| | CI | CT | HR |
|---|---|---|---|
| CI | 0 | 0 | 0 |
| CT | 1 | 0 | 0 |
| HR | 0 | 0 | 0 |

Table 5.14. The normalized direct-relation matrix for costs.

| | CI | CT | HR |
|---|---|---|---|
| CI | 0 | 0 | 0 |
| CT | 1 | 0 | 0 |
| HR | 0 | 0 | 0 |

Table 5.15. The total-relation matrix for costs.

| | CI | CT | HR | D | D+R | D-R |
|---|---|---|---|---|---|---|
| CI | 0 | 0 | 0 | 0 | 1 | -1 |
| CT | 1 | 0 | 0 | 1 | 1 | 1 |
| HR | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 1 | 0 | 0 | | | |

The assigned threshold value for costs is approved to be 1. The relationship between the sub-factors of costs is investigated considering the positioning of values on the impact-diagraph-map for costs shown in Figure 5.6. As seen on the diagraph-map of costs, the discrete D + R values of costs' sub-factors prove to have no inner dependency on each other. Cost of training seems to have a priority considering deployment of the Six Sigma projects. It is observed to be the dispatcher and the other sub-factors cost of implementation and cost of human resources are the receivers.

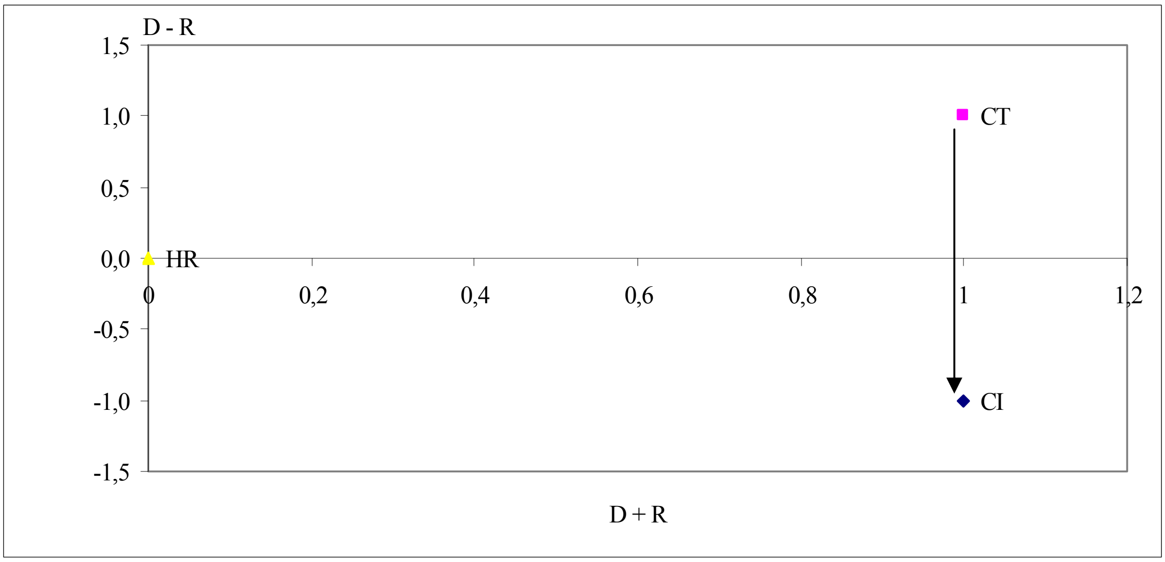


Figure 5.6. The impact-diagraph-map of total relation for costs.

After analyzing the relationships between factors and sub-factors by DEMATEL technique we can now regenerate and finalize our evaluation model for Six Sigma project selection. According to the results obtained, it is found out that strategies, and the factors benefits, opportunities and risks show strong inner dependency. After defining inner dependency, the finalized Six Sigma project evaluation model is formed as given in Figure 5.7.

As a further step in the proposed decision making model, to combine ANP and DEMATEL we obtained the inner dependence matrix by normalizing the total-relation matrix which prove to have inner dependency. According to the results and the given diagraph-maps of total relation matrix, strategies and the factors benefits, opportunities and risks have inner dependency. The normalized inner dependency matrix for strategies given in Table 5.16, benefits given in Table 5.17, opportunities given in Table 5.18 and risks given in Table 5.19 are directly utilized in unweighted supermatrix during ANP application.

Table 5.16. Inner dependence matrix for strategies.

| | BE | RG | PR |
|---|---|---|---|
| BE | 0,299 | 0,339 | 0,356 |
| RG | 0,357 | 0,300 | 0,345 |
| PR | 0,344 | 0,361 | 0,299 |

Table 5.17. Inner dependence matrix for benefits.

| | PE | CS | FP | LG |
|---|---|---|---|---|
| PE | 0,192 | 0,263 | 0,257 | 0,262 |
| CS | 0,156 | 0,145 | 0,231 | 0,190 |
| FP | 0,304 | 0,286 | 0,213 | 0,312 |
| LG | 0,347 | 0,306 | 0,299 | 0,236 |

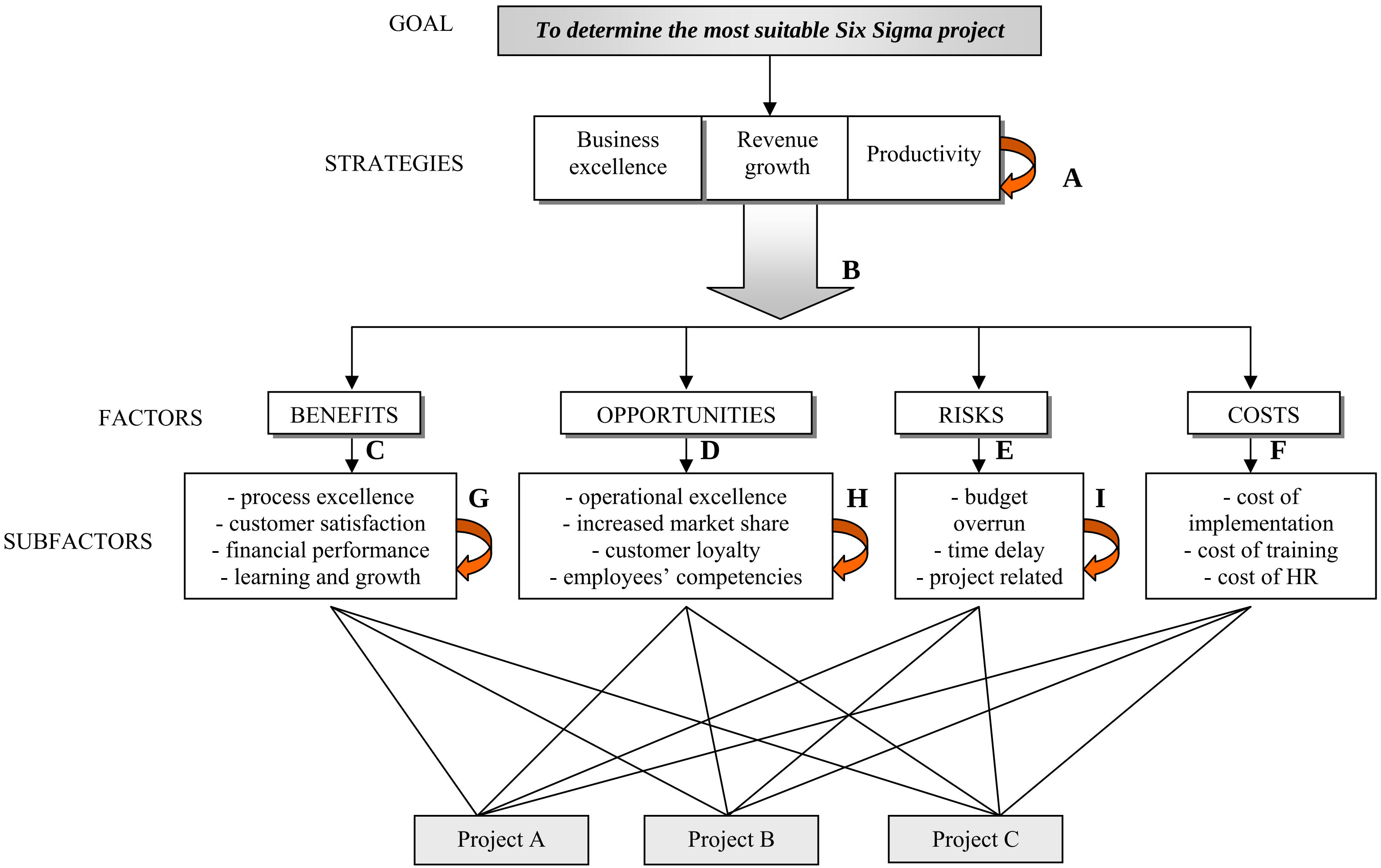


Figure 5.7. Finalized Six Sigma project evaluation model.

Table 5.18. Inner dependence matrix for opportunities.

| | OE | MS | CL | EC |
|---|---|---|---|---|
| OE | 0,185 | 0,254 | 0,246 | 0,292 |
| MS | 0,219 | 0,162 | 0,243 | 0,219 |
| CL | 0,236 | 0,265 | 0,179 | 0,236 |
| EC | 0,361 | 0,318 | 0,332 | 0,253 |

Table 5.19. Inner dependence matrix for risks.

| | BO | TD | PJ |
|---|---|---|---|
| BO | 0,334 | 0,368 | 0,369 |
| TD | 0,338 | 0,304 | 0,331 |
| PJ | 0,328 | 0,328 | 0,300 |

## 5.4. THE APPLICATION OF ANP

After determining the relationship structure with DEMATEL methodology, the ANP method is applied to calculate the weight of each criterion. Here again, the decision making group of ABC company's Six Sigma experts respond to a series of pairwise comparisons with Saaty's 1-9 scale where 1 represents equal importance, while 9 represents extreme importance that favours one element over another. If the element has a weaker impact than its comparison element the scale ranges from 1 to 1/9 indicating indifference. This ANP model is solved using the Super Decisions software.

The consistency ratio (CR) values of obtained results are all acceptable and the eigenvectors displayed are ready to enter into the supermatrix. Such an example, the pairwise comparison of strategies with respect to the goal is given in Table 5.20, and in Table 5.21 the pairwise comparison of strategies with respect to revenue growth is given. The rest of the pairwise comparison matrices are given in Table 5.22 - 5.40.

Table 5.20. Pairwise comparison of strategy with respect to the goal.

| Goal | BE | RG | PR | Weights |
|---|---|---|---|---|
| BE | 1 | 1/2 | 3 | 0,300 |
| RG | 2 | 1 | 6 | 0,600 |
| PR | 1/3 | 1/6 | 1 | 0,100 |
| CR | | | | 0,00013 |

Table 5.21. Pairwise comparison of strategy with respect to revenue growth.

| RG | BE | PR | Weights |
|---|---|---|---|
| BE | 1 | 2 | 0,667 |
| PR | 1/2 | 1 | 0,333 |
| CR | | | 0 |

Table 5.22. Strategies with respect to Goal.

| Goal | BE | RG | PR | Weights |
|---|---|---|---|---|
| BE | 1 | 1/2 | 3 | 0,300 |
| RG | 2 | 1 | 6 | 0,600 |
| PR | 1/3 | 1/6 | 1 | 0,100 |

Table 5.23. Benefits’ sub-factors with respect to Benefits.

| B | PE | CS | FP | LG | Weights |
|---|---|---|---|---|---|
| PE | 1 | 1 | 1/2 | 1 | 0,195 |
| CS | 1 | 1 | 1/2 | 2 | 0,231 |
| FP | 2 | 2 | 1 | 3 | 0,426 |
| LG | 1 | 1/2 | 1/3 | 1 | 0,148 |

Table 5.24. Opportunities' sub-factors with respect to Opportunities.

| O | OE | MS | CL | EC | Weights |
|---|---|---|---|---|---|
| OE | 1 | 1/2 | 1 | 2 | 0,185 |
| MS | 2 | 1 | 1 | 4 | 0,370 |
| CL | 2 | 1 | 1 | 3 | 0,345 |
| EC | 1/2 | 1/4 | 1/3 | 1 | 0,100 |

Table 5.25. Risks' sub-factors with respect to Risks.

| R | BO | TD | PJ | Weights |
|---|---|---|---|---|
| BO | 1 | 2 | 2 | 0,500 |
| TD | 1/2 | 1 | 1 | 0,250 |
| PJ | 1/2 | 1 | 1 | 0,250 |

Table 5.26. Costs' sub-factors with respect to Costs.

| C | CI | CT | HR | Weights |
|---|---|---|---|---|
| CI | 1 | 1 | 1/2 | 0,250 |
| CT | 1 | 1 | 1/2 | 0,250 |
| HR | 2 | 2 | 1 | 0,500 |

Table 5.27. Project alternatives with respect to Process Excellence.

| PE | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1 | 0,400 |
| A2 | 1/2 | 1 | 1/2 | 0,200 |
| A3 | 1 | 2 | 1 | 0,400 |

Table 5.28. Project alternatives with respect to Customer Satisfaction.

| CS | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 1/2 | 1 | 0,250 |
| A2 | 2 | 1 | 2 | 0,500 |
| A3 | 1 | 1/2 | 1 | 0,250 |

Table 5.29. Project alternatives with respect to Financial Performance.

| FP | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1/2 | 0,297 |
| A2 | 1/2 | 1 | 1/3 | 0,163 |
| A3 | 2 | 3 | 1 | 0,540 |

Table 5.30. Project alternatives with respect to Learning and Growth.

| LG | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1 | 0,400 |
| A2 | 1/2 | 1 | 1/2 | 0,200 |
| A3 | 1 | 2 | 1 | 0,400 |

Table 5.31. Project alternatives with respect to Operational Excellence.

| OE | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 2 | 0,500 |
| A2 | 1/2 | 1 | 1 | 0,250 |
| A3 | 1/2 | 1 | 1 | 0,250 |

Table 5.32. Project alternatives with respect to Market Share.

| MS | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1/2 | 0,297 |
| A2 | 1/2 | 1 | 1/3 | 0,163 |
| A3 | 2 | 3 | 1 | 0,540 |

Table 5.33. Project alternatives with respect to Customer Loyalty.

| CL | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 1/2 | 1 | 0,250 |
| A2 | 2 | 1 | 2 | 0,500 |
| A3 | 1 | 1/2 | 1 | 0,250 |

Table 5.34. Project alternatives with respect to Employees’ Competencies.

| EC | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1 | 0,400 |
| A2 | 1/2 | 1 | 1/2 | 0,200 |
| A3 | 1 | 2 | 1 | 0,400 |

Table 5.35. Project alternatives with respect to Budget Overrun.

| BO | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1/3 | 0,216 |
| A2 | 1/2 | 1 | 1/7 | 0,102 |
| A3 | 3 | 7 | 1 | 0,682 |

Table 5.36. Project alternatives with respect to Time Delay.

| TD | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1/2 | 0,286 |
| A2 | 1/2 | 1 | 1/4 | 0,143 |
| A3 | 2 | 4 | 1 | 0,572 |

Table 5.37. Project alternatives with respect to Project Related.

| PJ | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1 | 0,400 |
| A2 | 1/2 | 1 | 1/2 | 0,200 |
| A3 | 1 | 2 | 1 | 0,400 |

Table 5.38. Project alternatives with respect to Cost of Implementation.

| CI | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 2 | 1/2 | 0,286 |
| A2 | 1/2 | 1 | 1/4 | 0,143 |
| A3 | 2 | 4 | 1 | 0,571 |

Table 5.39. Project alternatives with respect to Cost of Training.

| CT | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 4 | 1 | 0,433 |
| A2 | 1/4 | 1 | 1/5 | 0,101 |
| A3 | 1 | 5 | 1 | 0,466 |

Table 5.40. Project alternatives with respect to Cost of Human Resources.

| HR | A1 | A2 | A3 | Weights |
|---|---|---|---|---|
| A1 | 1 | 3 | 1/2 | 0,300 |
| A2 | 1/3 | 1 | 1/6 | 0,100 |
| A3 | 2 | 6 | 1 | 0,600 |

According to the model developed given in Figure 5.7 the assigned matrices are shown in the general supermatrix formation in terms of letters in Figure 5.8.

| | *Strategy* | *B* | *O* | *R* | *C* | *Sub B* | *Sub O* | *Sub R* | *Sub C* |
|---|---|---|---|---|---|---|---|---|---|
| *Strategy* | **A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *B* | **B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *O* | **B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *R* | **B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *C* | **B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sub B* | 0 | **C** | 0 | 0 | 0 | **G** | 0 | 0 | 0 |
| *Sub O* | 0 | 0 | **D** | 0 | 0 | 0 | **H** | 0 | 0 |
| *Sub R* | 0 | 0 | 0 | **E** | 0 | 0 | 0 | **I** | 0 |
| *Sub C* | 0 | 0 | 0 | 0 | **F** | 0 | 0 | 0 | 0 |

Figure 5.8. The assigned sub-matrices are shown in general supermatrix formation.

All pairwise comparison matrices are computed and given in the form of unweighted supermatrix as shown in Table 5.41. A weighted supermatrix is transformed first to be stochastic as shown in Table 5.42. After entering the normalized values into the supermatrix and completing the column stochastic, the supermatrix is then increased to sufficient large power until convergence occurs. Table 5.43 provides a final limit matrix. This limit matrix is column stochastic and represents the final eigenvector. According to obtained results, Project C, optimizing inventory, is the most effective Six Sigma project alternative for the ABC Company. The second project alternative is improving the business processes.

Table 5.41. The unweighted supermatrix.

| | Goal | BE | RG | PR | B | O | R | C | PE | CS | FP | LG | OE | MS | CL | EC | BO | TD | PJ | CI | CT | HR | PA | PB | PC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BE | 0,300 | 0,299 | 0,339 | 0,356 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RG | 0,600 | 0,357 | 0,300 | 0,345 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PR | 0,100 | 0,344 | 0,361 | 0,299 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0,330 | 0,311 | 0,151 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| O | 0 | 0,151 | 0,151 | 0,208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0,208 | 0,208 | 0,311 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0,311 | O,330 | 0,330 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PE | 0 | 0 | 0 | 0 | 0,195 | 0 | 0 | 0 | 0,192 | 0,263 | 0,257 | 0,262 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CS | 0 | 0 | 0 | 0 | 0,231 | 0 | 0 | 0 | 0,156 | 0,145 | 0,231 | 0,190 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FP | 0 | 0 | 0 | 0 | 0,426 | 0 | 0 | 0 | 0,305 | 0,286 | 0,213 | 0,312 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LG | 0 | 0 | 0 | 0 | 0,148 | 0 | 0 | 0 | 0,347 | 0,306 | 0,299 | 0,236 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OE | 0 | 0 | 0 | 0 | 0 | 0,185 | 0 | 0 | 0 | 0 | 0 | 0 | 0,184 | 0,254 | 0,246 | 0,292 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MS | 0 | 0 | 0 | 0 | 0 | 0,370 | 0 | 0 | 0 | 0 | 0 | 0 | 0,219 | 0,163 | 0,243 | 0,219 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CL | 0 | 0 | 0 | 0 | 0 | 0,345 | 0 | 0 | 0 | 0 | 0 | 0 | 0,236 | 0,265 | 0,179 | 0,236 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EC | 0 | 0 | 0 | 0 | 0 | 0,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0,361 | 0,318 | 0,332 | 0,253 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BO | 0 | 0 | 0 | 0 | 0 | 0 | 0,500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,334 | 0,368 | 0,369 | 0 | 0 | 0 | 0 | 0 | 0 |
| TD | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,338 | 0,304 | 0,331 | 0 | 0 | 0 | 0 | 0 | 0 |
| PJ | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,328 | 0,328 | 0,300 | 0 | 0 | 0 | 0 | 0 | 0 |
| CI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,400 | 0,250 | 0,297 | 0,400 | 0,500 | 0,297 | 0,250 | 0,400 | 0,216 | 0,286 | 0,400 | 0,286 | 0,433 | 0,300 | 0 | 0 | 0 |
| PB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,200 | 0,500 | 0,163 | 0,200 | 0,250 | 0,163 | 0,500 | 0,200 | 0,102 | 0,143 | 0,200 | 0,143 | 0,101 | 0,100 | 0 | 0 | 0 |
| PC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,400 | 0,250 | 0,540 | 0,400 | 0,250 | 0,540 | 0,250 | 0,400 | 0,682 | 0,571 | 0,400 | 0,571 | 0,466 | 0,600 | 0 | 0 | 0 |

Table 5.42. The weighted supermatrix.

| | Goal | BE | RG | PR | B | O | R | C | PE | CS | FP | LG | OE | MS | CL | EC | BO | TD | PJ | CI | CT | HR | PA | PB | PC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BE | 0,300 | 0,058 | 0,065 | 0,069 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RG | 0,600 | 0,069 | 0,058 | 0,065 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PR | 0,100 | 0,065 | 0,069 | 0,058 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0,282 | 0,263 | 0,103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| O | 0 | 0,103 | 0,103 | 0,160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0,160 | 0,160 | 0,263 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0,263 | 0,282 | 0,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PE | 0 | 0 | 0 | 0 | 0,195 | 0 | 0 | 0 | 0,096 | 0,131 | 0,128 | 0,131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CS | 0 | 0 | 0 | 0 | 0,231 | 0 | 0 | 0 | 0,078 | 0,073 | 0,116 | 0,095 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FP | 0 | 0 | 0 | 0 | 0,426 | 0 | 0 | 0 | 0,152 | 0,143 | 0,106 | 0,156 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LG | 0 | 0 | 0 | 0 | 0,148 | 0 | 0 | 0 | 0,174 | 0,153 | 0,150 | 0,118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OE | 0 | 0 | 0 | 0 | 0 | 0,185 | 0 | 0 | 0 | 0 | 0 | 0 | 0,093 | 0,127 | 0,123 | 0,145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MS | 0 | 0 | 0 | 0 | 0 | 0,370 | 0 | 0 | 0 | 0 | 0 | 0 | 0,109 | 0,081 | 0,122 | 0,110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CL | 0 | 0 | 0 | 0 | 0 | 0,345 | 0 | 0 | 0 | 0 | 0 | 0 | 0,118 | 0,133 | 0,090 | 0,118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EC | 0 | 0 | 0 | 0 | 0 | 0,100 | 0 | 0 | 0 | 0 | 0 | 0 | 0,180 | 0,159 | 0,165 | 0,127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BO | 0 | 0 | 0 | 0 | 0 | 0 | 0,500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,167 | 0,184 | 0,184 | 0 | 0 | 0 | 0 | 0 | 0 |
| TD | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,169 | 0,152 | 0,166 | 0 | 0 | 0 | 0 | 0 | 0 |
| PJ | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,164 | 0,164 | 0,150 | 0 | 0 | 0 | 0 | 0 | 0 |
| CI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HR | 0 | 0 | 0 | 0 | 0 | | 0 | 0,500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,200 | 0,125 | 0,148 | 0,200 | 0,250 | 0,148 | 0,125 | 0,200 | 0,108 | 0,143 | 0,200 | 0,286 | 0,433 | 0,300 | 0 | 0 | 0 |
| PB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,100 | 0,250 | 0,082 | 0,100 | 0,125 | 0,082 | 0,250 | 0,100 | 0,051 | 0,071 | 0,100 | 0,143 | 0,101 | 0,100 | 0 | 0 | 0 |
| PC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,200 | 0,125 | 0,270 | 0,200 | 0,125 | 0,270 | 0,125 | 0,200 | 0,341 | 0,286 | 0,200 | 0,571 | 0,466 | 0,600 | 0 | 0 | 0 |

Table 5.43. The limit supermatrix.

| | Goal | BE | RG | PR | B | O | R | C | PE | CS | FP | LG | OE | MS | CL | EC | BO | TD | PJ | CI | CT | HR | PA | PB | PC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| O | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PE | 0,063 | 0,063 | 0,063 | 0,063 | 0,122 | 0 | 0 | 0 | 0,122 | 0,122 | 0,122 | 0,122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CS | 0,048 | 0,048 | 0,048 | 0,048 | 0,092 | 0 | 0 | 0 | 0,092 | 0,092 | 0,092 | 0,092 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FP | 0,072 | 0,072 | 0,072 | 0,072 | 0,139 | 0 | 0 | 0 | 0,139 | 0,139 | 0,139 | 0,139 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LG | 0,076 | 0,076 | 0,076 | 0,076 | 0,147 | 0 | 0 | 0 | 0,147 | 0,147 | 0,147 | 0,147 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OE | 0,023 | 0,023 | 0,023 | 0,023 | 0 | 0,123 | 0 | 0 | 0 | 0 | 0 | 0 | 0,123 | 0,123 | 0,123 | 0,123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MS | 0,020 | 0,020 | 0,020 | 0,020 | 0 | 0,106 | 0 | 0 | 0 | 0 | 0 | 0 | 0,106 | 0,106 | 0,106 | 0,106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CL | 0,022 | 0,022 | 0,022 | 0,022 | 0 | 0,115 | 0 | 0 | 0 | 0 | 0 | 0 | 0,115 | 0,115 | 0,115 | 0,115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EC | 0,029 | 0,029 | 0,029 | 0,029 | 0 | 0,156 | 0 | 0 | 0 | 0 | 0 | 0 | 0,156 | 0,156 | 0,156 | 0,156 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BO | 0,052 | 0,052 | 0,052 | 0,052 | 0 | 0 | 0,178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,178 | 0,178 | 0,178 | 0 | 0 | 0 | 0 | 0 | 0 |
| TD | 0,048 | 0,048 | 0,048 | 0,048 | 0 | 0 | 0,162 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,162 | 0,162 | 0,162 | 0 | 0 | 0 | 0 | 0 | 0 |
| PJ | 0,047 | 0,047 | 0,047 | 0,047 | 0 | 0 | 0,160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,160 | 0,160 | 0,160 | 0 | 0 | 0 | 0 | 0 | 0 |
| CI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,168 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,172 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PA | 0,167 | 0,167 | 0,167 | 0,167 | 0,171 | 0,184 | 0,149 | 0,178 | 0,171 | 0,171 | 0,171 | 0,171 | 0,184 | 0,184 | 0,184 | 0,184 | 0,149 | 0,149 | 0,149 | 0 | 0 | 0 | 0 | 0 | 0 |
| PB | 0,111 | 0,111 | 0,111 | 0,111 | 0,123 | 0,137 | 0,073 | 0,076 | 0,123 | 0,123 | 0,123 | 0,123 | 0,137 | 0,137 | 0,137 | 0,137 | 0,073 | 0,073 | 0,073 | 0 | 0 | 0 | 0 | 0 | 0 |
| PC | 0,222 | 0,222 | 0,222 | 0,222 | 0,206 | 0,179 | 0,278 | 0,246 | 0,206 | 0,206 | 0,206 | 0,206 | 0,179 | 0,179 | 0,179 | 0,179 | 0,278 | 0,278 | 0,278 | 0 | 0 | 0 | 0 | 0 | 0 |

## 5.5. THE APPLICATION OF ZOGP

The weights obtained from the ANP methodology are then used as priorities in the GP formulation to handle the constraints on resources. The values obtained in the limit matrix is calculated by 0,5 to be normalized. There exist several limitations of the available resources that have to be considered in the Six Sigma project selection for the logistics company in application. To complete this goal, there are four limitations: (1) a total maximum necessary investment budget of $40,000 is available now; (2) the highest ease of implementation percentage constrained by 30/100; (3) a total maximum of 6 months project duration for the firm is available now; (4) a total maximum necessary human resources cost of $90,000 is available now. In Table 5.44, the cost and organization resource usage information for each of the three project alternatives is presented.

Based on these data and the previously computed ANP values, we can formulate the goal constraints for this empirical problem as given in Table 5.44. The model formulation for selecting Six Sigma projects for ABC Company is given in Table 5.45.

Table 5.44. Resources usage information on selecting Six Sigma projects.

| | Project A: Improving the business process | Project B: Improving customer relations | Project C: Optimizing inventory | Available resource |
|---|---|---|---|---|
| Necessary investment | ($) 25,000 | ($) 10,000 | ($) 0 | ($) 40,000 |
| Ease of implementation | 40/100 | 60/100 | 50/100 | 30/100 |
| Duration | 6 months | 4 months | 4 months | 6 months |
| Necessary human resources | ($) 48,000 | ($) 32,000 | ($) 40,000 | ($) 90,000 |

Table 5.45. ZOGP model formulation for selecting Six Sigma projects.

| ZOGP model formulation | Goals |
|---|---|
| Minimize Z = | |
| $pl_1(d_1^+ + d_2^+ + d_3^+ + d_4^+)$ | Satisfy all limitations |
| $pl_2(0{,}334d_5^- + 0{,}222d_6^- + 0{,}444d_7^-)$ | Select highest ANP weighted project |
| Subject to | |
| $25000x_1 + 10000x_2 + 0x_3 + d_1^- - d_1^+ = 40000$ | Avoid over-utilizing maximum necessary investment |
| $0{,}4x_1 + 0{,}6x_2 + 0{,}5x_3 + d_2^- - d_2^+ = 0{,}3$ | Avoid over-utilizing maximum ease of implementation |
| $6x_1 + 4x_2 + 4x_3 + d_3^- - d_3^+ = 6$ | Avoid over-utilizing maximum project duration |
| $48000x_1 + 32000x_2 + 40000x_3 + d_4^- - d_4^+ = 90000$ | Avoid over-utilizing maximum necessary human resources |
| $x_1 + d_5^- = 1$ | Select Project A |
| $x_2 + d_6^- = 1$ | Select Project B |
| $x_3 + d_7^- = 1$ | Select Project C |
| $x_j = 0$ or 1 for j = 1, 2, 3 | |
| $d_i \geq 0$ for i = 1, 2, 3, 4 and | |
| $pl_1 > pl_2$ | |

This ZOGP model is solved using LINGO software [70]. The results are summarized as follows:

$x_1 = x_2 = 0$, $x_3 = 1$

$d_1^- = 40000$, $d_1^+ = 0$, $d_2^- = 1{,}33$, $d_2^+ = 0$, $d_3^- = 2$, $d_3^+ = 0$,

$d_4^- = 50000$, $d_4^+ = 0$, $d_5^- = 1$, $d_6^- = 1$, $d_7^- = 0$

According to the calculation regarding priorities of organizational objectives, Project C – Optimizing Inventory is chosen to be the most appropriate project alternative in Six Sigma project selection in logistics industry.

## 5.6. OBTAINED RESULTS AND DISCUSSIONS

This thesis integrated the DEMATEL, ANP and ZOGP methods to form a new hybrid decision making model for project selection. This model combined DEMATEL and ANP to consider the interdependencies among criteria and get prioritization of projects. The weights obtained with ANP are used in ZOGP to choose the best project alternative in a limited resource environment.

The DEMATEL method successfully computed the effects among criteria, it effectively divided a set of complex factors into dispatcher group and receiver group, and transformed into a visible structural model. According to the pairwise comparisons made utilizing DEMATEL, it is observed that Strategies, sub-factors of Benefits, sub-factors of Opportunities and sub-factors of Risks have inner dependency whereas sub-factors of Costs seem to have no inner dependency.

The inner dependent criteria obtained by DEMATEL are then normalized and carried in the supermatrix of ANP to be weighted. ANP method is a wise option to calculate priority weights among criteria. Besides, it assists ZOGP model to select the optimal project alternative in a company of limited resources. Along with the combined two decision making methodologies, it is achieved that the best Six Sigma project alternative to be chosen is Project C-Optimizing Inventory. Since this case study is hold in a real logistics firm having project alternatives with limited duration, investment and resources, an additional calculation methodology is applied.

Using the ZOGP helped to choose the project alternative full utilizing limited resources and without exceeding both budget and time. Considering the time, necessary investment, ease of implementation of the projects and necessary human resources constraints, a ZOGP model is formed for selection of the Six Sigma projects in a logistics firm. Entering the related data for every type of project in the model leaded to a final solution where Project C-Optimizing Inventory option is offered to be optimum Six Sigma project alternative.

In a further solution, to analyze the sensitivity of constraints on projects, one of the constraints' boundaries is checked while keeping the rest of the constraints fixed to see probable project alternatives. The constraint of necessary investment showed no change although the available resource value is raised or lowered. The constraint of ease of implementation is proved to be project 3 up to percentage 50/100 and project 2 for ease of implementation percentage 60/100; whereas the solver did not return any of the project alternatives having percentage above of 60/100. The constraint of duration is exceeded to be minimum 4 months; before 4 months none of the projects are chosen to be applied. The final constraint of necessary human resources needed a minimum budget of $32,000. The LINGO solver suggested Project 2 for the available resource up to $40,000 and by that value the solver suggested Project 3.

In addition to the calculations above, the company might anticipate the financial benefit to be gained at the end of each project. The expected benefit applying Project 1-Improving business process is acquired to be $250000, whereas Project 2-Improving customer relations is $300000 and Project 3-Optimizing inventory is $250000. In a further step, when the expected benefit (B) is added as a constraint in the ZOGP model there occured a change in the project selection. Given as a constraint, if $B \geq \$250000$, the program solver presented Project 3- Optimizing inventory as the best project alternative. If the expected benefit constraint is $B \geq \$250001$, the solver recommended

Project 2-Improving customer relations. The condition where constraint B $\geq$ \$300001, the solver suggested both of the projects, Project 1 & 2 to be implemented. By means of having maximum benefit to be gained, when the constraint B $\geq$ \$550001 the solver proposed all of the project alternatives to be implemented in the company.

## 6. CONCLUSION

Organizations continuously seek ways to improve the quality of processes and products and differentiate themselves from their competitors to raise customer satisfaction and revenues. Six Sigma is one of the methodologies utilized in the companies. This study aimed to combine two multi-criteria decision making methods DEMATEL and ANP and a goal programming model ZOGP to effectively identify the most appropriate project alternative especially in logistics companies.

Project selection is a complex decision making system composed of goals and sub-systems to better judge differences and interactions which can be referred to a typical multiple decision making criteria application. DEMATEL and ANP techniques are both in conjunction to systematically construct an evaluation network model for project selection. Utilizing only one of the techniques could be satisfactory in choosing the best project alternative; but integrating these two techniques as a combined MCDM approach is a wise option which can be regarded as a consolidated new tool considering inner dependency and weights of criteria. However, in real life the project selection might be restricted by limited resources or other selection limitations. Considering the company strategies and goals and assigning limited resources to the project alternatives is another issue. For this reason, ZOGP is used to select the best alternative within resource constraints.

After making a detailed literature survey and examining Six Sigma appliers' real life experiences, the criteria to be considered in Six Sigma project selection were determined, and an evaluation model was developed. To support and investigate the effectiveness of the proposed approach an empirical case study from logistics industry was used. It should be noted that an effective project selection method helps to ensure optimal resource utilization and greater contribution of projects toward company's missions and goals. In this thesis, selecting Six Sigma projects is based on a combined decision making approach. As a result, Project C-Optimizing Inventory alternative is initially proposed. In addition to this, the secondary best project alternative is Project A-Improving the Business Processes is offered. Consistent with the results observed, the case company is satisfied with the consequences. After supporting the Six Sigma project selection decision with the analytical tools, case company felt safe to employ the optimum project alternative.

There might be some limitations in combining these two analytical approaches such as different assessment scales; but this non-unification can be improved. One of the further studies might involve knowledge based or an expert system which can be integrated to help decision-makers make calculations more concisely, and interpret the results in each step of the applied techniques.

Another point is to define the threshold values in arithmetic order and assign an average threshold value in DEMATEL application. Moreover, the methods can be extended to apply in fuzzy environment. Since we utilized Delphi method to obtain a consensus in this study, group decision making might also be applied to agree different opinion of experts. For further study, the application can be carried out in more than one company or even this integrated method can be applied for different sectors.

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