THESIS ON MECHANICAL ENGINEERING E101

Partners Selection Tool for Virtual Enterprise in SMEs Network

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Declaration:

Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been submitted for any degree or examination.

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INTRODUCTION

Foreword

Corporations, alliances and large state-owned companies control today's global market. Many of them are so powerful that they have a lobby in national parliaments or governments [1–3]. This situation protects business positions in many areas and domains, such as Microsoft, Philip Morris, Lockheed Martin, and AT&T [4] in the global market. In many cases, the "global players" dictate their rules to the market [5–6]. They have a monopoly in the particular market niche since their positions are quite powerful and secure [7]. This could affect competitiveness or result in an economic crisis or a country's economic stagnation in global terms. A problem with large corporations is their rigidity, inability to react efficiently to changes and sluggishness.

In fact, more than 99% of all European businesses are Small and Medium Enterprises (SMEs) [8]. The important research question is the following: is it possible to create an environment that shares a significant amount of SME resources and directs them towards fulfilling a common goal? If successful, a new organisation form will emerge, one that allows SMEs to compete with multinational corporations and alliances and leverages the competitive advantages in the global market. Customers are demanding greater reliability and faster delivery [I]. These new organisation forms (organisation) will act to slow down the price growth levels by offering services and products direct to consumers.

Various networked organisations forms already exist in the market today, and they provide the basis for the establishment of a virtual organisation. However, all of them share the same problem – they lack a fast and objective procedure for selecting partners within the framework of a particular project (a virtual enterprise) [9]. **The goal of this thesis is to develop the partner selection tool for the particular large project realisation.**

The research work leads to a new framework development for the collaboration networks of production enterprises. The work presents the novel framework of collaborative environment. It enables enterprises to automate the process of a virtually (temporarily) united organisation formation, in order to exploit a worldwide business opportunity [10]. In a fast-changing global market, the company has a narrow window of time to respond to a business opportunity. In some cases, companies have to change their structures [II]. *"It is a typical situation for an SME in terms of limited capacities and capabilities. In the current business environment of northern Europe, there is a situation whereby SMEs need to form new ecosystems in order to be more competitive and flexible and to have the capability to compete with corporations"* [11].

Result publications

This section describes the results of the research based on participation at various conferences and publications in journals. The results of the PhD thesis were published at 8 international conferences. The articles have been published in proceedings that were presented at the conferences. Three articles were published in scientific journals. The articles directly connected to the research topic are listed under the section entitled "List of author's publications".

Approbation

The publications were presented at various international CIRP and DAAAM conferences, including the "XXII International CIRP Sponsorship Conference on Supervising and Diagnostics of Machining Systems" in Karpacz, Poland, in 2010; the 7th International DAAAM Baltic Conference. Industrial Engineering in April 2010 in Tallinn, Estonia; the "XXIII International CIRP Sponsorship Conference on Supervising and Diagnostics of Machining Systems" in Karpacz, Poland, in 2011; the 23rd and 24th International DAAAM Symposiums in 2012 and 2013 in Zadar, Croatia; and the 13th IFIP WG 5.5 Working Conference on Virtual Enterprises in 2012 in Bournemouth, UK.

Work structure

Figure A below outlines the graphic structure of the thesis. The first two chapters explain the definitions used in the thesis and discusses what has already been accomplished in the field of collaboration environments, enterprise networks, and virtual organisation (VO)/virtual enterprise (VE). The second chapter of the thesis presents an overview of existing partner network alternatives, methods, techniques and tools that are used for virtual organisation formation, partner network establishing and partner selection tool are given.

The third chapter describes the new theory, PN life cycle, functionality and required steps during a PN formation process. PN is a foundation or platform for VE. This chapter gives a theoretical foundation for subsequent research. It includes the process of incorporating new members in the PN and VE formation process, which consists of the new project initiation, resources allocation selection procedure, risk assessment and preparation of the project scope document. The project scope is attached to the agreement document, which the customer signs before the VE proceeds with project realisation. This chapter also gives an overview of the steps to be fulfilled after the VE establishment process is completed. Those steps include the sustainable management of virtual enterprise and continuous the quality improvement process within the framework of VE management.

The fourth chapter of the thesis presents a mathematical model for sustainable partner selection, where the following mathematical tools are applied: the

Analytic Hierarchy Process, TOPSIS method, fuzzy set theory and Pugh matrix. Through a combination of these tools, the model can select the best collaborative partners and define the most effective way to support project realisation via collaborative realisation. Focal player (FP), or a company that acquires the business opportunity and plans the VE to implement the corresponding project, applies a partner efficiency index (PEI) for the partner's evaluation. In addition, the definition of the criteria for partner selection is described in this chapter. The findings are correlated in a resulting table, in order to provide the required information for the decision maker. It includes the number of transfers between the partners and an index of efficiency for the particular project.

In the fifth part of the thesis, the proposed model is verified by a case study. Seven SMEs from the field of Estonian machinery have provided data for a SME network initiation that has enabled us to verify in practice the described process of VE forming and partner selection algorithm.

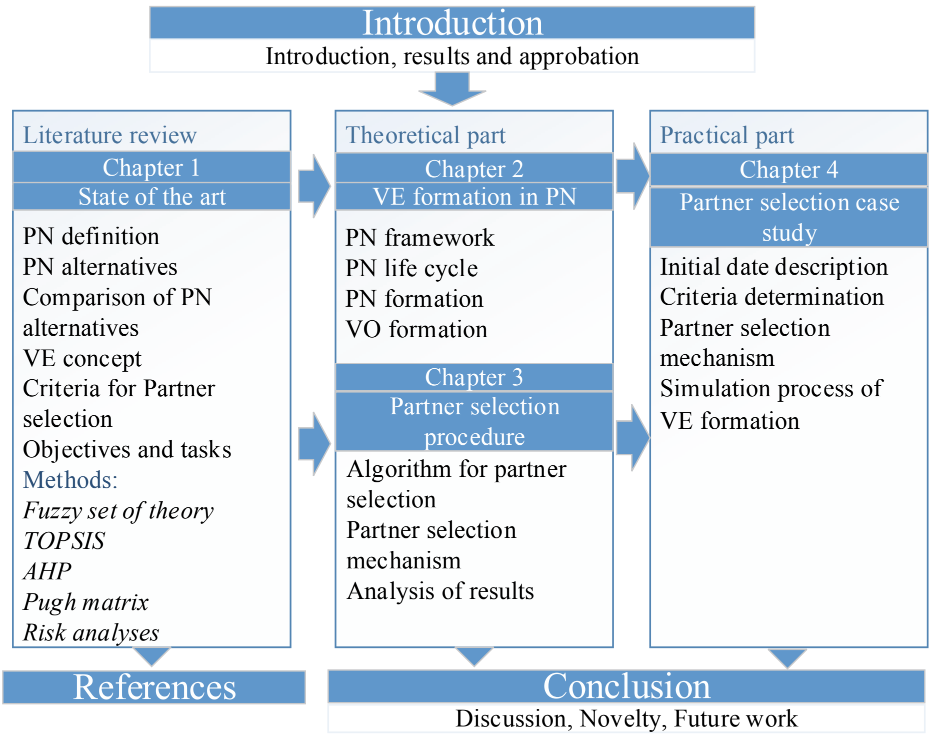


Figure A. General structure of the research

ABBREVIATIONS

AHP	Analytic Hierarchy Planning
ARIS	Architecture of Integrated Information Systems
BPM	Business Process Management
BPMN	Business Process Modelling Notation
CASE	Computer Aided Software Engineering
CC	Closeness Coefficient
CNO	Collaborative Networked Organisations
CP	Collaborative Project
CPM	Collaborative Project Management
DBMS	Database Management Systems
EMAS	Eco-Management and Audit Scheme
EPC	Event Process Chain
ERP	Enterprise Resource Planning
ETA	Event Tree Analysis
FNIS	Fuzzy Negative Ideal Solution
FP	Focal Player
FPIS	Fuzzy Positive Ideal Solution
IDEF0	Integrated Definition; Method 0
IS	Information System
KPI	Key Performance Indicator
PEI	Partner Efficiency Index
PN	Partner Network
PNMO	Partner Network Managerial Office
PSP	Partner selection problem
SLA	Service Level Agreements
SME	Small and Medium Enterprise
SPN	Sustainable Partner Network
SOCC	Service-Oriented Cloud Computing
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
UML	Unified Modelling Language
VAC	Value-Added Chain
VBE	Virtual Breeding Environment
VE	Virtual Enterprise
VO	Virtual Organisation

1 LITERATURE REVIEW

1.1 Partner network definition and related terms

In the current business situation, SMEs are faced with comprehensive competition in the global marketplace. The situation forces companies to struggle with challenges in order to maintain competitiveness. One of the responses is the formation of new ecosystems, which allows companies to become more flexible and sustainable in the marketplace. In recent years, the trend to establish group company coordination, cooperation and collaboration has increased. This activity helps to align the group of companies with a similar vision in order to find a faster solution to their common problem. It might be easier, smarter and more efficient to struggle together with the same problems.

It is necessary to distinguish enterprises by sizes. This is based on analysis undertaken by Sahno et al., in which SMEs are categorised according to annual labour force units, annual turnover and/or annual balance sheet. As a result of the research, an enterprise that has less than 250 employees or an annual turnover and balance sheet not exceeding 10 million euros is considered an SME [IV].

Cooperation, coordination and collaboration have different meanings. These meanings characterise the level of companies' integration in terms of common goals, strategy, vision and mission together with information exchange transparency and level of trust. These concepts and other base terms that are required for understanding this thesis can be defined as follows:

"*Cooperation – a voluntary arrangement in which two or more entities engage in a mutually beneficial exchange instead of competing against each other. Cooperation can happen where resources adequate for both parties exist or are created by their interaction"* [12].

"Coordination – the synchronisation and integration of activities, responsibilities, and command and control structures to ensure that the resources of an organisation are used most efficiently in pursuit of the specified objectives" [12].

"*Collaboration – widely recognised as a mechanism for leveraging competitiveness and thereby increasing survivability in turbulent market conditions. The different collaborative models enable organisations to capitalise on their individual strengths by sharing risks and resources, and combining complementary skills and capacities. Collaboration enables companies to gain new competitive advantages and to develop their individual capabilities by focusing on their core-competencies"* [12].

Virtual enterprise (VE) *"represents a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to respond* *more effectively to business opportunities, and whose cooperation is supported by computer networks"*[13].

Virtual organisation (VO) *"represents a concept similar to a virtual enterprise, and comprises of a group of (legally) independent organisations that share resources and skills to achieve the group's mission/goal, but that is not limited to an alliance of for-profit enterprises. Therefore, a virtual enterprise is a particular type of virtual organisation"* [13].

"The partner network is primarily developed by companies with ongoing network intentions in horizontal cooperation in order to respond faster to the market needs and to decrease the time required to build up the necessary network competences and processes, when the new business opportunity arises"[11]. PN is considered an extension of VBE [13], which is a form of business community composed of organisations that come together in preparation for a rapid response to business opportunities. In this community, it is not necessary to have dominant company. Therefore, the members of this community are not the partners of one particular company – they are all partners together. The term partner network is familiar in the field of industry. The term PN is based on the business partner network (BPN) definition, as used in Microsoft Partner Network, Oracle Partner Network and others.

"PN ties the companies together, via horizontal as well as via vertical communication, to be ready for the new business opportunities, that they will not be capable to respond alone, or to minimise their business risks. The main challenge is to keep such networks functioning in a way that the partner companies will find the motivation to stay in the created collaborative network"[11].

"The main difference between PN and other similar networks is the operating environment, which is constrained to legal aspects. When companies, entering into the PN, they should sign the frame agreement with collective juridical body, representing the PN. Based on that agreement the companies, which are working on financial proposal to the customer, can quickly form the Virtual Enterprise, in order to be ready for the legally respond to the market demand" [11].

1.2 Partner network alternatives (networked organisations)

The focus of this thesis is PN, and it is assumed that the research enterprises mentioned herein operate and are considered a part of PN. This section gives a review of existing alternatives to PN. The characteristics of PN alternatives and a comparison table are introduced below.

Supply chain

The logistics chain is a partially ordered variety of dealers engaged in a flow of materials from a particular manufacturer to its consumers.

Supply chain is a variety of elements interconnected through information, money and commodity flows. The supply chain starts with the purchase of raw materials from suppliers and ends with the sale of finished goods and services to customers [15]. Some elements can be wholly owned by the same organisation, while others are owned by similar companies (customers, suppliers and distributors) [16]. Thus, the supply chain usually consists of several organisations.

The supply chain, i.e. the chain of material and information flows from the supplier to the consumer, generally includes the following main elements:

- supply of materials, raw materials and semi-finished products;
- storage of products and raw materials;
- production of commodities;
- distribution, including shipment of goods from the finished products warehouse;
- consumption of finished products [17].

Strategic alliance

Strategic alliances are various forms of stable long-term cooperation between two or more partners striving to achieve specific business goals and benefit from the effect of their combined and complementary resources. This is about partnership beyond usual commercial operations, though not equating to a corporate merger [18]. Economic globalisation requires the active cooperation of companies from different countries. Cooperation through the implementation of research projects and marketing programmes as well as the establishment of joint ventures increases the competitiveness of companies, allowing them to develop new technologies, enter foreign markets, share risks and adapt to the requirements of antitrust law [19].

Strategic alliances are aimed at gaining long-term benefits and form part of the global corporate strategic plan [20–21]. Structurally, strategic alliances tend to combine several forms of incorporation, including joint ventures, licence agreements, long-term product supply and purchase contracts, joint research and development programmes, and the mutual presentation of sales networks [22–24].

Joint venture

Joint venture (JV) is a relatively new organisational and social form of international business. JV is usually referred to as a form of economic and legal cooperation with a foreign partner, which provides for the joint ownership of material and financial resources used to perform production, research and development, foreign trade and other functions [25]. JVs are also noteworthy for the fact that the products and services produced are jointly owned by the partners.

JV is a complex form of international economic cooperation defined by a closer relationship between business partners. JV members share their income, losses and risks, manage all production and sales cycles together, and promptly respond to the changing political situation in location countries. At the same time, however, each partner serves its own interests [26]. When a joint venture is established on an arm's length principle, its main purpose is to generate profit, no matter where the capital is. There is no doubt that joint ventures are created with the same purpose [27].

In many cases, JVs are required in response to particular economic conditions that exist at the time of establishment of the JV. Such conditions include a lack of available funds to create an optimum-sized enterprise or a cost saving measure [28]. Through engagement with foreign partners, the financial costs involved in the creation of a new or the expansion of an existing enterprise can be reduced.

De-investment/divestiture

Divestment is a process contrary to investment, i.e. conversion of earning assets to cash through sales. It is understood that divestment will eventually bring more profit to the enterprise than the preservation of assets in their current state [29].

There can be different reasons for divestment. One of the most common reasons is to eliminate non-core activities and focus on the core activity. The basic motive is to improve controllability and eradicate operational risks in those areas in which the company is not highly competent [9]. Moreover, the company may sell its core business or core assets in order to focus on a more promising and profitable activity. Companies also divest in order to increase the stability and predictability of their business activity. Finally, there are forced divestments due to pressure from state authorities (market de-monopolisation) or shareholders concerned about social responsibility.

There are several ways of divestment: the direct sale of assets or whole subsidiaries to other companies; allocation of a certain business activity to a separate company and the sale of its shares on the stock exchange; allocation of a certain business activity to a separate company and the transfer of its shares free of charge to existing shareholders of the original company [30].

Merger/acquisitions

A merger is the combining of two or more companies, resulting in the creation of a new economic unit (a new legal entity).

Merger of forms is a combination in which the merged companies cease to exist as independent legal entities and taxpayers. A new company takes direct control over all the assets and liabilities of its constituents to the company's customers, whereupon the constituents are dissolved.

Merger of assets is a combination in which the owners of participating companies transfer – as a contribution to the authorised capital – control rights to their companies, provided that the activities and the form of incorporation of the latter are maintained [30]. Once again, this is one possible way of establishing a company; however, in this case, the contribution can only be represented by the control rights to the company.

Acquisition is a transaction aimed at gaining control over a company and is carried out through the acquisition of the authorised capital (shares, equity interests, etc.) of the acquired company, provided that the legal independence of the latter is maintained.

Reverse acquisition is another effective way of gaining access to foreign investments.

Reasons for merges (acquisitions):

- operational savings by eliminating the duplicate functions of various services (marketing, accounting, procurement, etc.);
- synergetic effect when the value of a new entity exceeds the total value of its constituents;
- overcoming the restrictions of intercorporate accumulation;
- engagement of external sources of growth;
- cooperation in introducing new costly developments, the implementation of new scientific ideas, etc.;
- exclusion of mismanagement;
- strengthening the monopoly position (particularly in regard to horizontal mergers);
- production diversification, etc. [31].

1.2.1 Comparison of partner network alternatives

A comparative analysis of the existing networked organisations can be made in order to determine strengthens and weakness. The analysis allows us to define the best choice for SME for the particular collaboration. The analysis shows the reason why the PN is selected to make a collaboration environment for the SME.

Eight criteria have been taken into account in making an analysis. *Capability* reflects the level of production capability of the company. *Investment* details the amount of financial resources required to form the organisations. *Flexibility* describes the capability of the organisation to adapt to the fast changing situation in the marketplace. *Complexity of project* is the ability of the network to perform the project with complicated customer requirements and tasks. *Responsibility* defines the ability of the partner to meet customer and partner commitments. *Internal relationship* defines the level of the trust and relationship between members of the network. *Sustainability* defines the reliability and survival rate of the network and of maintaining the collaboration in a healthy state. *Agility* describes the capability of the network to quickly change during the project realisation time in case the project scope changes due to market or customer needs.

Table 1.1. Comparison of PN alternatives

	Invest-ment	**Flexib-ility**	**Complexity of project**	**Responsi-bility**	**Internal relation-ship**	**Sustaina-bility**	**Agility**
Supply chain	Low	High	Low	Purchase contract	Control	Low	Low
Strategic alliance	Low	High	Middle	Permanent contract	Trust	Low	High
Partner network	Low	High	High	Flexible contract	Trust	High	High
Joint venture	High	Low	High	Cooperative contract	Control	Middle	Low
Divestiture, sale	No	Low	Low	No	No	Middle	No
Acquisitions, merger	Very high	Low	High	Capital Investment	Control	Middle	Low

In Table 1.1, the criteria are rated on a three-point scale: “low”, “middle” and “high”. The investment, flexibility, complexity of a project, sustainability and agility criteria are evaluated on this scale [32].

As shown in Table 1.1, PN structure has the best-balanced profile. PN provides various advantages and best suits collaboration as a strategic alliance to leverage the competitiveness of SMEs on the global market.

1.3 Virtual enterprise concept

This section summarises the idea of VE from different sources. VE is one of the main concepts in this research. Many researchers have their own definitions of VE with some variation on the basic meaning. The VE definition that is used by the author in the current thesis does not fully align with the definitions of VE that are presented in the current section. The author has introduced these other definitions in order to give a holistic picture of VE definitions.

Byrne was first to give the definition of virtual enterprise in 1993. He defines VE as *"a temporary network of independent companies—suppliers, customers, even erstwhile rivals—linked by information technology to share skills, costs, and access to one another's markets"*[33].

Gallivan describes a virtual enterprise as *"such non-hierarchical configurations of activity, and I refer to the parties that coordinate their activities as agents. These agents may be individuals, as well as small or large business entities, or possibly non-profit organisations"* [34].

Mowshowitz defines the idea of virtual enterprise as *"a goal-oriented activity. [It] is an analogy between virtual memory and the practices of multinational firms. The analogy combines elements drawn from three disparate lines of inquiry. These are (1) the structure of virtual memory, (2) the distinction between an object language and a metalanguage that is made in the foundations of mathematics, and (3) the practices of complex organisations"*[35].

Chesbrough et al. talk about virtual company as *"free agents come together to buy and sell one another's goods and services; thus virtual companies can harness the power of market forces to develop, manufacture, market, distribute, and support their offerings in ways that fully integrated companies can't duplicate"* [36].

If we sum up the definitions and characteristics of the different points of views introduced in scientific literature, VE can be defined as a new entity that is temporary created for VE goal fulfilment and dissolved after the goal is achieved. The process structure of VE remains the same as a structure of processes in physical enterprise. Furthermore, the VE members bring their vital core activities to a new organisation. The "Virtuality" of the entity also means the enterprise that established the VE does not have sufficient physical resources for project realisation and will use the PN resources.

1.4 Partner selection problem

Partner selection problem (PSP) has a strategic impact on the success of VE formation and its competitiveness [37]. The PSP has received attention from the industrial sector and the academic community, as it includes complexity, formation constrains, "*natural of discrete decisions*" [38], "*risks factors*" [39], "*a* *large number of alternatives and criteria of different types (quantitative, qualitative, and stochastic)*" [40].

Many methods and methodologies exist nowadays that are used to solve the PSP problem. Niu et al. introduced four categories of methodologies for partner selection and gave samples for each of the categories:

- *" exact algorithms, such as the Branch and Bound algorithm*
- *mathematical modelling and programming, e.g. goal programming integer programming and their enhanced types*
- *fuzzy decision-making and multi-attributive decision-making (MADM) algorithms*
- *heuristic and meta-heuristic algorithms" [41]*

This research belongs to category 3 ("*fuzzy decision-making and multi-attributive decision-making (MADM) algorithms*"), since it is using methodology such as the analytical hierarchy process (AHP) [42], the fuzzy-AHP approach [43] and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [44]. Niu et al. proposed the enhanced method of ant colony optimiser algorithm (ACO) [41].

F. Ye and Q. Lin [45] propose an extended TOPSIS method, which takes into consideration various risks for the decision maker and facilitates the partner selection process.

J. Xiao et al. proposed a non-traditional method for partner selection, which takes many aspects into consideration simultaneously, such as running cost, reaction time and running risk. The method defines it as *"an adaptive quantum swarm evolutionary algorithm with time-varying acceleration coefficients"* [46].

B. Lotfi Sadigh et al. use the multi-agent system (MAS) in order to select the best partner for VE. The research is focused on the VE formation phase and proposes *"a hybrid multi agent model"* [47]. There are several agents that are assigned to qualify companies from the list of candidates.

There is a further method used to select the partner and focus on problem of PSP exists. Zhang, Y. et al. [48] have improved on the Pareto genetic algorithm for partner selection. The method gives several solutions for the partner selection based on the different criteria (cost, time, quality, carbon emission, lead content).

There are many other methods for PSP solving; however, these methods do not consider the number of transfers between the partners, and they do not propose the allocation of the work between the partners according to partner reliability.

1.5 Criteria for partner selection

The objective of this section is to give a review of literature and articles that have examined evaluation criteria and define the most popular of them for the selection of partners, vendors and suppliers. As a basis for the study, three main articles on selection criteria were considered.

In the thesis, the author will use criteria for partner selection from the list of criteria proposed by Dickson's analysis of supplier criteria, which was presented in his research work in 1966. The survey is based on the interview of managers from 273 companies. Dickson identified 23 as the most important. The criteria are *"quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capability, financial position, procedural compliance, communication system, reputation and position in industry, desire for business, management and organisation, operation control, repair services, attitude, impression, packaging ability, labour relations record, geographical location, amount of past business, training aids, reciprocal arrangement"* [49]. These are criteria that will be taken as an initial list and the most popular from this list will be selected for partner selection during the formation of a VE.

Ho et al. studied 78 articles in which the authors deal with methods for the selection of suppliers. As a result, 87% of the articles consider quality as an evaluation criterion for the selection of suppliers. The second position is delivery and 82% authors considered this criterion important for the supplier evaluation. According to the articles, the criteria in question have the following percentages: *"price/cost (81%), manufacturing capability (50%), service (45%), management (32%), technology (32%), research and development (31%), finance (30%), reputation (19%), flexibility (23%), relationship (4%), risk (4%), safety and environment (4%)"* [50].

Mukherjee studied evaluation criteria for the supplier selection based on 78 scientific papers. The author discovered that only 22 of 78 articles have considered the supplier selection criteria and given statistics: *"cost (73%), quality (77%), delivery (46%), service (32%), supplier profile (27%), reliability (5%), environment (5%), responsiveness (5%), logistical performance (5%), commercial plans & structure (5%), production (5%), facility and technology (5%), professionalism of salesperson (5%), quality of relationship with vendor (5%), risk factor (14%), technology and capability (41%), mutual trust & easy communication (18%), collaboration (5%), annual demand (5%), availability (5%), supplier's willingness (5%), R & D (5%)"* [51].

Weber et al. made a study of the Dickson criteria and defined the vendor criteria importance. Their survey is based on 74 articles that considered a vendor selection issue. The criteria are ordered in the ranking table according to their consideration in the article: Price is the most popular criterion, as it was considered a criterion in 80% of 74 articles. It is followed by *"delivery in 58%, quality 52%, production facilities and capacity 30%, geographical location 21%, technical capability 20%, management and position in the industry 11%, financial position 9%, and performance history 9%."* [52].

Table 1.2. Criteria for partner selection

Criteria	**Number of articles (pcs)**	**Percentage of usage (%)**
Price	130 (63+16+61)	75
Quality	125 (68+17+40)	72
Delivery	118 (64+10+44)	68
Production facilities and capacity	65 (39+3+23)	37
Technical capability	49 (25+9+15)	28
Repair services	42 (35+7)	24
Management and organisation	35 (25+10)	20
Financial position	30 (23+7)	17
Reputation and position in industry	23 (15+8)	13
Geographical location	17 (1+16)	10
Performance history	7	4
Attitude	7 (3+4)	4
Communication system	4	2
Impression	1	<1
Training aids	1	<1
Reciprocal arrangement	1	<1
Warranties and claim policies	–	–
Procedural compliance	–	–
Desire for business	–	–
Operation control	–	–
Packaging ability	–	–
Labour relations record	–	–
Amount of past business	–	–
Total	**174**	

Based on analysis of the three articles that have studied the criteria for partner/supplier/vendor selection, a result table to define the most appropriate criteria for the partner selection case is presented.

The results in Table 1.2 show that it necessary to consider quality, delivery and cost/price criteria for partner selection. The study shows that this process greatly helps in finding the most appropriate partners for VE. Other criteria can also be used; however, the other criteria of selection have less weight and, depending on the case, the customer or the FP has to decide which of them to take into account.

1.6 Objectives and tasks

Objectives

The objective of the current thesis is to solve the previously described problem by offering an alternative to the existing global market layout, which is governed by large corporations. The main idea is to collect information about the available resources of SMEs into a new temporary entity and to utilise those resources for the realisation of the tasks of a particularly large project as well as meet customer expectations.

In addition, the current work also should suggest a calculation tool for faster partner evaluation (assessment) based on various criteria for the particular project. However, it is a challenge to create a sustainable environment for such collaborative entity formation, since there are many issues to be considered and a significant amount of work to be fulfilled before the model can be verified. Such an environment is a complex system with a lot of interconnection tasks, a number of targets and participants [III].

Tasks

It is necessary to implement the following tasks in order to achieve these objectives:

- To define the environment for the consolidation of resources of independent SMEs;
- To develop a tool for agile virtual enterprise (VE) formation;
- To develop a tool for the selection of the best partners for VE;
- To verify the proposed tool by a case study;

Hypotheses

1. H_0: SMEs have low competitiveness in the global market.
   H_1: combining small enterprises into a network makes it possible to compete with large corporations.

2. H_0: SMEs lose a lot of time in partner selection for project realisation.
   H_1: the proposed framework helps decreasing project initiation time and project realisation risks

3. H_0: the SMEs have low efficiency in the realisation of large projects.
   H_1: VE increases the efficiency and productivity of project realisation, by SMEs focusing on core activities and delegating other activities to partners.

4. H_0: large corporations dictate product price level.
   H_1: an increased number of global market players slow down prices and increase the quality of the product for the end customers.

The thesis should answer the research question and verify the hypotheses; however, the vision of partner network (PN) is that of an alliance of independent enterprises with a common collaborative principle that is based on trust, mutual respect and benefits. PN has to direct a new organisational development. The author of the thesis believes that this new PN framework will become a valuable tool that will be applied by SMEs in order to stay competitive under the fast changing conditions of the global market.

Scope

The scope of the thesis is to set the bounds on the area of current research. The research focuses on production enterprises (especially for SMEs) and is intended to improve their competitiveness. In the future, however, the developed method could also be successfully adopted for other domains (design, logistic, purchasing, sales, etc.) where it is possible to organise a network of enterprises.

2 USED METHODS AND TOOLS

The thesis is based on mathematical theories, analytical tools and methods. The applied methods, tools and theories are given in this section. The descriptions of the methods are taken from existing literature, a list of which accompanies this thesis. A comparison table of selected methods, integration and the methods reflected in literature is also presented in this section.

One of the goals of the thesis is to simplify the decision-making process by introducing the possible methods for project realisation and to provide the possibility for solution selection based on particular project priorities. Since the tool selects the partners based on criteria, the author has analysed the existing methods for rating the alternatives based on specific criteria and found that the criteria are divided into two types: qualitative and quantitative,.

The quantitative nature of criteria is a crude estimation of criteria that have uncertainty in their evaluation and information expressed in linguistic terms [53], [54]. Qualitative means *"intuition, experience and common sense"* [55]. The qualitative rate defines *"a series of ordered semantic values; each semantic value included in the set {very low, low, moderate, high, very high} is associated to a numerical value that is used for the calculations"*[56].

Qualitative criteria are a numerical output of the evaluation criteria to enable data analysis, choice or decision-making in the system. Quantitative factors can be measured precisely in numerical terms. *"Quantitative factors give numerical basis for decision-making, namely reduces decisions merely to monetary value placed on different choices"* [57].

Based on performed literature review, it can be concluded that the theory and methods used for the partner selection tool should consider both types of criteria. The most suitable theory in this context is the fuzzy set, which takes the "mixed" criteria type into account during the evaluation of alternatives.

2.1 Fuzzy set theory

The fuzzy set theory is a mathematical tool that extends the usage of traditional tools of modelling. The traditional tools are precise and crisp, which means that they use only two values (yes/no; 1/0); however, the fuzzy set is able to use such a type as more-or-less, which allows it to implement qualitative criteria in calculation.

In regard to systems or frameworks, Zadeh writes: *"as the complexity of a system increases, our ability to make a precise and yet significant statement about its behaviour diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics – The closer one looks at a real-world problem, the fuzzier becomes its solution"*[58]. Zadeh, as the founder of fuzzy set, defined it as *"a class of objects with a continuum of grades of membership… the notion of a fuzzy set provides a* *convenient point of departure for the construction of a conceptual framework which parallels in many respects the framework used in the case of ordinary sets, but is more general than the latter…"* [59].

Zimmermann defined fuzzy set theory as method of *"a strict mathematical framework (there is nothing fuzzy about fuzzy set theory!) in which vague conceptual phenomena can be precisely and rigorously studied"[60].*

Klir et al. defined *it as follows: "Fuzzy set theory allows each element of a given set to belong to that set to some degree"[61].*

The fuzzy set theory (FST) has a broad spectrum, but only selected functions were applied in the current research. In the current research it was applied trapezoidal and triangular fuzzy numbers as fuzzy membership function type. Fuzzification is used for qualitative criteria assessment, but the quantitative criteria are kept as crisp numbers. The fuzzy aggregation and normalisation methods have been applied in the current research. The application of the methods is introduced in chapter 4, which was dedicated to partner selection methods in VE.

2.2 TOPSIS method

Hwang & Yoon proposed TOPSIS (technique for order preference by similarity to an ideal solution), which is a multi-criteria method to solve a problem decision from a number of alternatives that also considers both positive-ideal (FPIS) and negative-ideal solution (FNIS) [62]. In a multi-attribute decision-making problem, the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [63].

The TOPSIS method is *"a technique for order preference by similarity to ideal solution from among multi-criteria models in making complex decisions and multiple attribute models for the most preferable choice"*[64]

It is necessary to execute eight steps in order to calculate by using TOPSIS method:

(1) FP organises and defines the evaluation criteria for partner selection;
(2) Selecting the linguistic variables for the calculation of criteria importance weights and the linguistic ratings of partners for qualitative criteria;
(3) Aggregation of criteria weights to obtain the aggregated fuzzy weight $\hat{w}_j$ of criterion C_j, and calculation of the decision-makers' ratings to determine the aggregated fuzzy rating x_{ij} of partner A_i under criterion C_j;
(4) Construction of the fuzzy-decision matrix and the normalisation of the fuzzy-decision matrix;
(5) Construction of the weighted normalised fuzzy decision matrix;
(6) Determination of the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) parameters;
(7) Calculate the distance of partners from FPIS and FNIS, respectively;

(8) Closeness coefficient (CC_i) calculation for each partner; Closeness coefficient simultaneously represents the distances to FPIS (A+) and FNIS (A–) by taking the relative closeness to the FPIS.

The mathematical form of the described steps has the following sequence:

Assume:

Committee of decision makers $F = \{F_1, F_2 \ldots F_K\}$;

Possible partners $A = \{A_1, A_2 \ldots A_m\}$;

Criteria $C = \{C_1, C_2 \ldots C_n\}$;

The performance ratings of A_i (1, 2…m) with respect to criteria C_j (j=1, 2…n) have $\tilde{X}$ matrix view:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots \tilde{x}_{1n} \\ \tilde{x}_{12} & \tilde{x}_{12} & \ldots \tilde{x}_{12} \\ \tilde{x}_{12} & \tilde{x}_{12} & \ldots \tilde{x}_{12} \end{bmatrix} \tag{2.1}$$

Aggregated fuzzy weights $\tilde{W}$ have the following view:

$$\tilde{W} = \left[\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n \right], \tag{2.2}$$

The normalised fuzzy-decision matrix is presented as:

$$\tilde{R} = \left[\tilde{r}_{ij} \right]_{mxn}, \tag{2.3}$$

where $\tilde{R}$ is the normalised fuzzy matrix with elements $\left[\tilde{r} \right]_{mxn}$, i= 1,2,…,m, j=1,2,…,n.

The weighted normalised matrix considers the different importance of each criterion:

$$\tilde{V} = \tilde{v}_{ij \; mxn} \tag{2.4}$$

where $\tilde{v}$ is the normalised weighted element of the fuzzy-decision matrix i = 1,2,…,n and j = 1,2,…,m

$$\tilde{v} = \tilde{w}_j(\cdot)\tilde{r} \tag{2.5}$$

Accordingly, to the weighted normalised decision matrix, normalised positive numbers can also approximate the elements $\tilde{v}_{ij}, \forall i, j$. Then, (FPIS, A^+) and (FNIS, A^-) are defined as:

$$A^+ = \tilde{v}_1^+, \tilde{v}_2^+, \ldots, \tilde{v}_n^+ \tag{2.6}$$

$$A^- = \tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^- \tag{2.7}$$

where, $\tilde{v}_j^+ = \max_i \{v_{ij}\}$ and $\tilde{v}_j^- = \min_i \{v_{ij}\}$, i = 1,2,…,n and j = 1,2,…,m.

The distance of each partner from A^+ and A^- can be calculated as

$$d_i^+ = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^+) \tag{2.8}$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \tag{2.9}$$

where $d_v(\circ,\circ)$ is the measurement of distance between two fuzzy numbers.

The CC_i is defined to determine the ranking for all possible partners once the d_i^+ and d_i^- of each partners A_i(i = 1; 2; . . . ;m) have been calculated. The CC_i of each partner is calculated as:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad i = 1,2,\ldots,m \tag{2.10}$$

It is clear that $CC_i = 1$ if $A_i = A^+$ and $CC_i = 0$ if $A_i = A^-$. In other words, supplier A_i is closer to FPIS (A^+) and farther away from FNIS (A^-) as CC_i approaches 1.

2.3 Analytic hierarchy process method

Analytic hierarchy process (AHP) is a method for the classification and ranking the alternatives; Saaty developed this method in 1973 [65]. This method is easy to use for practical tasks, which is one reason why it is widely used and successfully implemented in different applications and tasks [66]. The principle of the method functionality is based on *"pairwise comparisons to establish relations within the structure"* [67].

Various researchers have provided different interpretations of the AHP method:

"AHP is an excellent approach that can be used in multifactor decision-making environment, and especially when subjective and/or intuitive consideration has to be incorporated. AHP provides a structured approach for determining the scores and weights for the multiple criteria used and standardises them, so that they can compared and decisions made"[68].

"The Analytic Hierarchy Process (AHP) provides a general theory of measurement for expressing both tangible and intangible factors. Intangible or qualitative factors are looked upon as dimensions. Through a redundant paired-comparison process. AHP translates qualitative preferences into ratio scaled data. In addition, the structuring stage of AHP facilitates problem understanding" [69].

The AHP method consists of four main steps:

- Hierarchy definition. The problem must be described in the hierarchy structure. The goals to be achieved or the problems to be solved must be introduced as a tree structure. Then, the criteria must be defined and the alternatives goals have to be introduced. The hierarchy tree allows us to divide the complex problem into parts.
- Priorities determination. It is necessary pairwise to compare the criteria that will be used for the alternatives selection. As a result, the priority matrix will be obtained.
- Alternative comparison. It is possible to compare alternatives based on each criterion if the relative importance of each criterion is known. The next step is to compare alternatives with each criterion when the prioritising of the criteria is obtained.
- Decision-making. It is possible to obtain criteria grades when the comparison results are completed.

Saaty proposed *"a scale of absolute numbers used to assign numerical values to judgments made by comparing two elements with the smaller element used as the unit and the larger one assigned a value from this scale as a multiple of that unit"* [42]

2.4 Pugh matrix

The Pugh matrix was developed by Professor S. Pugh and was first introduced in 1991 [70]. Typically, the matrix assists in making a decision from the number of alternatives by comparing with a baseline. The matrix is used by a group of decision makers when they make a selection from various possible solutions.

Goel defined Pugh matrixes as *"particularly useful for integration of multiple processes as well as selection of tools and technologies"* [71].

Muller et al. define a Pugh matrix where *"the concepts defined as one axis and the criteria on the other axis. Every field of the matrix contains an assessment of that specific concept for that specific criterion. This basic concept can be extended by adding weights per criterion"* [72].

2.5 Risk analysis

Vieira et al. [73], [74] suggest a comprehensive method of risk assessment that is based on historical key performance indicator (KPI) values and is calculated by ETA (event tree analysis). In the current research, historical data for the rating of partners according to several criteria for the calculation was used, which already decreases the risks of project implementation. The main question for risk minimisation is – how can we divide the orders between the enterprises? If all partners that have responded to quotations have the same competencies [75], one possible solution is to divide the tasks between the candidates in proportion to their PEI.

Based on research by Riives et al. [76], risk management is applied in an SME network. The risk categories that have to be taken into account are defined as follows: *"quality risks, delivery accuracy risks, risks of cost management"* [76].

The collaborative network is a complex system and it is never completely predictable, even if the working principles are known. Managers should be prepared to deal with the unexpected events that complexity most certainly will bring forth, and they should be able to correct any deviation from the planned course of action as soon as possible. To achieve this kind of error-based regulation, they should not try to predict or determine the behaviour of a complex system, but instead be prepared for the most probable scenarios. Complexity is an important criterion in the selection of an appropriate organisational form and input for the project [III].

In the current work, the partners are classified by III groups depending on their PEI. The main goal and focus on risk management is to diversify the project tasks, and therefore minimise a project, FP and customer risks in the process.

2.6 Used tools

The thesis uses several tools to describe the business process and to design the network of SMEs. This section gives a brief overview of the used tools. Many alternatives exist to solve similar objectives, but the tools have been selected in relation to availability for the current research. There is no need to compare the proposed tools with similar functionality tools, since they are only used to support, describe and visually represent the proposed framework.

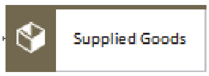
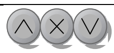
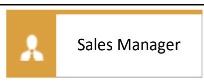
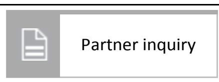
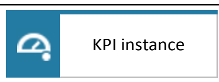
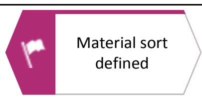
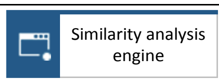
2.6.1 BPMN

Business Process Management Notation (BPMN) is considered suitable for process modelling for IT users while EPC/VAC is for business users. From a business perspective, the BPMN and UML are too complex for business users and considered too IT-related to model all aspects that need to be described. In addition, the BPMN proposes swim lane type models, while customers prefer an approach that is not swim lane based.

2.6.2 Event-driven process chain (EPC)

The event-driven process chain (EPC) is a modelling technique for the description of the business process [V]. It is widely used by industry companies for business processes modelling of the value chain. EPC represents logical dependencies of activities in the business process. The representation of the business processes is a first step in the development of an IT system for the SME network in the thesis.

Table 2.1. EPC objects used for business process modelling in PN organisation

Symbol	Name / Description
	Product/Service – illustrate process inputs and outputs
	AND, OR and eXclusive OR (XOR) predicates
	Role or Person type – describes the responsible role
	Value Added Chain – name of sub processes
	Document – document used in the process
	KPI (Key Performance Indicator) – KPIs related to the process or sub–process
	Event – occurs before and after process steps and activities
	Application system – relation to system or application

2.6.3 ARIS

ARIS is a tool that supports several process modelling notations, including "IDEF family, value added chain diagrams (VAX), UML modelling notation, BPEL, BPMN, and others" [109]. Different companies have different approaches in ARIS (e.g. LEGO System A/S, Fortum Heat and Power, Statoil, Vestas Wind

Systems A/S), but there is no rule-set that has been previously developed for building up models in ARIS. The framework proposes to use the developed modelling approach, which enables one to document the organisational structure in regard to the corresponding roles and processes with inputs and outputs that are associated with certain documents. From a process modelling perspective, ARIS is a tool that supports several process modelling notations including BPMN, EPC/VAC and others. There was consideration between BPMN and EPC/VAC. From a business perspective, the BPMN and UML are difficult for business users to understand and are considered too IT-related to model all aspects that need to be described. The BPMN proposes swim lane type models, while customers prefer an approach that is not swim lane based [84].

2.6.4 IDEF1X – Data modelling method

"IDEF1X is used to produce a graphical information model, which represents the structure and" [77] *"semantic data modelling"* [78] *"within an environment. Use of this method permits the construction of semantic data models, which may serve to support the management of data as a resource, the integration of information systems, and the building of computer databases"* [77].

"The technique is used to model data in a standard, consistent, predictable manner in order to manage it as a resource" [77].

2.7 Review of partner evaluation and selection approaches

Lately, there have been many mathematical methods and techniques developed based on qualitative or quantitative factors for the selection of partners from alternatives. This section reviews the most widely used techniques in literature. The extensive study of the problem shows several directions for partner selections in multiple criteria decision-making. Different mathematical methods are used in techniques, such as *"analytic hierarchy process (AHP), analytic network process (ANP), case-based reasoning (CBR), data envelopment analysis (DEA), fuzzy set theory, genetic algorithm (GA), mathematical programming, simple multi-attribute rating technique (SMART), Lagrangian relaxation and their hybrids"* [50]. The techniques are classified in two main directions: quantitative perspectives and qualitative perspectives.

Quantitative techniques evaluate factors such as price, time, distance, profit and use trivial arithmetic calculation. They lead to the appropriate result seen from a financial perspective, but not necessarily the best solution from a manufacturing or customer point of view [79].

The second direction of the partner selection methods deals with the qualitative perspective and considers quality, skill, flexibility and competence as criteria. In practice, qualitative decision-making is based on the subjective impressions of the decision maker. Usually, it is not a fact-based decision, but it employs an intuitive human judgment and existing relationships between companies. In some cases, even the decision maker itself has difficulty with clarification of the decision made. Qualitative partner evaluation deals with multi-criteria, uncertainty and data fuzziness that require the use of mathematical tools that must take these facts into account. The fuzzy set theory is applied in this case. There are a variety of related frameworks dealing with the fuzzy theory issues that support cases where uncertainty has taken place.

A combination of qualitative and quantitative perspectives should be considered in order to make the selection process more feasible and applicable for focal players in the current research [80]. There are methods that help the decision-maker to consider both qualitative and quantitative criteria in calculations. *"The methodology uses fuzzy QFD (quality function deployment) to convert qualitative information into quantitative parameters and then combines this data with other quantitative data to parameterise a multi-objective mathematical programming model"* [81]. There are developed methods that only consider specific problems or are limited to a particular area. Talluri developed a method for selecting a partner in a formation of a VE, which uses two-phase mathematical programming approaches for efficient partner selection [82]. O'Brien applied an integrated approach for AHP and linear programming, which considers both qualitative and quantitative factors in selecting the best suppliers [83].

The integration of AHP, fuzzy theory based method, TOPSIS and Pugh matrix is used in this research work, which helps to make the best partner selection process feasible and sophisticated in the scope of the partner network.

Other authors combine the existing supplier selection methodologies and adopt them for PN needs. For this purpose, the author suggests developing the PEI in order to consider qualitative and quantitative perspectives for making the selection process more feasible and applicable for FP.

Table 2.2. Summary of AHP, TOPSIS, Fuzzy methods integration

References on implemented approaches	AHP	TOPSIS	Fuzzy
[84–88]	X		X
[89–92]	X	X	
[93–95]		X	X
[96–98]	X	X	X

In order to discover the possible accomplishments of the methods combination, the results of the literature review are summarised. As shown in Table 2.2, the combinations of methods are found for different tasks implementation and realisation. The combination of all three methods was applied in this thesis in order to implement tasks selection for multi-criteria decision-making.

The combination of methods is suited to multi-criteria decision-making, but these methods have to be extended and consider the overall partner rating, the number of transfers between the partners and the allocation of the work between the partners based on partner reliability.

3 PARTNER SELECTION FRAMEWORK FOR VIRTUAL ENTERPRISE FORMATION

The development of a partner selection framework is the main goal of this research. The suggested framework organises a set of ideas and facts that provide the partner network structure, as it is introduced in Figure 3.1.

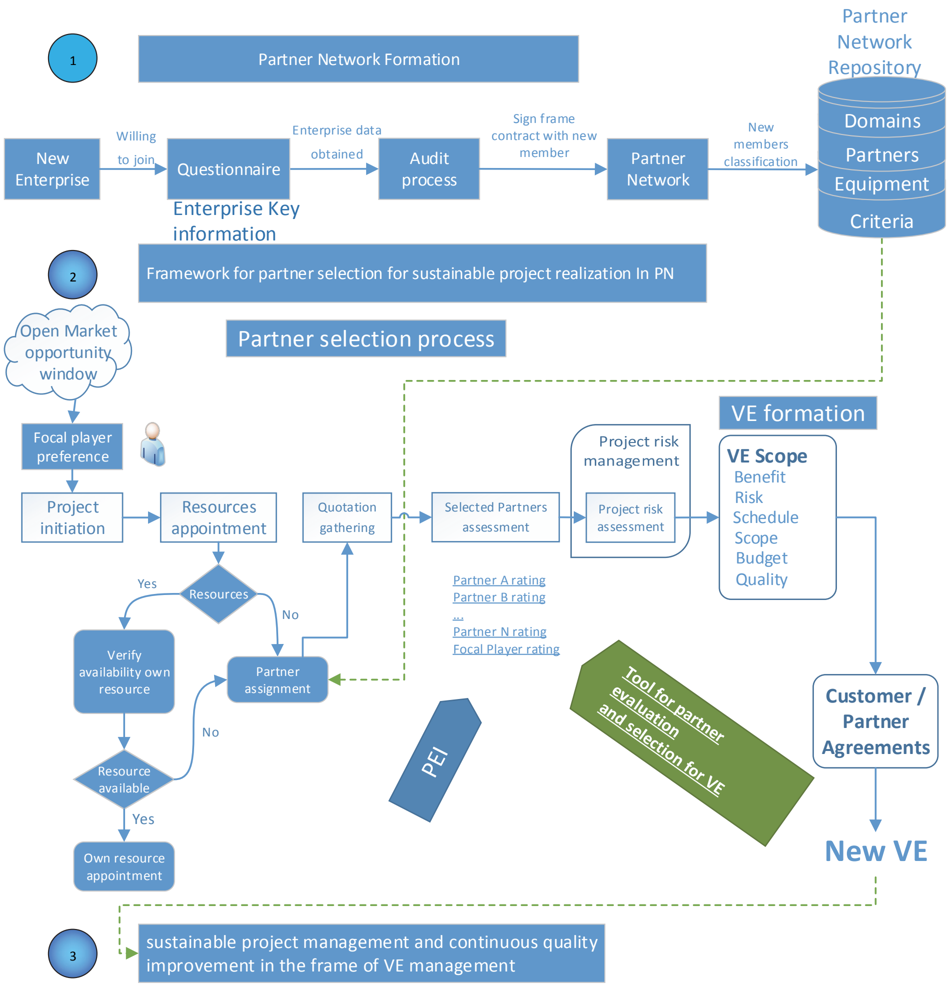


Figure 3.1. Partner selection framework

The VE is formed around the Focal Player (FP), which is the company that brings the business opportunity and acts as a general project manager [14].

"The companies that in current phase mainly do not have ambitions to dominate in the goal oriented PN, could be considered as satellites with lower network maturity index. Mostly their main goal of such partners is to add only minor

subcontracts from PN to the orders from existing customer base, in order to retain or to increase the current turnover" [14].

The network value creation occurs based on objectives and participant interactions within PN. The win-win principle is underlined in PN formation. The benefits are seen for both the individual company and collaboration transactions. There are several reasons behind involving a single SME in PN:

- Get access to the new markets. Collaboration with partners from different regions (incl. countries, continents, etc.) opens access to new markets for the partner. Sharing information inside PN gives an overview of domestic market requests, demands and opportunities. It is easier to enter a new market through activities performed together with a collaborative partner and to share some expenses together.
- A company focuses on its core activity. A company that is a member of a PN does not need to have all the processes and resources ordered for the production of a particular product or all the resources required for project realisation, if these processes or resources can be covered by partners in the PN.

- Companies in PN leverage *"their competitiveness in production and new product development and launching new technologies access and knowledge share among supplier, customer and competitors" [99].*

"Any cooperation is based on an explicit agreement that also specifies a time horizon for the existence of the network. The participation in the strategic network is voluntary and any member may quit according to the rules specified in the agreement. Each partner keeps its legal independence. A necessary prerequisite for any cooperation is the ability and willingness of each partner to adapt his services and business to the requirements of the collaboration network" [9].

As an evolution of the PN concept, a new organisational structure for an alliance of SMEs, named sustainable partner network (SPN), has been introduced in the current thesis. SPN is regarded as being a particular case of VBE [13], which is a kind of business community composed of organisations that come together in preparation for rapidly responding to business opportunities. Sustainable means *"mutually beneficial interactions in which constituents (internal and external) share knowledge, resources and expertise"* [100] and maintaining the network in a healthy state. SPN is a domain-oriented structure (business area) that consists of standardised business processes. SPN is created according to the common business process template (BPMN based), which is apparent to all participants. In the following part of the thesis, the SPN definition is used as an SME network organisation.

3.1 Sustainable partner network formation

Many SMEs exist in the marketplace and this idea of research is to combine their resources to increase capacity. Usually, a SME has limited resources for development and the SPN environment provides an opportunity to overcome this limitation. A new candidate must go through a set of stages of maturity levels in order to become an accepted member of SPN. The stages of company maturity are introduced in Figure 3.2.

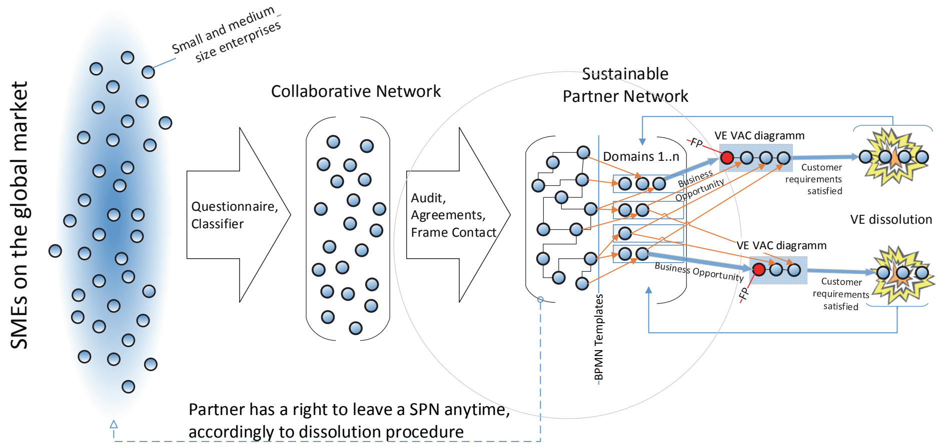


Figure 3.2. Sustainable partner network formation

As can be seen in Figure 3.2, the first step is the preparation of candidate enterprises to join a SPN. In order to be able to join a SPN, the candidate fills in a questionnaire in which the company provides initial data for classification in the SPN repository. The second step is auditing of the candidate. The third step is the signing of the contractual framework and service level agreements (SLA). After the new business opportunity is developed, the fourth step is the initiation of a VE (Virtual Enterprise), which is described as a VAC (Value Added Chain) of a collaborative project by FP (Focal player) [VII].

The first two stages are controlled by a SPN managerial legal entity, which is called partner network managerial office (PNMO). The main obligations of the PNMO are [V]:

- represent the SPN members in meeting with customers;
- measure the SPN members KPIs;
- ensure the information channel for SPN members for the exchange of agreed information;
- support the joining of new members and SPN members drop off organisational processes [V].

VE formation is initiated by a company from the SPN and the initiator recognised as the Focal Player (FP). Focal player (an enterprise or entity with a business opportunity) may combine VE planner [13] and project manager roles [80]. The FP can outsource certain roles (ex. VE planner, project manager, etc.) to other participants with the required competence, but the initiator still remains the FP. The FP is not a single role but rather an actor that can play several roles associated to the SPN and VEs:

- Broker (acquires business opportunities and brings them to the SPN)
- VE Planner (plans/designs the VE)
- VE manager or coordinator (manages the VE during its operation)

In addition to tasks performed previously by the VE planner, FP puts together the value added chain (VAC) diagram of VE, selects the criteria for partner assessment, carries out a PEI calculation for partner selection and is responsible for project initiation and realisation. FP identifies a business case (a tender) from which it could receive benefits with the involvement of its partners. In most cases, it has less than two weeks to make a proposal to the customer, which includes the financial elements, content explanation, delivery dates, etc. Due to this time restriction upon identifying a business case, the FP must identify from SPN the companies that have the required machinery, competences, services and capacities; then a decision is made on which companies are invited to collaborate in the project. Even after these companies are identified, there will be further discussion about responsibilities, VAC and the sharing of risks, costs and income, how to give guarantees to the customer, etc.

In most cases, the SPN operates on a project-based environment. Due to the fact that each project is different, the FP spends a significant amount of time on different kinds of negotiation. After all negotiations are completed, the formal agreement is signed. Since the finalisation of agreements takes time, there will also be lost opportunities due to the lack of time to agree internally all required aspects or to combine them together as a financial proposal for the customer. The SPN network is established in order to minimise such kinds of time constraints. Agreements are signed in the phase of forming the initial frames, which aids in ensuring smooth cooperation in the phase of financial proposal preparation, which also includes the principles of sharing the risks, costs, profits and warranties.

Still, there are a lack of adequate concepts and tools for ensuring the effectiveness of integrating partners in SME networks as well as partner profiling to support the initiation of collaborative networks in terms of standardisation, comparableness and consequently transparency of potential partners' business performance concerning their products and processes. In order to accelerate partner selection, a system for data collection can be introduced as a mechanics, in which partners could publish their business cases and from which partners can cover the needs for additional competences/resources that are required to form a VE [VI].

3.2 Model of collaborative project establishing

The model for collaborative project realisation for SMEs is depicted in Figure 3.3 [V].

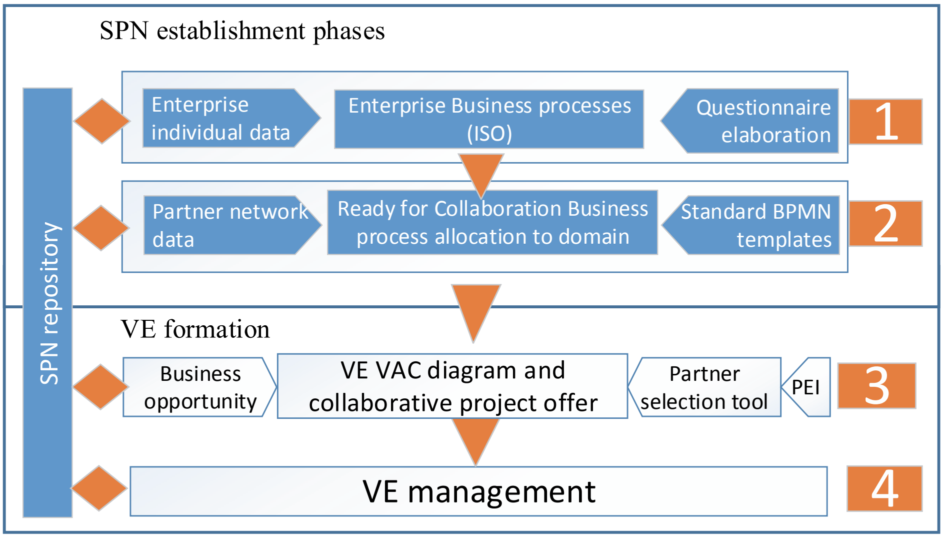


Figure 3.3. Conceptual model for the collaborative projects realisation

The conceptual model consists of four steps:

Step1. Preparation of candidate enterprises to join a SPN. In order to be able to join a SPN, the candidate enterprise fulfils four sub-steps [V]:

a. Filling in the questionnaire. Based on the questionnaire, it is decided in which area enterprises provide services (related to the business processes of an enterprise) and the enterprise data is added to an appropriate category [V].

b. Passing a SPN audit that measures organisational maturity. Organisational maturity means that an enterprise describes its business processes based on quality standards (e.g. ISO, eco-management and audit scheme (EMAS)) [101] requirements as BPMN or event process chain (EPC) models [V].

c. Signing of a contractual agreement or service level agreement (SLA) [V].

d. Filling in the forms for enterprise data transformation towards SPN database tables pertaining to machine centres and their availability [V].

Step 2. Development of standard templates for a new partner and description of business processes ready for collaboration. A partner adopts the proposed templates for their own business process and integrates them into SPN. The adopted business processes are saved in the SPN repository and they are used for the establishment of collaborative business processes. If necessary, the ready for collaboration business processes can be easy plugged in a new VE.

In order to assess the enterprise readiness to join a SPN, the maturity of a collaborative business process and the processes of data collection for SPN are audited by independent experts once the enterprise business processes are mapped in the collaborative business processes of SPN. The input to collaborative business processes is updated automatically [VII].

Step 3. Collaborative Business process VAC diagram description and the Partner Efficiency Index (PEI) calculation. Based on the business opportunity, FP describes the VAC diagram of the collaborative project and calculates the partner efficiency index (PEI). PEI enables the selection of optimal partners based on a partner selection tool and supports the measurement of collaborative business-process efficiency. The SPN establishment and the creation of the PEI process consists of two sub-steps [V]:

The initiation of collaborative projects consists of the preparation of a collaborative project offer, VE formation and an agreement development process. The steps of the collaborative project (CP) address the preparation and partner selection for VE formation. Then a request for a new quotation is received, FP selects the required domain, defines the project steps and describes the production route (as in the case of manufacturing). Next, the FP defines the routing operations for which selects suitable partner based on resource specifications and resource availability data. The Fuzzy Processing mechanism calculates the PEI for each operation of the production route and is presented by a candidate partner. Subsequently, it follows a similarity analysis in order to manufacture the product sub-assemblies in one location. The AHP methodology is used for a pairwise comparison of the project price and time importance prior to the final calculation of the PEI for possible partner enterprises. Final step is agreements elaboration for VE formation. After all stages of setting up a VE, the candidate partners receive offers from a FP. The FP sorts the candidate list based on a combination of previous experience of collaboration within a SPN and a PEI. After confirming the candidate partner's proposals by the FP, the VE formation takes place. The FP calculation uses data received from the proposal, the SNP repository of the candidates and finally sends the results as a proposal to the customer. After acceptance of the proposal by the project customer, the customer and the FP sign the contract. After that, the FP and the selected VE partners sign the VE contracts [V].

Step 4. Sustainable collaborative project management. After the VE starts, it is important to provide an appropriate environment for successful implementation. This environment enables the tracking of project progress, based on input data that VE members submit [V].

3.2.1 Recruitment of new enterprises to sustainable partner network

An initial process for SPN formation is a partner business processes description and allocation to the appropriate domain. A new member is involved in SPN strategic goal achievement through participation in SPN projects.

Functional competence is a description of how partners could support the Life Cycle of the products in the network in which they are aiming to do so. A functional competence is described as a solution type addressed by the competence, the resources and capabilities it is composed of and how robust it is in the terms of agility and sensitivity [V].

A partner's ability to enter into and participate in VEs. Two basic elements include the partner's ability to manage and develop groupings and to display alliance spirit and behaviour [VI].

The maturity of the potential partner information systems is an important issue that should be considered during the joining process. Is the company able to use or integrate its applications to SPN and is the new member ready to share the type of information to which FP wants to give access?

Additional aspects that should be considered in relation to new unknown partners are their trustworthiness, values, visions, used terminology, etc. In parallel with the partner selection or as an element of assessing potential partners, some initiatives could be taken concerning establishing and ensuring that the partners have a shared goal hierarchy, i.e. mission, vision, strategies and objectives [102],[VII].

3.2.2 Partners evaluation in network

A new member fills a preliminary questionnaire in order to provide the initial data and to fulfil basic requirements for SPN members (the developed questionnaire is introduced in appendix part A. The questionnaire embraces information about the company and its key information items (Figure 3.4).

The required information does not include any data that should be treated as confidential or secure from the company viewpoint. At the same time, the information describes viable aspects of the company that are sufficient to evaluate the company's contribution to potential collaborative projects in the SPN. The research that has been done within the framework of the current thesis revealed the key information items. They was split into several groups:

- Company business objectives. This information is necessary to understand the purposes of the company and their expectations in SPN.

- Described organisational processes. The described processes represent an important issue, since they give the possibility to plug the company processes into the VAC diagram of a VE when the company starts a collaborative project within a short period.

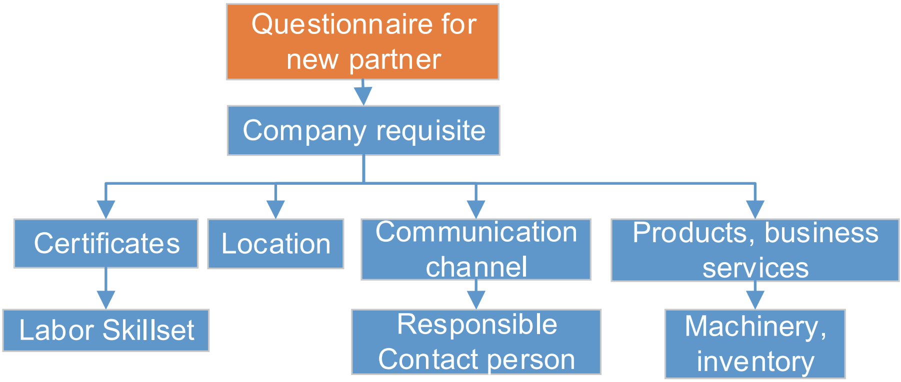


Figure 3.4. Company key information items

- Communication channels provide information for communication with a partner within the framework of a collaboration network and contacts and response channels in a partner enterprise.
- Company capacity and capability. The partner resources that they are able to share with the SPN.
- Company certificates, achievements, etc. This information is used in order to define the partner maturity, partner reliability and the information about the developments in the company.
- Previous experience in virtual enterprises. This information is used to estimate the efficiency indexes and reliability of the partners sharing information related to previous project experiences and provide important initial information when commencing subsequent projects.

3.2.3 Audit process

A new member-auditing step follows the key information items definition. A company tutor implements this step. The company tutor is a fully accepted member of the SPN. After the company is a fully accepted as member of SPN, it becomes a tutor and then it is able to invite new companies. The aim of the audit is to verify the company against the introduced information in key information items. The tutor should validate the information in the questionnaire. *"Sufficient samples are taken to ensure all requirements are addressed. This includes performance monitoring, measuring, reporting and reviewing against key performance objectives and targets"* [103]. Initially, a company tutor is responsible for the invited companies, their adaptation and integration to the SPN against the rest of the partner network managerial office (PNMO). The process is intended to smooth the inaccuracies that have taken place during the evaluation process and to clarify the details of cooperation principles to the new members.

When the audit process is completed, the frame contract is signed, in which the details of SPN principles are defined.

The aim of the enterprise audit is to prepare potential business partners for joining SPN. The audit process is the first and unavoidable step for a new enterprise. This important process helps verify new member information and make this information available for existing SPN members. The audit is established in order to collect more information related to the new member and to prescribe what should be done before the new enterprise can be accepted as an SPN member. After the audit is completed, the information related to the new member possibilities, capacities and its core activities will be added to the virtual environment. The purpose of the audit is to assess the following enterprise information items [XI]:

- Management (Strategy, outlook for the future, organisation chart, management review);
- Partnership management (the determination of needs and fulfilment of SPN requirements);
- Personnel (resource management, competence, certificates);
- Quality system (quality management, quality policy, quality objectives);
- Risk management;
- Production facilities (shop floor, storage, working environment);
- Machines and tools (condition, storage of the tools and maintenance);
- Purchasing (supply policy, supplier selection);
- Production (audit of management systems and dataflow);
- Logistics (shipping procedure, stock);
- Processes (process description, supporting processes, process metric);
- Metrics (on-time-delivery per customer, internal audit, monitoring and measuring of lead time);
- Environmental management [XI].

The audit of the management system and dataflow is made to prepare the process of information synchronisation between SPN members. The main goal of this audit is to analyse the existing management and to support the information system (IS) of the potential partner enterprise, followed by introduction of the Web Services approach. There are many management systems (ERP systems, MS EXCEL, etc.) that can be used by SMEs and appropriate Web services messages should be selected for fast and safe communication within the SPN members. The system supports collaboration in the traditional way with possibilities of automatic exchange of messaging between partners, and directly between VE partners. The SPN data exchange structure document is available for the new and existing members of SPN [XI].

3.2.4 Process modelling in sustainable partner network

Conventional process modelling approaches focus on the sequence of processes, but the current research thesis is innovative and directed to organisations that operate in a SPN. Organisations that participate both in SPN and VE have their own goals, indicators, processes, organisational culture and maturity level (e.g. estimated based on capability maturity model integration, lean six sigma). Therefore, the thesis considered EPC/VAC notations based on the 4+1 level approach for SPN business process modelling:

1. Enterprise Process Map Value-Added Chain (VAC) model
2. Process level VAC model includes Sub-Procedures
3. Sub-process level Event Process Chain (EPC) model includes Activities and Responsibilities
4. Activity level EPC model includes operations
5. Level or IT Application views related to IS integration

Kangilaski et al. introduce the principles of the internal process description. In the research, the approach of modelling product/service process, which companies brings to the market, was detailed [VII].

In order to motivate the SPN members to describe the existing business processes, the PNMO suggests working out the best practice business process templates for the particular domain. The purpose is to simplify and speed up the ISO 9001–2015 certification for newcomers, support the dynamic improvement of production quality systems and enhance the current business process maturity for already certified SME partners. The maturity of internal business processes will also enable the enterprise to be more efficient in a partner network.

First level CPM business process VAC diagram

The collaborative business process starts from *customer enquiry*, which is the input to the *Marketing* process. The latter process results from *Order data*, which is input for the *Sales* business process [VIII]. *Order specification* is the output of the *Sales* business process and is an input of the *Design* business *process*. It generates the service/material specifications that are consumed by the *Purchase* business process and results in *Technical assignments* that are used by the *Manufacturing* business process together with the *Technical documentations and semi-finished goods* delivered by the *Purchase* process. The *Manufacturing* business process generates *Financial and Shipment documents* consumed by the *Logistics* process. The output of the *Logistics* business process is *Supplied goods*, as shown in Figure 3.5. After the FP Company receives an inquiry from the customer, the project manager proceeds accordingly to the SPN business process.

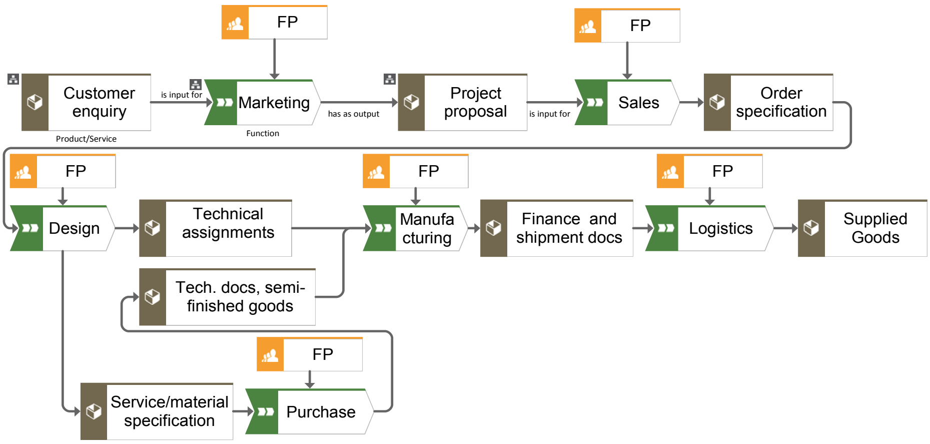


Figure 3.5. VAC Model of SPN Processes

Second level business process marketing VAC diagram

FP initiates the project planning process. During the proposal preparation, the FP decides to outsource the design and manufacturing of the metal frame parts of a conveyor. *The partner selection* function has to be undertaken to locate appropriate candidates in Figure 3.6.

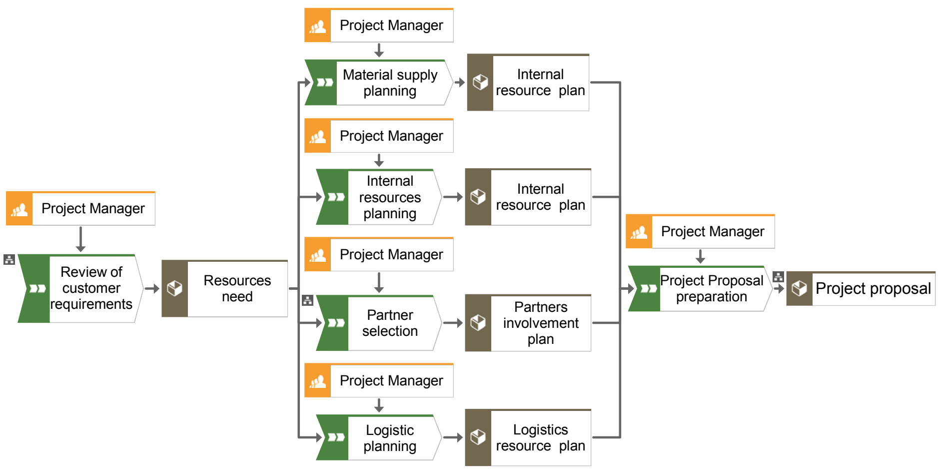


Figure 3.6. Marketing Sub-Process VAC Business Model

The second level VAC diagram documents the sub-processes with their inputs/outputs and the sub-process owner's managers (Figure 3.6). The *Marketing Process* starts from the *Review of customer requirements* business sub-process. The customer starts this sub-process by sending a quotation to SPN. The *Review of customer requirements* sub-process leads to *material supply*, *internal resources planning*, *partner selection* and *logistics* planning sub-processes managed by the *Project Managers* of FP or a partner organisation. The final step of the *Marketing process* is the *Project Proposal preparation* sub-process, which results in the submission of the *Project proposal* to the customer.

Third level review of customer requirements EPC diagram

When FP starts the *review of customer requirements* process, it is described at the third level by an EPC diagram.

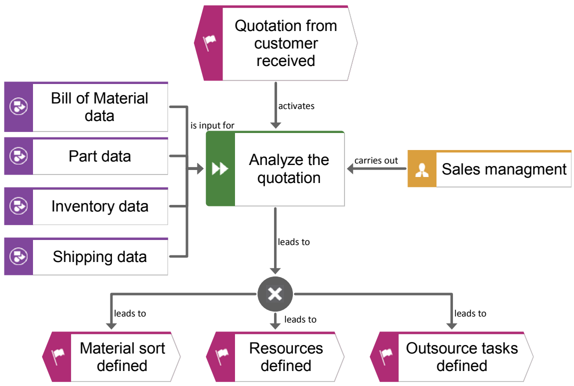


Figure 3.7. Project Planning Sub-Process EPC Business Model

The third modelling level is used to document sub-process steps and to determine their sequence. It shows where the process value is generated and where the external inputs are used. From an auditing perspective, it is convenient to show process steps where auditing actions should take place (tollgates). Each sub-process step is assigned to a certain role that identifies the managerial responsibility. That level is modelled by Event Process Chain (EPC) diagram models. The Analysis of the quotation EPC diagram is introduced in Figure 3.7. The *Review of customer requirements* sub-process is initiated by the set of documents received together with a customer quotation. The *Sales Manager* carries out the *Analysis of quotation* sub-process that leads to the *definition of Materials, Resources and Outsourcing needs*.

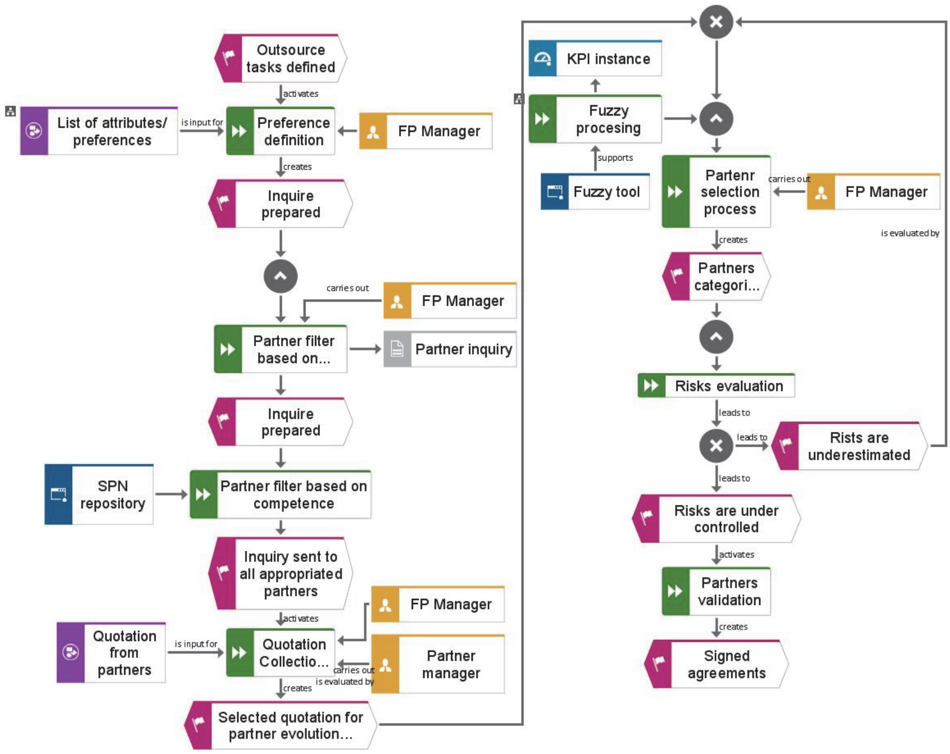


Figure 3.8. Partner Selection Sub-Process

The partner selection EPC diagram is introduced in Figure 3.8. The project is started from the *Outsource tasks definition* and the *Sales Manager* defines the particular project preferences for the partner selection purpose, followed by a similarity analysis and partner inquiries preparation. After the *Sales Manager* has received and verified the quotations, he starts *Fuzzy processing* in order to support the partner selection sub-process. After that, the *Sales Manager* performs the *Risks evaluation* sub-process and *Partner validation*, which results in signed agreements. The risk evaluation process supports FP activities with the purpose of minimising project risks.

Fourth level fuzzy processing sub-process EPC diagram

The operations that a decision maker of FP needs to perform are given at the fourth-level EPC diagram. The Fuzzy Processing sub-process diagram includes the operations required for partner assessment. In the current case study, the FP calculates the PEI index in order to assess the selected partners for the outsourcing of a conveyor design and manufacturing operation of the metal frames.

The fourth modelling level covers activities that include additional operations. This level is designed in order to show how certain sub-process steps are performed on a further detailed level, where the inputs/outputs are documents/products/services, related business rules, process participants, resources and IT applications.

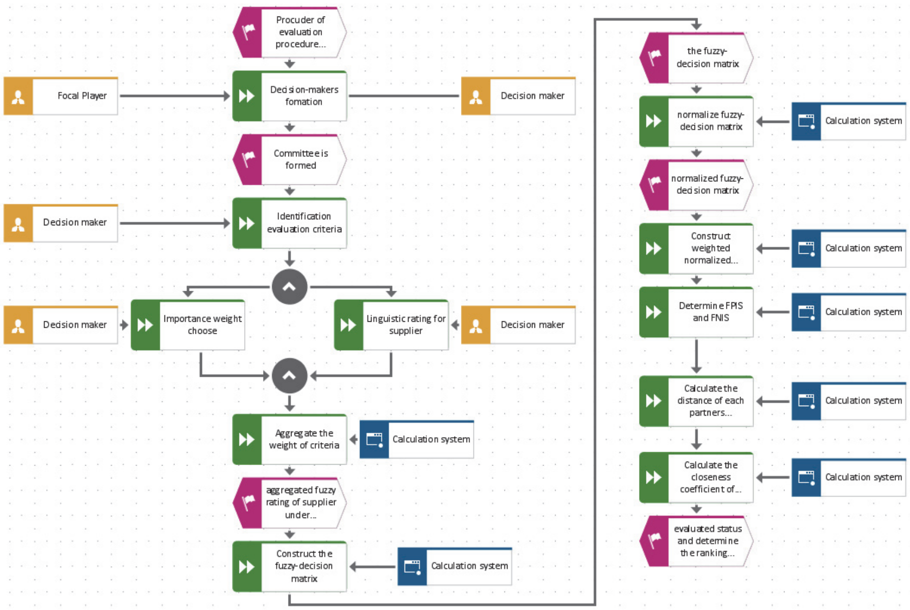


Figure 3.9. Fuzzy processing Sub-Process

Therefore, this layer is quite information intensive. Frequently, if processes are not simple, this modelling layer remains out of scope. However, if the modeller needs to add job descriptions for positions, then it is mandatory to model this level. The *FP* initiates the *Fuzzy Processing* sub-process and the formation of the *Decision-making* committee. After that, the committee performs *Identify evaluation criteria* for a particular project partner. *A decision maker chooses an importance weight* of each criteria and the *Linguistic ratio for Supplier* are activated and followed by the *Calculation System Aggregates the importance weight of criteria's*. The fuzzy logic based calculation system calculates the PEI used by decision makers for a partner assessment. Based on PEI calculation, the system defines the *distance of each partner* and the *closeness coefficient*. Based on this information, the FP ranks the partners as shown in Figure 3.9.

3.2.5 Sustainable partner network repository

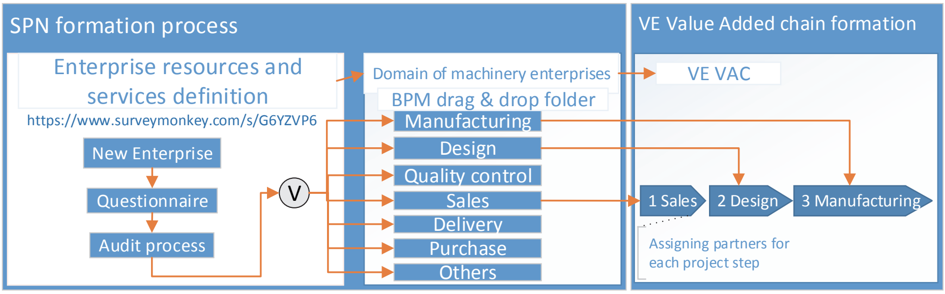


Figure 3.10. SPN formation process

SPN repository is a database that classifies the partners by categories depending on the company's capability and their role in SPN. Figure 3.10 illustrates the structure of the SPN repository. FP is able to use the category of the SPN repository in order to form the value chain for the VE.

The structure of the SPN repository is modelled by using the IDEF1X method (Figure 3.11). The purpose of the model is to design an informational project. The information model is divided into 2 layers. The first layer represents the SPN repository where the collected data about the partners, sources, domains, criteria and partner skills are stored. The SPN repository has a steady pattern and data are updated when each new member joins the SPN. The second layer represents data that are necessary for VE formation. The data are obtained from the SPN repository, partner proposals and customer requests. The purpose of second layer repository is to generate a VE structure and a final proposal for the customer in the shortest time and it also describes the participants' contributions in a VE.

The repository structure has been modelled in the ERwin Data Modeler (AllFusion) CASE (computer aided software engineering) system, which generates a programming code for several DBMS (database management systems) such as SQLserver, Oracle, MySql and others. A sample of generated code for SQLserver is presented in Figure 3.12.

The structure of the repository is shown in "Partner Selection Tool", which uses data from several objects (tables) for PEI calculation.

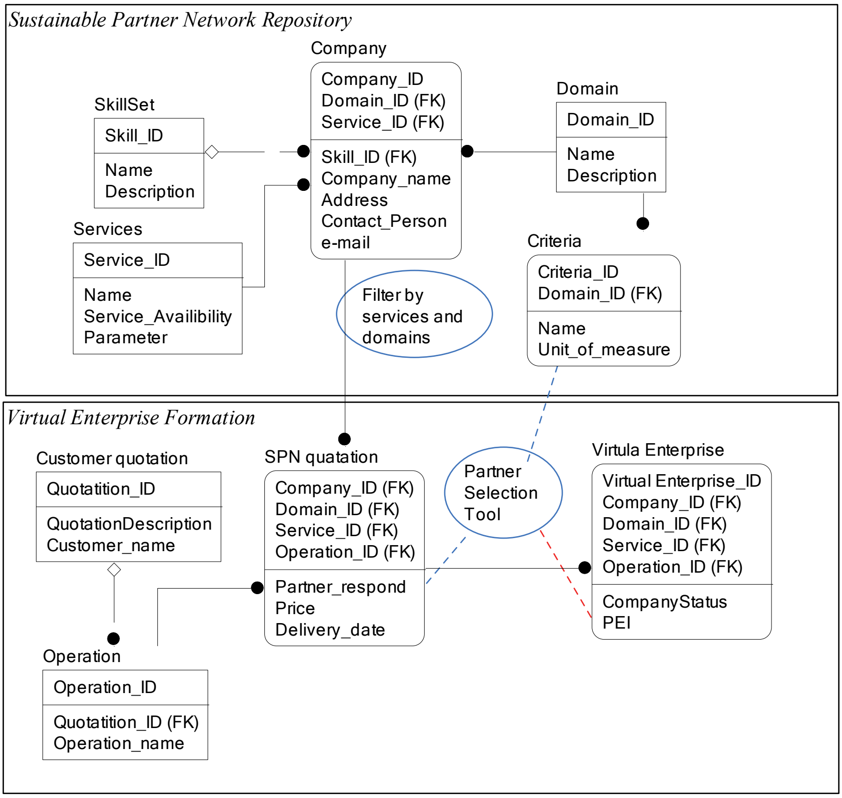


Figure 3.11. SPN repository data structure

```
CREATE TABLE Company
(   Company_ID  char(18)  NOT NULL ,
Skill_ID  char(18)  NULL ,
Service_ID  char(18)  NOT NULL ,
Domain_ID  binary  NOT NULL)
go
ALTER TABLE Company
ADD CONSTRAINT XPKCompany PRIMARY KEY
NONCLUSTERED (Company_ID  ASC,Domain_ID
ASC,Service_ID  ASC)
```

Figure 3.12. Fragment of programming code for DB table generation

The key attributes in determining relationships between the DB structure objects are shown in the DB tables. However, the number of attributes may be changed if a more detailed description of objects is required.

The partner audit phase ends with a description of the new member in the SPN repository and the determination of new member roles in the SPN. The roles are classified and they assist in allocate partners in the hierarchy of the SPN repository. Figure 3.13 depicts a sample of the SPN repository [V].

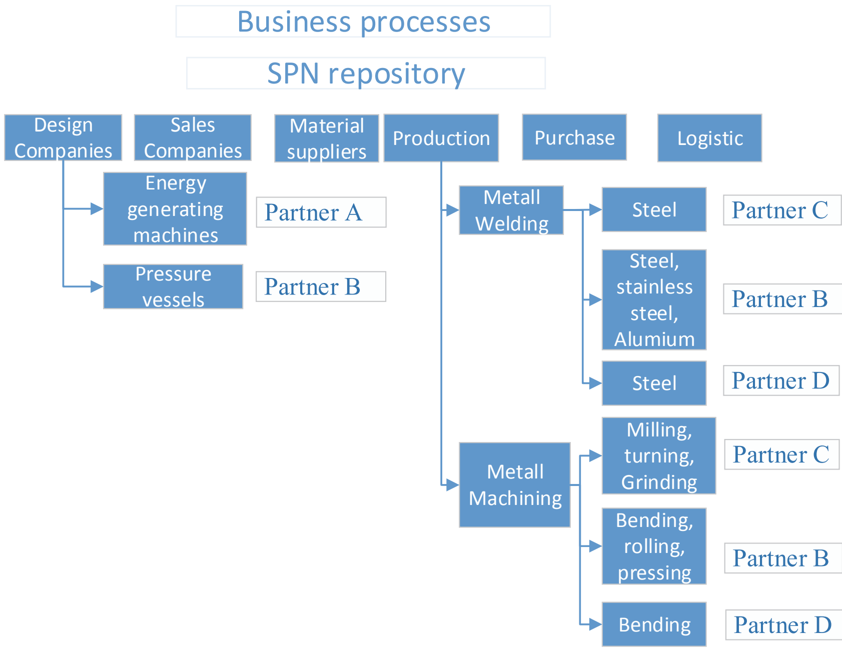


Figure 3.13. SPN repository [V]

A new partner might have several roles and provide a number of services for SPN. FP is able to evaluate a partner across several categories (as a designer, a producer, supplier, etc.) during a selection of partners for a VE, depending on the category to which the company belongs [V].

3.3 Virtual enterprise formation process

"Virtual Enterprise (VE) is a temporary alliance of independent companies that are formed to fulfil particular task or project. Building a VE means that the SPN members are initially recruited among the partners and are employed as subcontractors for the necessary tasks by companies in better financial and market position in their role as the general project managers. In case the needed competencies are not represented in a SPN or they are not of a sufficiently high quality, the external companies will be asked to participate" [104]. *"The procedure of VE formation based on SPN participants is given in Figure 3.14. Each partner fulfils a specific role, which is defined during the period of formation VE. The business opportunity identified by the FP or by a SPN Member will cause the necessity to start the project. In order to enable the FP to initiate new project, the companies belonging into the SPN have to exchange periodically information about their available resources and SPN should provide the information about the PEI, which is calculated based on the completed projects*

results. In case of a new comer the enterprise is assessed based on process maturities" [80].

"*Available resources give an overview to FP about the capability to participate in the project and PEI or process maturity gives an estimate about reliability and quality of their outcome. Based on its competence, the FP will analyse the business opportunity to find out whether it is worthwhile to launch a new project after which the FP will team SPN members for the project. This includes business planning, which leads to the development of an integrated business model including business concept (processes, communication, skills, resources, etc.) and financial model (flow of funds, responsibilities, compensation of participation). When VE is formed, the actual operation starts, which may range from design to manufacturing and retail. The successful accomplishment of the operation leads to the desired business impact, after which – unless there is a directly succeeding order – the project is terminated. The termination means the ending of the unique group of companies and their employees to make space for the next upcoming business opportunities"* [104].

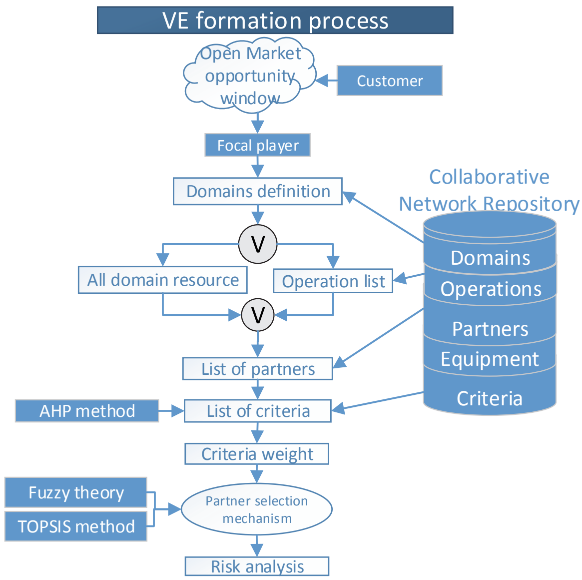


Figure 3.14. VE formation process

VE dissolves when the task is completed, but a VE lifetime might vary in duration from one month to several years, according to the type of project.

VE is an application domain in which MAS (Multi-Agent Systems) technology is appropriate, since they include the generic characteristics of complex applications and enable automatic data transfer between partners [105]:

1. *Distributed situation assessment, which emphasises how agents, with different spheres of awareness and control, should share their local*

interpretations to arrive at consistent and comprehensive explanations and responses.

2. *Distributed resource scheduling and planning, which emphasises how agents should coordinate their schedules to avoid and resolve conflicts over resources, and to maximise system output.*

3. *Distributed expert systems, which emphasise how agents share information and negotiate over collective solutions with their different expertise and solution criteria.*

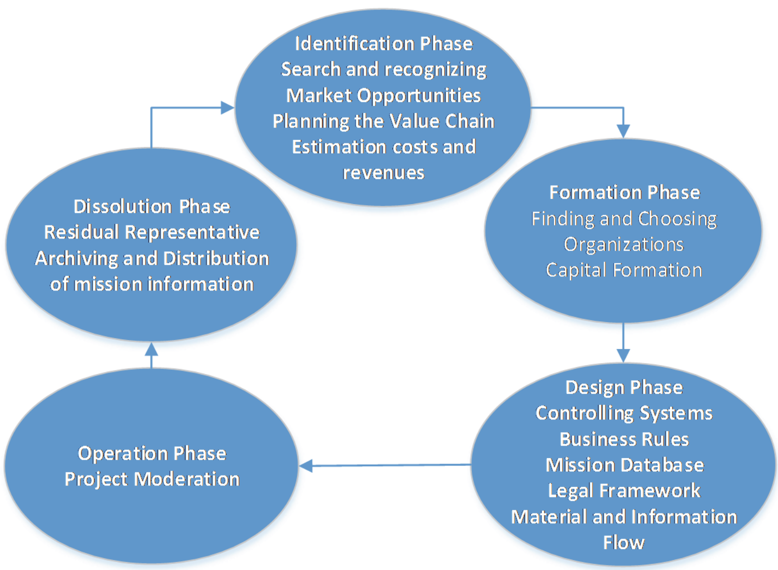


Figure 3.15. VE life cycle

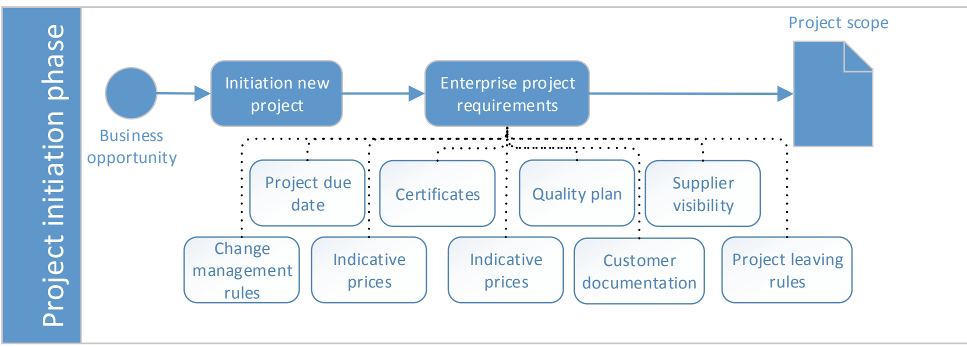


Figure 3.16. Project initiation

Description of VE organisation establishment process in SPN environment.

1. Project Initiation. Project initiation and definition of project requirements.

The project scope document is based on the following data: time, max indicative price (if applied), list of customer requirements (environmental, tolerances, dimensions, etc.), required certificates, customer documentation requirements, quality plan and rules to leave the project.

2. Project plan preparation. At the current step, the project is divided into several parts: own resources, collaboration with SPN partners, outsourced to external companies.
3. Searching for SPN partners.
   SPN company classification by domains helps narrow the search based on defined criteria: product description, functionality, working conditions (temperature, environment, field of usage).
   The suitable partners are discovered based on a partner selection tool, which verifies whether there is a partner in SPN that can fully cover the project needs (deliverables and project scope information). If not then, the partner with the highest similarity degree is suggested (e.g. a partner that can fulfil 70% of tasks). This process is repeated until all the tasks are fully covered (e.g. searching for a partner that can fulfil the remaining 30% of outsourced tasks).
4. Preparation of quotations to SPN. This process is semi-automated: partners are contacted automatically. In the event of a disagreement, the process is supported by FP until a consensus (on price, time, quality, and quantity) is reached.
5. Evaluation of proposals. This task is supported by the following parameters: PEI, delivery time, risk evaluation and mitigation activities, price, list of deliverables covered and quality plan.
6. Project proposal forming. Based on the collected data, the full project proposal is prepared. The following data are taken into consideration (time, budget, risk, list of deliverables, subcontracted tasks scope, quantities.). ISO 21500 or PMBOK [106] has been used to define the VE data for project initiation.
7. Submitting the project proposal to the customer. The project proposal is sent out to the customer. During the procedure of agreement confirmation, the deliverables and scope of the project could be changed.
8. Agreement elaboration with SPN suppliers/subcontractors;
9. Project management activities. As a foundation for VE management, ISO 21500 or PMBOK can be adopted [106]. This process helps monitor the current status of the projects based on scope, risk, quantity, price and time. The real project schedule is verified with proposed schedule based on the project current date (compared with project plan), and the project budget is verified according to actually consumed resources and materials (registered expenses are compared with project current stage).

3.3.1 IT application principle of virtual enterprise formation

A SPN framework offers preparation and partner selection tools for VE formation, as given in Figure 3.17. After receiving the new order/request from a SPN enterprise or from the customer, the collaborative project initiator (FP) selects the required domain, defines the project steps and describes the operations to be fulfilled. Then the FP describes the routing, while suitable partners are selected from the SPN repository based on resource specifications and resource availability. The PEI calculation is performed for every candidate partner by each operation of a production route. The latter is followed by analysis of the manufacturing sequence; the purpose is to verify whether it is possible to manufacture the product subassemblies in one location. The output of an analysis is a list of the best possible enterprise partners according to the FP preference for a particular project. The AHP methodology allows for a pairwise comparison of the project price and time importance prior to the final calculation of the PEI, which is used for selection of possible partner enterprises [IX].

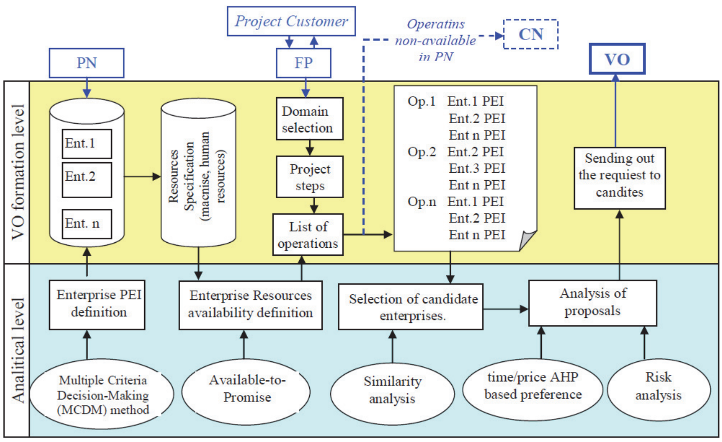


Figure 3.17. IT model of Virtual Organisation Formation Application [IX]

3.3.2 Drafting agreements for sustainable project realisation

After completing all stages of setting up a described collaborative project, the candidate partners selected for design and manufacturing operations receive the offers from a FP. The latter modifies the list based on a combination of the previous experience of collaboration within a SPN and PEI. After a FP confirms the VE-candidate partner's proposals, the partners form the VE. The calculation system supports the process of partner selection by FP based on collaborative project measures and the FP finally sends a proposal to the customer. After a customer accepts the proposal, the customer and the FP sign the contract. Additionally, a FP and the selected VE partner also sign the VE contract. Those contracts guarantee that the service is paid for by all the partners after the project is completed [VI].

3.4 Sustainable management of virtual enterprise

Once the collaborative project is started, it is important to provide the environment for its successful implementation. This environment will help track the progress of the project, based on the input data, which will be submitted regularly by VE members. This environment will reduce the risks of the VE and help monitor the VE goal realisation of the products in real time. The project management in VE is characterised as management of an agile temporary entity with autonomous independent units [IX].

Performing industrial projects is often difficult to accomplish. Reaching all goals on quality, time, cost and respecting human wellbeing are the strategic plans for the proposed SPN. Making decisions effectively and immediately would help to achieve the goals and prevent the wasting of time as well as human and material resources. Therefore, the most important roles of the FP are to define the required partners and correctly form the VE, in order to calculate the budget and timeframe, estimate the risks of a new project proposal and provide collaborative project management (CPM) after the project proposal is accepted. In the course of performing these tasks, companies that are part of a VE have to exchange periodically statuses of their tasks with an SPN [VI].

Savimaa et al. described the management framework for a formed VE, which introduces the approaches and methods for effective VE management [X].

4 PARTNERS SELECTION TOOL

4.1 Partner selection algorithm

"The key issue in forming a VE is to select agile, competent, and compatible partners" [107]. The partner selection is the key issue for successful virtual enterprise formation [108–109]. The partner selection tool relies on the fuzzy set theory, Pugh matrix, TOPSIS and AHP methods. Chen, et al. have described the universal mathematical method [110] that considers both quantitative and qualitative criteria, which provides a good basis for the following case study.

The partner selection calculation process relies on the TOPSIS method. It is necessary to carry out ten steps in order to calculate the partner rating. The first eight steps are inherited directly from the TOPSIS method (see section 2.2). The next two steps were added to adopt the TOPSIS method for partner selection in the SPN environment:

- According to the CC_i, the resources availability status of each partner can be recognised and the ranking of the partners can be determined. The Partner Efficiency index (PEI) is defined as the sum of CCi for each enterprise;
- Solution for FP decision-making. Partner selection decision-making is based on particular project priorities in respect to max VE efficiency, min transfers or min risk.

More details on the described mathematical method can be found from the source [110]. Figure 4.1 illustrates the algorithm of TOPSIS and AHP methods calculation. Practical implementation of the algorithm is given in chapter 5.1.

In order to calculate the ranking of the partners, the FP first defines the set of possible partners ($A = \{A_1, A_2, ..., A_m\}$) and forms a committee of decision-makers ($F = \{D_1, D_2, ..., D_K\}$). The committee defines the evaluation preferences as ($C = \{C_1, C_2, ..., C_n\}$). The experts rate each partner A_i with respect to criteria C_j, after which the tool identifies the partners and calculates the rank of the partners. FP also defines the number of experts; the more experts that are invited the better the end result. The committee consists of experts appointed by the FP, who can also be one of the committee members.

Second, the committee defines fuzzy ratings D_k and chooses appropriate linguistic variables for qualitative criteria, collects the quantitative data and the weight of importance $W_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$ for potential partners. The weights and rankings are represented as a positive trapezoidal fuzzy number. After that, the sum of criteria weights is calculated in order to get the aggregated fuzzy weight $\hat{w}_j$ of criterion C_j . The preparation phase of the data collection is completed by providing the rankings of the partners for the decision-makers. This enables users to get the aggregated fuzzy rating x_{ij} of supplier A_i under criterion C_j.

In subsequent steps, the fuzzy calculation by TOPSIS method is used to construct the fuzzy-decision matrix followed by matrix normalisation. Matrix normalisation is a way of conversion of the different units of measure to a common denominator, which helps provide comparative analysis of the criteria. The normalised fuzzy-decision matrix $\tilde{R}$ is built for analysis. When the normalised fuzzy-decision matrix is calculated, the next step is to divide each value from the matrix by criteria weight, which results in a weighted normalised fuzzy-decision matrix.

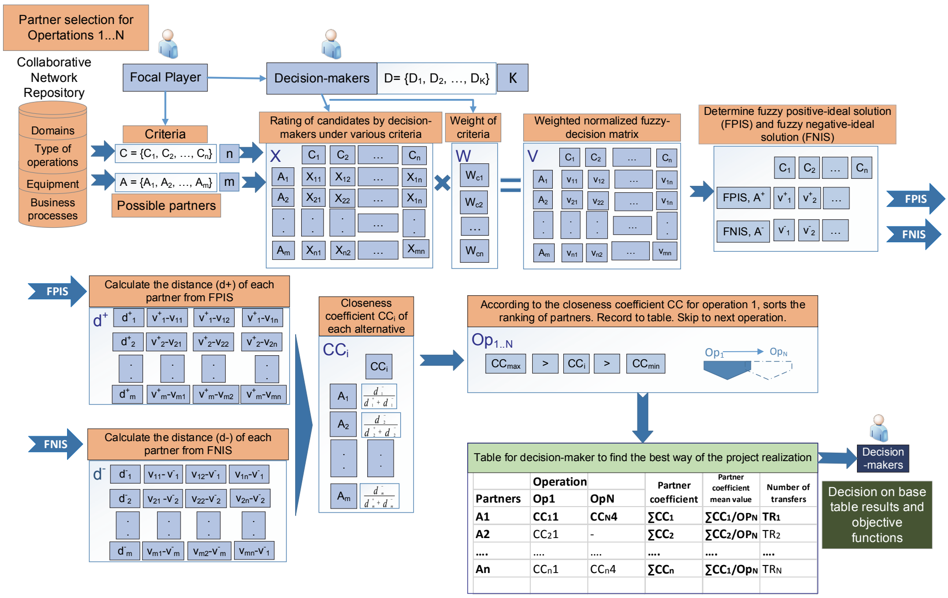


Figure 4.1. Partners selection calculation algorithm

Notes: $C_{1...n}$ – criterions; $A_{1...m}$ – possible partners; $D_{1...k}$ – decision-makers number; $x_{11...mn}$ – criterions value; $w_{c1...cn}$ – criterions weight value; $v_{11...mn}$ – criterions normalise weight value; d – distance; CC_j – closeness coefficient; $Op_{1...N}$ – operations

The weighted normalised fuzzy-decision matrix is a base for the determination of two extreme points. These are the fuzzy ideal positive solution A^+ (FPIS) and fuzzy ideal negative solution A^- (FNIS) for a particular criterion from the list of criteria. The obtained extreme points are used to compare the results of the received ratings of the partners and to calculate the distance from FPIS and FNIS, respectively. When the distances are calculated, it is possible to calculate the closeness coefficient of each partner CC_i, which is described by a single number.

According to the closeness coefficient, it is possible to assess a partner and determine the rankings for all partners. The partners are assigned to each operation accordingly to the closeness coefficient ranking. FP stores all calculated closeness coefficients in a table. The results table in Figure 4.1 gives an overview of the project realisation sequence and helps determine key performance indicators before the project starts.

It divides the PEI [from 0 to 1] of each partner into 3 intervals to diversification the VE risks. Depending on the obtained PEI, the partner assessment status is divided into three classes. The rules of the three classes are introduced in Table 4.1

Table 4.1. Partner selection status

PEI	Risks diversification rate	Recommendations for partners allocation
PEI [≥ 0 > 0.5]	High	Recommended to use at least 3 partners
PEI [≥ 0.5 > 0.8]	Medium	Recommended to use at least 2 partners
PEI [≥ 0.8 ≥ 1.0]	Low	Recommended to use one partner

If PEI ranges from 0 to 0.5, then partner A_i belongs to class I and the status of risk diversification is "High (recommended to use at least 3 partners)";

If PEI ranges from 0.5 to 0.8, then partner A_i belongs to class II and the status of risk diversification is "Medium (recommended to use at least 2 partners)";

If PEI ranges from 0.8 to 1.0, then partner A_i belongs to Class III and the status of risk diversification is "Low (recommended to use one partner)."

Table 4.1 represents the partner risk status and by using the obtained partner CC_i and the risk status it is easy to determine their rank and to classify it by the order.

4.2 Analysis of calculation results

The data collected into Table 4.2 gives users the possibility to analyse the project realisation opportunities by PEI for candidates and the total number of transfers in the project. Transfer number is an amount of physical transportations between the VE partners. It enables FP to select the best alternatives for project realisation.

Table 4.2. PEI calculation results for project realisation

	Operation				
Partners	Op1	OpN	Partner coefficient	Op_N provided by a partner	Partner coefficient mean value
A1	CC_{11}	CC_{N4}	$\sum CC_1$	$\sum Op_1$	$\sum CC_1/\sum OP_N$
A2	CC_{21}	-	$\sum CC_2$	$\sum Op_1$	$\sum CC_2/\sum OP_N$
….	….	….	….	….	….
An	CC_{n1}	CC_{n4}	$\sum CC_n$	$\sum Op_N$	$\sum CC_1/\sum Op_N$

The new VE organisation has several targets (Figure 4.2) that help strive for effective project realisation. The first target is to select the reliable partners with a maximum PEI. The next target is to minimise the number of transfers that consider geographical closeness and logistics issues for project partner selection. The FP has to minimise the logistics expenses, since logistics does not add any value to a product. Logistics expenses increase the final product cost, thereby decreasing the competitiveness of the entire project. The FP also calculates the project risks, assesses them and minimises their influence on the project.

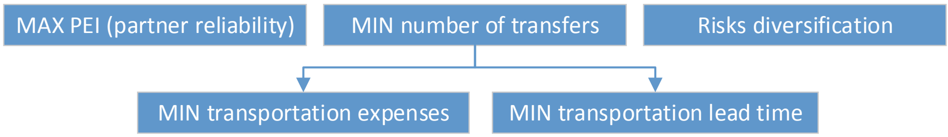


Figure 4.2. Target functions for the partner selection

The partner selection tool provides 3 possible solutions for VE formation to decision-making: with the most efficient way (max PEI), with the minimum number of transfers and with a minimum risk for VE goal realisation. A sample table with possible solutions is introduced on Table 4.2.

The developed tool selects partners for the particular operations based on the highest partner PEI. It composes the chain of the partners to obtain the most effective way for project realisation. In this way, it characterises partners by the VE efficiency index. The VE efficiency index is a mean value of the partner with a highest PEI index for a particular operation. The VE efficiency index is a value that estimates the overall project and is used by the FP for decision-making. The VE efficiency index is calculated according to the following equation:

$$VE_{effic.} = \frac{\sum_{j=1}^{n} PEI_j}{n}, \qquad (4.1)$$

where $\sum_{j=1}^{n} PEI_j$ sum of the partners with the highest PEI for a particular operation,

n is a number of operations.

The results are inserted in Table 4.3 and give an overview of the project realisation sequence, while also helping determine key performance indicators before the project starts. Priority minimum transfers in VE help calculate how many times the materials will be transferred between partners before the FP receives the final product.

Table 4.3. Solution for decision-making

Priority:	max VE efficiency			
Solution	**VE efficiency index**	**Partners**	**Number of transfers**	**Risk diversification rate**
Choice 1	$\sum\sum CC_{max}$	A_1->A_2->...->A_N	N_1	R_1

Priority:	min number of transfers			
Solution	**VE efficiency index**	**Partners**	**Number of transfers**	**Risk diversification rate**
Choice 2	$\sum\sum CC_2$	A_1->A_N->...->A_2	N_{min}	R_2

Priority:	min risk			
Solutions	**VE efficiency index**	**Partners**	**Number of transfers**	**Risk diversification rate**
Choice N	$\sum\sum CC_N$	A_N->A_2->...->A_1	N_2	R_{min}

5 PARTNER SELECTION TOOL APPLIED IN PRACTICE

The authors have conducted the following case study in collaboration with design/production companies from the metal construction industry. The purpose of the case study is to verify the developed concept of the sustainable partner network initiation, VE forming and the collaborative partner's selection algorithm. In this chapter, the developed conceptual model of the partner network has been applied in practice and the VE was established based on customer demand.

In total, seven Estonian production and design companies have participated in current research project. Two of them are design companies and five are production companies, including a FP.

The following participants took part in the project:

- Focal Player FP: Densel Baltic OÜ;
- Design partners: Apeco OÜ, ANK Technology OÜ, Eesti Energia Tehnoloogia Tööstus OÜ,
- Production partners: Finest steel OÜ, OÜ ERALD NORDIC, RGR Airon OÜ.

The main task for the current case study is to establish a new VE and to demonstrate its stages of operation.

The tasks for VE initiation were prepared based on a real industrial case. The conceptual model is called to simplify the ordering and best collaborative partner selection processes, and it is aimed to fully satisfy customer needs. The case objectives are:

- applying the described process in the practice;
- selecting the best partners for project realisation based on the qualitative and quantitative criteria;
- preparing project scope document for partners;
- preparing the contract for signing and to start the collaboration project within the framework of a VE.

The case study highlights the hidden gaps in the theory, and helps discover the overrated or unnecessary data used in the proposed theory.

5.1 Initial data for case study

Initial data, project requirements and expectations are collected from real customer requests. In the case study, the customer has sent a general drawing, the amount of required pieces, the material specification, the parts parameters (dimensions) and the delivery time.

The project has the following requirements:

- Product requirements: according to drawing A, linear and angular dimension according to ISO 2768 –mk.
- Amount of pieces: 12 pcs
- Project delivery time: 7 days
- Certificate requirement for material: cold worked steel S235J2
- Quality requirements: measurement report
- Supplier visibility: not required
- Price confirmation: According to the price quotation introduced by FP, it should be prepared within 2 working days.

The parts are used for the production of wind generators and are called "coil plate". The manufacturing, planning process and production technology elaboration is the responsibility of the FP. If necessary, FP invites the partners required for the project realisation. The manufacturing process consists of the following operations:

- designing the coil plate accordingly to the customer parameters;
- designing a drawing for the laser and bending process;
- laser cutting operation;
- bending operation;
- grinding operation;
- measuring report preparation;
- packaging, marking and transportation to customer warehouse operations.

The tasks of FP are to describe the production process, to determine which part FP can produce through utilisation of its own resources, to assign the partners for the remaining operations and to minimise the project cost and delivery time.

The FP, in being responsible for the project company, has prepared the plan for the realisation and the plan is split on the seven phases. The plan gives the project overview and allows the FP to define the processes that will be implemented by the partners (Figure 5.1).

ID	Task Name	Start	Finish	Duration	sept 2015			okt 2015				
					28	29	30	1	2	3	4	5
1	design the coil plate (drawing, flat draft, draft for benging)	28.09.2015	28.09.2015	1d								
2	laser cutting	29.09.2015	29.09.2015	1d								
3	bending	30.09.2015	30.09.2015	1d								
4	Transportation	1.10.2015	1.10.2015	1h								
5	Grinding operation	1.10.2015	1.10.2015	1d								
6	measuring report preparation	2.10.2015	2.10.2015	1h								
7	packing, marking and transportation to customer	2.10.2015	2.10.2015	2h								

Figure 5.1. Project realisation phases

5.2 Criteria determination

The criteria for partner selection come from the different sources. For example, prices, delivery time and payment terms are received from partner proposals. Qualitative criteria are determined as a linguistic variable and the calculation of these criteria has a complex and unstructured nature. The experts assess qualitative criteria, and define the units of measure.

In the current research, the partner selection tool is shown based on criteria introduced in Table 5.1.

Table 5.1. Criteria and unit of measure

	Criteria for production	**Unit**
C_{op}	Price	€
T_D	Delivery time	days
L_p	Geographical closeness	km
C_t	Payment terms	net days
D_t	Delivery terms	€/batch
I_s	Index of partner skills	from 0.1 to 1
I_Q	Index of quality	from 0.1 to 1
	Criteria for design	**Unit**
T_R	Realisation time	days
R_Q	Reply for quotation	days

Other information such as partner reliability (e.g. on time delivery, on quality delivery), partner capability, capacity, etc., can be received from the SPN repository. PEI calculation common view is shown in equation (4.1).

$$PEI = f(C_{op}, T_D, L_p, C_t, D_t, I_S, I_Q,\ T_R, R_Q) \qquad (4.1)$$

The data item in Table 5.1 have different units of measurement and they must be normalised for calculation, as given in equation (4.1).

$$PEI_{norm} =$$

$$f\left({C_{op}}^{-2}, {T_D}^{-1}, {L_p}^{-2}, {C_t}^{-2}, {D_t}^{-2}, I_S, I_Q\ , {R_Q}^{-1}, {T_R}^{-1}\right) \qquad (4.2).$$

Mathematically optimised PEI is shown in equations (13) and (14). See sample data for laser cutting operation in Table 5.12.

$$PEI_{optimProd} = f(min\ C_{op}, min\ T_D, min\ L_p, max\ C_t, minD_t, max\ I_S, max\ I_Q\ ) \tag{4.3}$$

$$PEI_{optimDesign} = f\left(min\ C_{op}, min\ T_R, min\ R_Q\ \right) \tag{4.4}$$

5.3 Partner selection tool

The VAC diagram introduced in Figure 5.2 represents the number and sequence of processes, together with alternative partners for project execution.

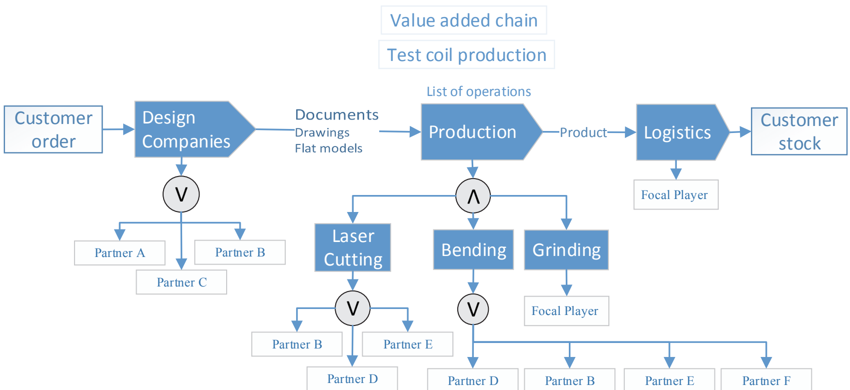


Figure 5.2. VAC diagram for the current study VE

In the case study, FP resources do not cover two domains: design and production. First, FP selects partners for the design domain. Three partners exist, and these provide the design services in SPN. The FP has to select the most effective partner by sending the project invitation, asking for a quotation according to the project requirements and using the evaluation tool previously introduced in this thesis. The FP sent tasks to partners by e-mail. Partners provided quotations in 1–2 working days with a price and a fulfilment time of assignment. The information is added to Table 5.2. In the following section, the partner selection tool for the design companies is introduced in detail.

Table 5.2. Partner request for design

Design Partners	R_Q (day)	T_R (day)	C_{OP} (€)
Partner A	2	1	20
Partner B	0	1	15
Partner C	2	1,5	60

Partner selection for design operations

At first, FP defines the importance or the weight of the criteria. The Analytic Hierarchy Process (AHP) can be applied when FP needs to compare different criteria for which the respective weight of importance is not apparent. *"By using the pairwise comparisons, the relative importance of one criteria over another will be expressed"* [111]. The criteria comparison result, which was calculated by the implementation AHP method, is expressed in Table 5.3.

Table 5.3. Criteria comparison result for design operation

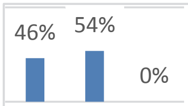
						Grade	
						Max.	1
		Criteria				Min.	0.1
	Criteria	Reply for quotation	Task realisation time	Price	**Row Total**	**Row Total**	**Scaled Importance**
R_Q	Reply for quotation	1.00	0.20	0.10	1.3	5.5%	0.1
T_R	Task realisation time	5	1.00	0.20	6.2	26.4%	0.4
C_{OP}	Price	10	5	1.00	16.0	68.1%	1.0
						100.0%	

The criteria scaled importance is calculated and determined by FP. The criteria weights are taken into account in design partner selection. The result for the selection partner is introduced in Table 5.4. The TOPSIS method is applied to categorise the partners.

Initial data for the calculation of design partners are obtained from the different sources. The information in the table is collected and entered by the FP. The source for the data collection is the SPN repository, quotations from the partners and information from previous projects (VEs) regarding the partners (ex. partner reliability, flexibility, etc.).

Table 5.4. TOPSIS method calculation result

				Options					
	Criteria	**Units**	**Scaled Importance**	Partner A	**Partner B**	Partner C	**Goal**	**- Ideal**	**+ Ideal**
R_Q	Reply for quotation	days	0.1	2	**0**	2	min	2	0
T_R	Realisation time	days	0.4	1	**1**	1.5	min	1.5	1
C_{OP}	Cost of operation	€	1	20	**15**	60	min	60	15
	Closeness coefficient CC			**0.86**	**1.00**	**0**			
			Percentage	**46%**	**54%**	**0%**			



Below the mathematical calculation, steps for design partner selection are shown according to the partner selection algorithm (Figure 4.1).

Step 1: Rating of candidates under the criteria

The data for calculation is taken from Table 5.4 and made a transposed matrix according to equation (2.1):

$$X = \begin{bmatrix} & C1 & C2 & C3 \\ A1 & x_{11} & x_{12} & x_{13} \\ A2 & x_{21} & x_{22} & x_{23} \\ A3 & x_{31} & x_{32} & x_{33} \end{bmatrix} = \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 2 & 1 & 20 \\ Partner\ B & 0 & 1 & 15 \\ Partner\ C & 2 & 1{,}5 & 60 \end{bmatrix}$$

In the calculation tool for the candidates, the rating table looks as presented in Table 5.5.

Table 5.5. Initial data for the calculation

				Options		
	Criteria	**Units**	**Scaled Importance**	Partner A	**Partner B**	Partner C
R_Q	Reply for quotation	days	0.1	2	**0**	2
T_R	Realisation time	days	0.4	1	**1**	1.5
C_{OP}	Cost of operation	€	1	20	**15**	60

The first calculation step is the initial data transformation in order to have comparable scales. Therefore, the normalisation of the decision matrix has to be performed. The normalised method mentioned above gives the following result from the initial data Table 5.5.

Step 2: Normalisation decision matrix

According to equation (2.2):

$$X_{normDesign} = f\left(R_Q{}^{-1}, T_R{}^{-1}, C_{Op}{}^{-2}\right) \qquad (4.5)$$

$$X_{NORM} = \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0.2 & 0.1 & 0.2 \\ Partner\ B & 0 & 0.1 & 0.15 \\ Partner\ C & 0.2 & 0.15 & 0.6 \end{bmatrix}$$

Table 5.6 introduces the normalised matrix in the calculation tool.

Table 5.6. Normalised decision matrix for design partner selection

Normalised matrix

		Partner A	Partner B	Partner C
Criteria	**R_Q**	0.2	0	0.2
	T_R	0.1	0.1	0.15
	C_{OP}	0.2	0.15	0.6

Step 3: Weight of the criteria

Criteria weight calculation according to the AHP method.

$$W = \begin{bmatrix} w \\ w_{C1} \\ w_{C2} \\ w_{C3} \end{bmatrix} = \begin{bmatrix} w \\ 0.1 \\ 0.4 \\ 1 \end{bmatrix}$$

Step 4: Weighted normalised fuzzy-decision matrix

According to equations (2.4, 2.5):

$$V = X_{NORM} \times W = \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0.2 & 0.1 & 0.2 \\ Partner\ B & 0 & 0.1 & 0.15 \\ Partner\ C & 0.2 & 0.15 & 0.6 \end{bmatrix} \times \begin{bmatrix} w \\ 0.1 \\ 0.4 \\ 1 \end{bmatrix}$$

The result of the weighted normalised table is represented in table 5.7.

Table 5.7. Weighted normalised decision matrix for design partner selection

Weighted normalised matrix

		Partner A	Partner B	Partner C
Criteria	**R_Q**	0.02	0	0.02
	T_R	0.04	0.04	0.06
	C_{OP}	0.2	0.15	0.6

Two additional columns appeared in the initial Table 5.8. One of them is a column with an ideal negative solution (it is the worst meaning from the criteria rows), and the second one is a column with an ideal positive solution (it is the best meaning from the criteria rows).

Table 5.8. Pugh matrix of initial data with ideal negative/positive solutions

				Options					
	Criteria	**Units**	**Scaled Importance**	Partner A	**Partner B**	Partner C	**Goal**	**- Ideal**	**+ Ideal**
R_Q	Reply for quotation	days	0.1	2	**0**	2	min	2	0
T_R	Realisation time	days	0.4	1	**1**	1.5	min	1.5	1
C_{OP}	Cost of operation	€	1	20	**15**	60	min	60	15

Step 5: Determine fuzzy positive-ideal solution (FPIS)

The fuzzy positive-ideal solution (FPIS, A^+) and fuzzy negative-ideal solution (FNIS, A^-) can be defined according to equation (6):

$$FPIS, A^+_{norm.} \times \mathrm{W} = \begin{bmatrix} v \\ (v_1^+)^{-1} \\ (v_2^+)^{-1} \\ (v_3^+)^{-2} \end{bmatrix} \times \mathrm{W} = \begin{bmatrix} & {v^+}_{norm}^{\quad W} & \\ 0 & 0.04 & 0.15 \\ 0 & 0.04 & 0.15 \\ 0 & 0.04 & 0.15 \end{bmatrix}$$

Calculation of the distance from (d^+) for each partner from FPIS.

According to equation (2.8):

$$d^+ = \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0.02 & 0.04 & 0.2 \\ Partner\ B & 0 & 0.04 & 0.15 \\ Partner\ C & 0.02 & 0.06 & 0.6 \end{bmatrix} - \begin{bmatrix} R_Q & T_R & C_{OP} \\ 0 & 0.04 & 0.15 \\ 0 & 0.04 & 0.15 \\ 0 & 0.04 & 0.15 \end{bmatrix}$$

$$= \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0.02 & 0 & 0.05 \\ Partner\ B & 0 & 0 & 0 \\ Partner\ C & 0.02 & 0.02 & 0.45 \end{bmatrix}$$

The distance of each alternative (supplier) from A^{+} and A_i can be currently calculated as:

$$d^{+}_{partner\ A} = 0.02 + 0 + 0.05 = 0.07$$

$$d^{+}_{partner\ B} = 0$$

$$d^{+}_{partner\ C} = 0.02 + 0.02 + 0.45 = 0.49$$

Table 5.9. Positive ideal solution definition

Distances between Ai and A+

		Partner A	Partner B	Partner C
Criteria	**R_Q**	0.02	0	0.02
	T_R	0	0	0.02
	C_{OP}	0.05	0	0.45
	Total	**0.07**	**0.00**	**0.49**

Step 6: Determine fuzzy negative-ideal solution (FNIS)

According to equation (2.7)

$$FNIS, A^{-} \times \mathrm{W} = \begin{bmatrix} v \\ (v_1^{-})^{-1} \\ (v_2^{-})^{-1} \\ (v_3^{-})^{-2} \end{bmatrix} = \begin{bmatrix} v_{norm} \\ 0.2 \\ 0.15 \\ 0.60 \end{bmatrix} \times \mathrm{W} = \begin{bmatrix} & {v^{-}}_{norm}{}^{W} & \\ 0.02 & 0.06 & 0.6 \\ 0.02 & 0.06 & 0.6 \\ 0.02 & 0.06 & 0.6 \end{bmatrix}$$

According to equation (2.9)

$$d^{-} = \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0.02 & 0.04 & 0.2 \\ Partner\ B & 0 & 0.04 & 0.15 \\ Partner\ C & 0.02 & 0.06 & 0.6 \end{bmatrix} - \begin{bmatrix} R_Q & T_R & C_{OP} \\ 0.02 & 0.06 & 0.6 \\ 0.02 & 0.06 & 0.6 \\ 0.02 & 0.06 & 0.6 \end{bmatrix}$$
$$= \begin{bmatrix} & R_Q & T_R & C_{OP} \\ Partner\ A & 0 & 0.02 & 0.4 \\ Partner\ B & 0.02 & 0.02 & 0.45 \\ Partner\ C & 0 & 0 & 0 \end{bmatrix}$$

The distance of each alternative (supplier) can be currently calculated as:

$$d^{-}_{partner\ A} = 0 + 0.02 + 0.4 = 0.42$$

$$d^{-}_{partner\ B} = 0.02 + 0.02 + 0.45 = 0.49$$

$$d^{-}_{partner\ C} = 0$$

Table 5.10. Negative ideal solution definition

Distances between Ai and A-

Criteria		Partner A	Partner B	Partner C
	R_Q	0	0.02	0
	T_R	0.02	0.02	0
	C_{OP}	0.4	0.45	0
	Total	**0.42**	**0.49**	**0.00**

When rows with negative and positive solution are obtained, the task is then for the calculation tool to compare the columns with the ideal positive/negative solution and proposed meanings by the partners. The result of the calculation will be the coefficient from 0 to 1, and the closer number to 1 the closer the partner's criteria are to the ideal solution column.

Step 7: Closeness coefficient calculation for each partner from the design partner list.

According to equation (2.8):

$$CC_i = \begin{bmatrix} & CC_i \\ Partner\ A & \dfrac{d_A^-}{d_A^+ + d_A^-} \\ Partner\ B & \dfrac{d_B^-}{d_B^+ + d_B^-} \\ Partner\ C & \dfrac{d_C^-}{d_C^+ + d_C^-} \end{bmatrix} = \begin{bmatrix} CC_i \\ 0.86 \\ 1.0 \\ 0 \end{bmatrix}$$

Step 8: Partner selection for design operation on the calculation results.

The closeness coefficient (CC_i) is used as the result of the partner selection and their prioritising. The coefficient gives a number from 0 to 1 depending on how close the partner coefficient is to FPIS index and how far it is from FNIS. The design operation risks also have to be considered. To decrease risk, the operation has to be split into parts based on the direct proportion of the closeness coefficient between the partners. In the current case, it is recommended to give 54% of the work to Partner B company and 46% to Partner A. The final decision will be made by FP, since the method only gives the recommended mathematical solution for the problem. In Table 5.11, the partner selected for design operation is marked by grey.

Table 5.11. Calculation results for design partner selection

Design Partners	R_Q	T_R	C_{OP}	CC_i	Risks (%)
Partner A	2	1	20	0.86	46
Partner B	0	1	15	1	54
Partner C	2	1.5	60	0	0

Partner selection for laser cutting

As seen from the VAC diagram, the next step is to define the partner for the laser cutting operation. The request was sent to three partners who have the capability and equipment to perform the laser cutting operations. In Table 5.12, the obtained quotations from partners for laser cutting operations are presented:

Table 5.12. Result of requests for laser cutting operation

Partners list	C_{op}	T_D	L_p	C_t	D_t	I_s	I_Q
Partner B	34.68	5	15	14	7.5	0.9	1.0
Partner D	22.08	7	17	14	10	0.9	0.8
Partner E	23.28	2	6	15	3.5	0.8	0.9

FP needs to determine the criteria for the analysis and selection of partners for the production operation. The FP defined the preferences (criteria). There are 7 (price, delivery time, geographical closeness, payment terms, delivery term, partner skill, quality) criteria that have been considered for laser cutting operation partner selection.

The criteria ratings are determined by the AHP method. The FP defines the relation between the criteria and the AHP method calculates the scaled importance for the criteria, which are subsequently used as criteria weights in the TOPSIS method. The result of the calculation is introduced in Table 5.13.

Table 5.13 Criteria comparison for laser cutting operation

Grade	
Max.	1
Min	0.1

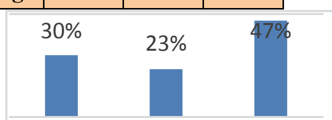
	Criteria	Price	Delivery time	Geographically closeness	Payment terms	Delivery terms	Partner skill	Quality	Row Total	Row Total	Scaled Importance
C_{OP}	Price	1.0	1.0	2.0	8.0	8.0	1.0	0.5	21.5	21.4%	0.7
T_D	Delivery time	1.0	1.0	2.0	5.0	8.0	1.0	0.2	18.2	18.1%	0.6
L_P	Geographically closeness	0.5	0.5	1.0	2.0	0.5	0.2	0.1	4.8	4.8%	0.2
C_t	Payment terms	0.1	0.2	0.5	1.0	1.0	0.2	0.1	3.1	3.1%	0.1
D_T	Delivery terms	0.1	0.1	2.0	1.0	1.0	0.2	0.5	5.0	4.9%	0.2
I_S	Partner skill	1.0	1.0	5.0	5.0	5.0	1.0	1.0	19.0	18.9%	0.7
I_Q	Quality	2.0	5.0	8.0	10.0	2.0	1.0	1.0	29.0	28.8%	1.0
										100.0%	

Experts have to be involved in the process in order to estimate the qualitative criteria. Quantitative criteria have a degree of fuzziness and it is difficult to define the numbers for them. In this case, the expert opinion has arbitrary characteristics and more experts should be involved in order to estimate the qualitative criteria and obtain results that are more objective. The fuzzy set theory is an efficient method for qualitative criteria estimation. The fuzzy set theory is applied in the current case study. The result of partner's selection for laser operation by using the TOPSIS method is shown in Table 5.14.

Based on the results obtained by the TOPSIS method, the FP selects the 3rd partner as the most suitable partner for the laser cutting operation. If the FP decides that it is too risky to rely on 1 partner and FP needs to diversify the operation risks, then it proposes to divide the operation between the partners accordingly to the following percentages: 30%, 23% and 47%.

Table 5.14. Result of selection partner for laser cutting operation

	Criteria	Units	**Scaled Importance**	Options: Partner B	Options: Partner D	Options: **Partner E**	**Goal**	**- Ideal**	**+ Ideal**
C_{OP}	Price of operation	€	0.7	34.68	22.08	**23.28**	min	34.68	22.08
T_D	Delivery time	days	0.6	5	7	**2**	min	7	2
L_P	Distance to partner	km	0.2	15	17	**6**	min	17	6
C_t	Payment terms	net days	0.1	14	14	**15**	max	14	15
D_T	Delivery terms	€/batch	0.2	7.5	10	**3.5**	min	10	3.5
I_S	Index of partner skill	from 0.1 to 1	0.7	0.9	0.9	**0.8**	max	0.8	0.9
I_Q	Index of Quality	from 0.1 to 1	1.0	1	1	**0.9**	max	0.9	1
	Closeness coefficient CC			**0.48**	**0.37**	**0.75**			
		Percentage		**30%**	**23%**	**47%**			



Partner selection for bending operation

The final operation, which the FP needs to purchase from the partner, is a bending operation. There are four partners who can provide the bending service in the PN. The FP has to select the best one. The 4 requests were sent to the partners and FP obtained the quotations from the partners with qualitative parameters. Pivot table 5.15 contains the initial data for the analysis.

Table 5.15. Result of requests for the bending operation

Partner list	C_{OP}	T_D	L_P	C_t	D_T	I_S	I_Q
Partner B	10.92	4	15	14	7.5	0.9	1.0
Partner D	13.92	7	17	14	10	0.9	1.0
Partner F	18.72	7	21	14	24	0.9	0.8
Partner E	15.12	2	6	15	3.5	0.8	0.9

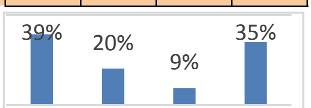
The data obtained from expert assessments (index of partner skill, index of quality) were added into the table, and they were complemented by data received from the frame contracts with partners (delivery terms, geographical closeness).

The data from the results table has been inserted into the tool, which uses the TOPSIS method. The result of partner selection for the bending operation is presented in Table 5.16.

The result is interpreted in following conditions: 0.75>0.67>0.39>0.11, from the company point of view 1>4>2>3. In order to decrease the risks and to increase the reliability of operation realisation, the FP is able to split the work among the partners in the following proportion: 39%, 35%, 20% and 9%.

Table 5.16. Result of selection partner for bending operation

				Options						
	Criteria	Units	Scaled Importance	Partner B	Partner D	Partner F	Partner E	Goal	- Ideal	+ Ideal
C_{OP}	Operation Cost	€	0.7	10.92	13.92	18.72	15.12	min	18.72	10.92
T_D	Delivery time	days	0.6	4	7	7	2	min	7	2
L_P	Distance to partner	km	0.2	15	17	21	6	min	21	6
C_t	Payment terms	net days	0.1	14	14	14	15	max	14	15
D_T	Delivery terms	€/batch	0.2	7.5	10	24	3.5	min	24	3.5
I_S	Index of partner skill	from 0.1 to 1	0.7	0.9	0.9	0.9	0.8	max	0.8	0.9
I_Q	Index of Quality	from 0.1 to1	1.0	1	1	0.9	0.9	max	0.9	1
	Closeness coefficient CC			**0.75**	**0.39**	**0.11**	**0.67**			
			Percentage	**39%**	**20%**	**9%**	**35%**			



Now, partner closeness confidences are defined for all the operations that FP decided to purchase from SPN. FP has all the necessary data for analysis and decision-making that is required in selecting the most sustainable partner.

Result of the calculation

The results of the calculation are presented in Table 5.17. There are 36 (3x3x4) methods for project realisation, but the most efficient way is to utilise the maximum of the mean value of all closeness coefficients. This number is called the VE efficiency index and it is equal to 0.85. However, in this case FP has to consider 3 transfers. It means that the materials will be transferred three times between partners before the FP receives the final product. At the same time, the high transportations costs or longer distances between the partners are not acceptable to the FP. In the current research, the new parameter or transfer number was added to assist the decision maker in finalising the decision.

Table 5.17. Result selection partner for project realisation

Partners	**Operations**			**Partner efficiency index**	**OpN provided by a partner**	**PEI mean value**
	Design	**Laser cutting**	**Bending**			
Partner A	0.86	-	-	**0.86**	**1**	**0.86**
Partner B	**1.00**	0.48	**0.75**	**2.23**	**3**	**0.74**
Partner C	0.00	-	-	**0.00**	**0**	**0.00**
Partner D	-	0.37	0.39	**0.76**	**2**	**0.38**
Partner E	-	**0.75**	0.67	**1.42**	**2**	**0.71**
Partner F	-	-	0.11	**0.11**	**1**	**0.11**

The tools also provide alternative ways for project realisation with a smaller efficiency index, but with a minimum number of transfers, which can be an important factor in the partner selection process. The third scenario for VE formation is to minimise the VE risks. All three scenarios with a max PEI, min number of transfer and min VE risk are introduced in Table 5.18.

Table 5.18. Scenario for the VE formation

Priority:	max VE efficiency			
	VE efficiency index	Partners	Number of transfers	Risk diversification scale
Choice 1	**0.83**	B->E->B->F	3	max
Choice 2	0.53	B->F	1	max

Priority:	min transfers			
	VE efficiency index	Partners	**Number of transfers**	Risk diversification scale
Choice 1	0.53	B->F	**1**	max
Choice 2	0.85	B->E->B->F	3	max

Priority:	min risk			
	VE efficiency index	Partners	Number of transfers	**Risk diversification scale**
Choice 1	0.68	B->BED->BE->F	6	**min**
Choice 2	0.75	AB->BE->EB	4	

The decision maker is able to analysis all three provided scenarios and select the most suitable in the particular situation, ether with a max PEI or with min transfers or min risks.

In the current case, a tool for partner selection for VE formation was shown and applied in practice. FP has received a proposal from the customer and needs to give a fast response for the customer request. The tool has an objective estimation procedure, which considers both qualitative and quantitative parameters. The mathematical tools and methods – such as the TOPSIS method, AHP method and Fuzzy set theory – have been implemented in the tool, which enables users to consider the qualitative parameters. As a result, the tool has proposed the best method for project realisation and FP has selected the partners for VE formation. The partner selection tool takes 7 parameters into account, where 5 are quantitative and obtained from partner quotations and the SPN repository and the remaining 2 parameters were qualitative and have been estimated by the expert. The fuzzy set theory was used to estimate the qualitative parameters.

Implementation of user for application

The general picture of FP activities is introduced in Figure 5.3. Most of the information is preliminarily stored in the SPN repository during the new partner description process, and the remainder of the information is entered in the calculation engine by FP according to the particular case. The information that is required for the current case and which is added by FP is relatively straightforward, and the data collection process is divided into five stages. These stages are presented in Figure 5.3 and have the following structure.

(1) FP select from a domain for which the partner is needed. The domain partner data is collected from the SPN repository. In the current case, the FP has selected the design domain.

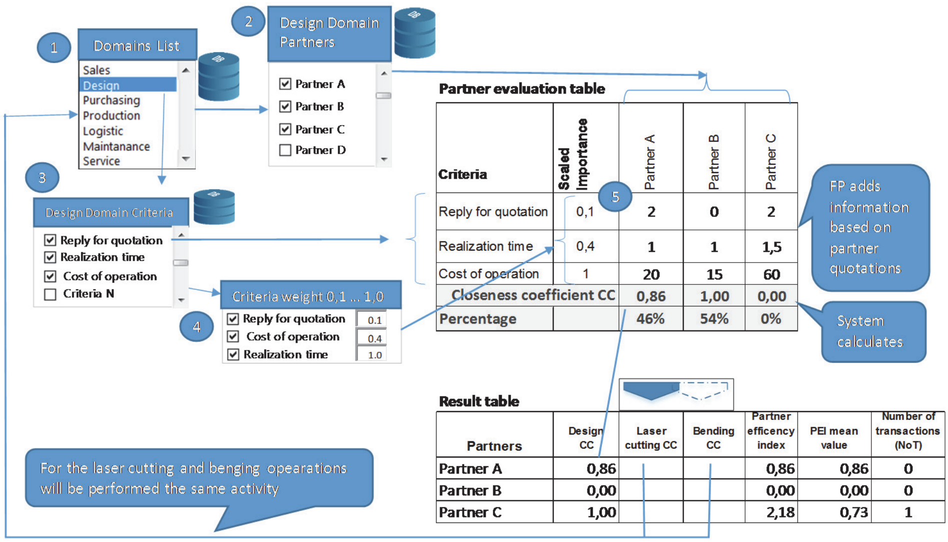


Figure 5.3. Focal player activities for partner selection

(2) The system has filtered out the partners who provide the design services and it presents the list of potential partners/companies. The database of domains has an interconnection with the companies. This interconnection between the companies and domains was established during the process of partner SPN formation and new member integration. FP is able to check mark the partners from the list generated by the system.

(3) The system filters a criteria list from the database of criteria for the design domain. FP selects the criteria based on the project preferences and customer requirements.

(4) FP defines the criteria weights. If the criteria weight is difficult to define, FP is able to use the AHP method, which is integrated into the system tool.

(5) FP input is obtained from the information of partners according to the criteria, and data are collected from the quotations received from the partners. After the partners, criteria and their weights are defined, the calculation results for design partner selection are given in Figure 5.3.

5.4 Virtual enterprise formation process simulation

As described in previous sections, the VE formation model has to be built and simulated in order to compare the proposed solutions with the existing process of projects formation in a SME. First, AS_IS model has been described, which forms a process of the conventional supply chain with the assumption that the project manager carries out those activities during the project formation process. In current research, the ARIS software tool for modelling was used, which also allows for simulating and obtaining the simulation result for the models analysis. The Supply chain formation process for project realisation or AS-IS model is introduced in Figure 5.4. This process is described by the BPMN model, which is based on EPC/VAC notations. The process starts from a quotation receiving and finishes by sending out the project realisation proposal to the customer. The model also includes the documents and roles of participant.

The supply chain formation process introduced in Figure 5.4 starts from a project description, understanding and definition of customer expectations. The result of the activity is introduced in the project plan document. The project manager is the only actor in the current process. The project description is a first step (activity) and it is finished by the project plan preparation (activity: project description). The second step is resources definition. During the activity the project manager defines and assesses the availability of own resources and the possibility to include the supplier into the new supply chain (activity: resource definition). If there are enough own resources to execute the particular operation then the project manager includes it to the production plan (activity: own resource reservation). In case if there are no enough own resources to cover the particular operation then project manager has to select/ search for a supplier (activity: supplier search). A new supplier search can take a lot of time and even if the supplier is found it does not guarantee that a company is still acting and can execute the operation in appropriate way (Risk: does the company exist?). When the list of potential suppliers is defined the project manager prepares and send the quotation to suppliers defined in supplier list activity) quotation preparation). After project manager receive the due date of proposal he collects all quotations (activity: collecting quotation from suppliers) for analyses and selection of supplier for particular operation (activity: supplier selection). When the project manager has made a choice, he/she fix the selected supplier into the project plan and send a final proposal to the customer (activity: proposal finalisation).

Table 5.19. Project initiation functions

Name	Process Time (h)	Process cost (€)
Project description	2	20
Own resources reservation	1	10
Resources definition	1	10
Supplier search	5	50
Quotation preparation	1.5	15
Collecting proposals from suppliers	16	0
Suppliers selection	2	20
Proposal finalisation	2	20

As a result of the project initiation process modelling, it is clear that the project formation process in the supply chain consists of 4 risks, 8 functions and 1 participant. Each of the functions consumes time in terms of realisation and leads to expenses for the company. The author has grouped the consumption of process time and costs in Table 5.19.

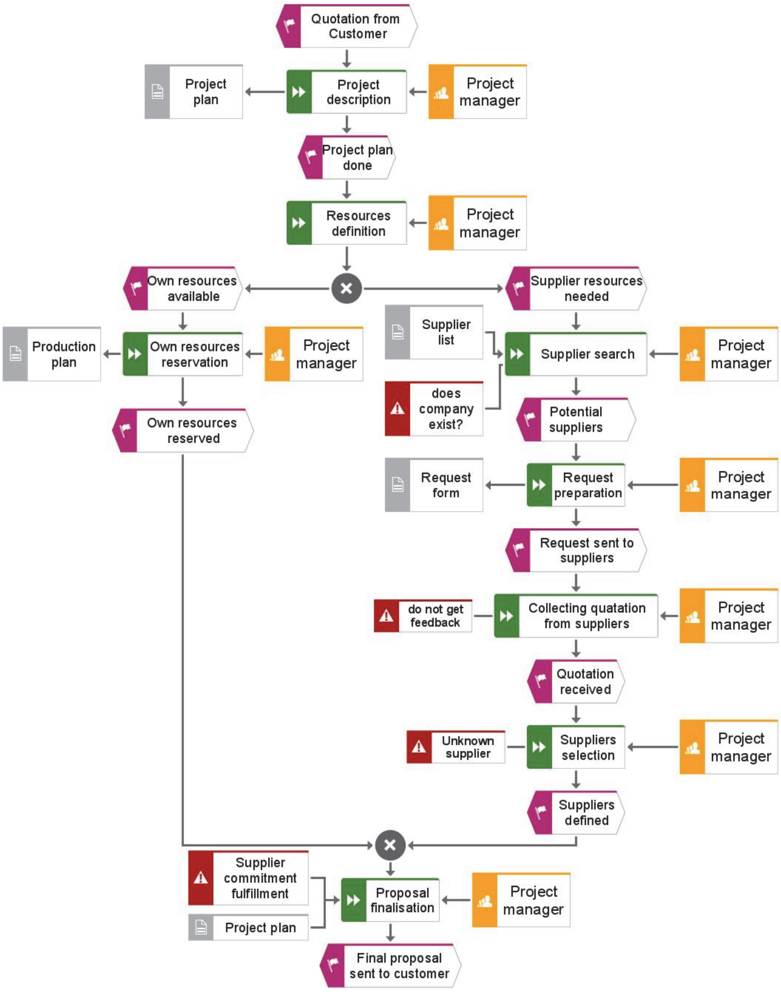


Figure 5.4. Supply chain formation EPC model for project realisation

The times and expenses have been inserted into a model, which has been simulated by an ARIS ExtPackSim tool. In order to simulate 99 random projects, the simulation model has been restricted to 99 cycles. The simulation results are given in table 5.20.

The simulation with normal distribution shows that the formation of 99 projects in conventional Supply Chain requires 1,903 hours and €10,190. It is necessary to compare the AS-IS model with a new model or TO-BE, as proposed in the thesis. The VE formation process or TO-BE model has also been developed in

ARIS as shown in Figure 5.5. Similar to previous model, it starts with a customer quotation and finishes by providing a proposal to the customer.

Table 5.20. Simulation result of project initiation

Name	Process folders received (pcs)	Processing time sum (h)	Total function costs (€)
Project description	99	196	1,960
Own resources reservation	40	40	400
Resources definition	98	98	980
Supplier search	58	290	2,900
Quotation preparation	58	87	870
Collecting proposals from suppliers	58	924	0
Suppliers selection	57	114	1,140
Proposal finalisation	97	194	1,940
Supplier selection	**99**	**1,903**	**10,190**

During the comparison of both models the first, important finding emerges: it is a reduction in the number of risks. There were 4 risks concerned in the AS-IS model, but only 1 risk left in the TO-BE model. Partners auditing, questionnaire, building of frame contract and repository are the actions that allow the risks to be eliminated in the Supply Chain formation model. There are a similar number of functions, but most of them are automated and the SPN repository is also plugged into the TO-BE model.

The times for the TO-BE functions realisation are estimated and represented in Table 5.21.

Table 5.21. VE formation price times and costs

Name	Time for process (h)	Process cost (€)
Project description	2	20
VAC description	2	20
Own resources reservation	1	10
Partner filter	0.1	1
Quotation preparation	0.5	5
Collecting proposals from partners	16	0
Partner selection	1	10
Proposal finalisation	1	10

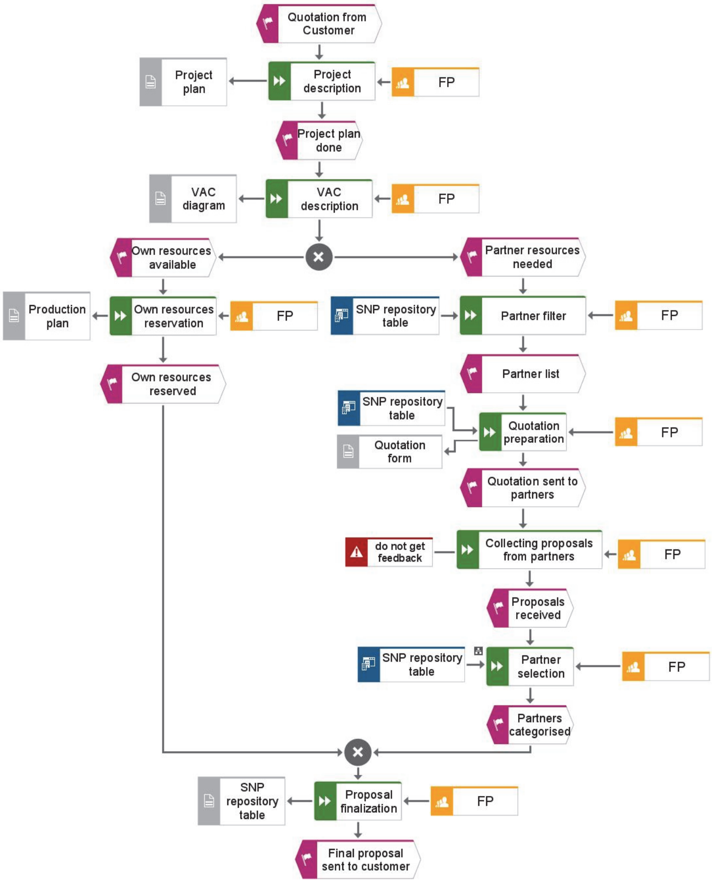


Figure 5.5. VE formation EPC model for project realisation

Table 5.22. Simulation result of VE formation

Name	Process folders received (pcs)	Processing time sum (h)	Total function costs (€)
Project description	99	198	1,980
VAC description	99	198	1,980
Own resources reservation	41	41	410
Partner filter	58	5:48	5.8
Quotation preparation	58	29	29
Collecting proposals from partners	58	928	0
Partner selection	58	58	580
Proposal finalisation	99	99:00:00	990
VE formation process	**99**	**1556:48**	**5,974.8**

The proposed times and costs in Table 5.22 are added to the TO_BE ARIS model and simulated. Like the previous model, the simulation of 99 cycles of the VE formation with normal distribution were carried out and the results of the simulation are introduced in Table 5.22.

As seen from the simulation results, the process of 99 VE formation requires ~1,557 hours and ~€5,975.

The following equation is used to compare the AS-IS and TO-BE models:

$$\text{Comparison unit} = 100\,\% - (\text{TO-BE unit} / \text{AS-IS unit}) * 100\% \qquad (15)$$

The following numbers were received from the comparative analysis of time, cost and risks of the AS-IS and TO-BE models according to the equation (15):

- Time reduction = 100% – (1,556 / 1,903)*100% = 100% – 0.818 * 100% ≈ 18 %
- Cost reduction = 100% – (5,975 / 10,190)*100% = 100% – 0.586 * 100% ≈ 41 %
- Risk reduction = 100% – (1 / 4)*100% = 100% – 0.25 *100% = 75%

The proposed new approach helped decrease the time required for project formation by up to 18%, related costs by up to 41% and risk number by up to 75%.

6 CONCLUSIONS

The achieved objectives of the current research are summarised in this section. In the current research, the author has investigated a new form of networked organisation for SME collaboration, called Sustainable Partner Network (SPN). The concept of SPN as well as the new partner selection tool is expected to become a valuable tool for SMEs in order to stay competitive in the fast-changing global market.

1. *The environment, which enables the resources of independent SMEs to be consolidated, is defined.* SPN is an essential tool that helps increase the competiveness of a company from SPN initiation until the tracking of collaborative projects. Horizontally cooperating SMEs form a SPN in order to respond faster to the market demand and to decrease the time required to build up the necessary network of competences and the value added chain, when the new business opportunity arises (section 1.2.1). SPN is defined as a long-term strategic alliance (a kind of VBE), which is a network with aligned partner business strategies. The author considers SPN to be an alternative to large and less flexible enterprises.
2. *The framework for virtual enterprise (VE) formation is elaborated.* A framework for VE formation was defined, which includes the steps that an SME needs to undertake in order to become a SPN member. The SME audit process is proposed, which enables the user to obtain key enterprise information (i.e. enterprise profile) and classify the enterprise depending on resources and competences. Thereafter, the SME is able to use SPN resources to increase its own resource capacity by using the partner collaboration procedure for VE formation. (Chapter 2).
3. *The tool for most effective partner selection from PN is developed.* It was proposed as the rapid way for VE formation in the research and applied the Pugh Matrix, TOPSIS and AHP methods along with the fuzzy set theory (section 1.5) in order to develop the tool. The AHP method is used for a pairwise comparison of the criteria required for Partner Efficiency Index (PEI calculation) for possible partner enterprises. The TOPSIS method helped rank the partners and classified them by the criteria. The tool combines maximum PEI with a minimum number of transfers in order to discover the best solution for particular project realisation (section 3.2) The calculation tool supports the Focal Player (FP), or the enterprise that have the order, decision-making process in PN. Additionally, for the simulated example, FP is able to use the PN resources for the faster (decrease the formation time to 18%) and cheaper (decrease the formation cost to 41%) preparation of a project proposal to the customer and to establish the collaboration process once the customer has accepted the proposal. The developed tool allows an SME to increase the capability and availability of resources and decrease the project risks to 75% in collaboration with partners, see chapter 3.

4. *Practical implementation of proposed tool.* "Collaboration enhancing sustainable conceptual model development and implementation for the SMEs in the machinery domain" was validated. The case study was prepared in collaboration with seven Estonian enterprises. The collaborative project was fulfilled in the field of mechanical part production for the wind generator. The author has defined the criteria for the selection of design and production companies, which was followed by PIE calculation for each operation. The author has obtained three suitable alternatives, given in resulting table, where the first alternative had the maximum PIE coefficient and the second contained the minimum amount of transfer between partners and thirdly the diversification of risks between partners. The selection tool and practical application for partner selection has been developed in Microsoft Excel.

Approval of hypotheses

- The proposed framework creates the new environment for collaboration between SMEs. It allows for increasing the capability and capacity of SMEs to fulfil particularly large projects. VE can perform projects as big as large corporations, which increases the competitiveness of SMEs in the global market.
- The created simulation proves that the formation time for the project initiation decreases to 18% and the number of critical risks is reduced from 4 to 1.
- The developed framework enables the SME to focus on core activities, but other activities are fulfilled by the SPN partners. The VE structure and the participant commitments are well defined before the project begins and the contracts between the VE partners are signed; this increases the productivity and efficiency of projects in the SME network.
- The SPN framework is designed to bring new players to the global market. Due to increased competition, the companies who can provide the lowest price and sufficient product quality gain an additional market share. Under such conditions, the customers obtains the best quality with the lowest price.

Novelty of research

The research considers the concept of sustainable partners network (SPN), mechanism of SPN member evaluation, partner efficiency index and partner selection table (Figure 4.2), which are inherently built-in to the partner selection tool. The new tool for selecting partners in the SMEs network that is used to establish virtual enterprise is based on the concept of SPN.

Novelties of the research:

- A new organisational form for SME collaboration was introduced and was named Sustainable Partner Network (SPN);

- The framework for SPN was introduced and elaborated. It gives the basis to establish a temporary unity (VE) of independent SME for project implementation;
- A tool for SPN member evaluation was developed. In this frame
  - a questionnaire was developed;
  - key information items were defined that are preconditions for a new SPN candidate;
- A partner efficiency index (PEI) was proposed as an aggregate indicator for the particular company, which combines many parameters and is used to characterise an SPN member in front of other partners.
- The new tool is developed on top of a project-based partners selection framework based on a collection of methods, i.e., the fuzzy set theory, technique for order of preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), Pugh matrix and risk analysis.
- The partner selection table (Figure 4.2) was developed for the decision-maker, which enables one to find the most effective method for project realisation. The table gives an overview of the project steps and indicates the partner grades or PEI mean value for partners and the number of transfers for project realisation.

Future work

The current research has been based on the existing theory of business process management (BPM), which includes business process definitions, business procedure description and analysis. It was assumed that each descriptive process has its own KPI, which the partner is able to measure.

A future step is to continue developing the SPN framework and the relationship between SMEs. The framework is focused on establishing SME collaboration towards achieving a common goal. The current work finishes at the stage when a collaboration project (project scope) has been elaborated and agreements are signed. The partners are ready for collaboration, though this is not enough to satisfy the customer needs and the project is not yet realised. In future work, the framework for sustainable project management must be elaborated, in order to maintain control over the ongoing project by the FP and monitor how partners are implementing their commitments. In addition, the system has to inform and report immediately to FP or a customer to impact on the project realisation and prevent negative consequences from affecting the project in cases of emergency.

In additional, one proposal for future work is that the agreement preparation process must be automated in order to generate a ready-made contract and send it to customers and partners. The final goal of this research is to help SMEs fully satisfy their customer needs in terms of the on-time delivery of sufficient quality products at reasonable prices.

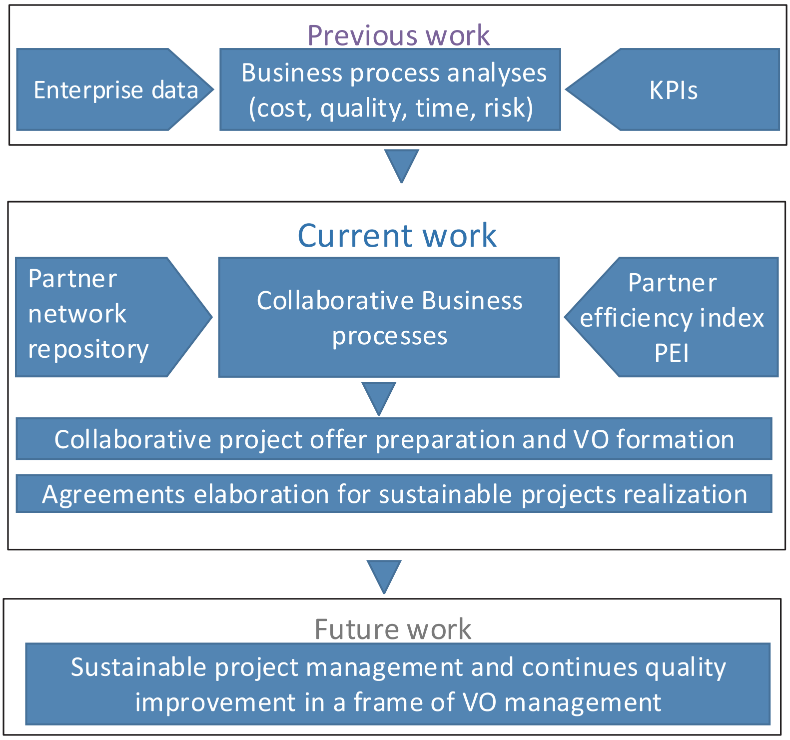


Figure B. Previous, current and future work

ABSTRACT

Partners Selection Tool for Virtual Enterprise in SMEs Network

Today, small and medium enterprises (SME) have to struggle with large corporations and survive under the pressure of competitiveness on the global market. The thesis is dedicated to the problem of collaboration between SMEs. The goal of the current research is to develop a partner selection tool for increasing the capability, capacity and flexibility of SMEs without incurring significant investments. The idea is to combine the available resources of SMEs into a new SME network, called Sustainable Partner network (SPN). If an opportunity appears on the market, the SPN forms a new organisation (virtual enterprise VE) to utilise the resources of the SMEs in order to realise particularly large project tasks and customer expectations.

It was found that appropriate partner selection is a vital success factor in any collaboration. The partner selection procedure is a complex task that requires a sophisticated approach to find the best solution in the shortest time, but personnel and resources are limited for this critical action. The thesis fills the research gap by enabling a new agile partner selection tool that considers partner efficiency, number of transfers and risks diversification. The thesis presents a calculation tool to provide greater certainty in the decision-making process and to consider the multiple criteria. Consequently, the focus incorporates the usage of the fuzzy set theory, TOPSIS and AHP mathematical methods.

The developed partner selection tool evaluates companies inside the SPN and proposes the most efficient way for VE formation according to the decision maker preferences. However, the decision maker has the option to analyse all the proposed VE formation ways and choose its most appropriate way for the particular case.

The thesis provides a feasibility case study for findings approval, where several SMEs from the field of machining collaborate to achieve a common goal. The proposed approach is adaptable to any other field where the best partner is selected based on a set of criteria.

The current research presents a SPN framework that solves the previously described problem by offering an alternative to the existing global market layout, which nowadays is governed by large corporations.

KOKKUVÕTE

Partnerite valiku metoodika virtuaalettevõtetele VKE-de võrgustikus

Tänapäeva väike- ja keskmise suurusega ettevõtted (VKEd) on sunnitud konkureerima suurte ettevõtetega, püüdes maailmaturu karmides konkurentsitingimustes ellu jääda. Käesolev doktoritöö on pühendatud VKEde koostööprobleemidele. Uurimistöö eesmärgiks on arendada partnerite valimise metoodikat nii, et oleks võimalik suurendada VKEde võimalusi, potentsiaali ning paindlikkust ilma lisanduvate kuludeta. Idee seisneb VKEde olemasolevate ressursside ühendamises uude VKE võrgustikku, milleks on jätkusuutlik partnerite võrgustik (SPN – *Sustainable Partner Network*). Juhul, kui turul tekib ärivõimalus, formeerib SPN uue organisatsiooni (virtuaalse ettevõtte – VE), et kasutada VKE ressursse tekkinud ärivõimalusega seotud projekti eriti suurte eesmärkide realiseerimiseks ning klientide ootuste täitmiseks.

On tõestatud, et sobiva partneri valimine on mis tahes koostöö aspektist äärmiselt tähtis. Partneri valimine on keeruline ülesanne, mis eeldab parima valiku tegemist piiratud aja jooksul ja limiteeritud personaliressursse kasutades. Käesolev doktoritöö täidab uuringutes oleva lünga, tuues esile partnerite valiku paindlikkuse mehhanismi, mis arvestab partneri efektiivsust, tarnemahtu ning riskide jaotamist. Doktoritöös esitatud arvutuskäik aitab teha valikut ebakindlates tingimustes mitme kriteeriumi analüüsimisel. Uurimistöös on kasutatud Theory of Fuzzy Set, TOPSIS ja AHP matemaatilisi meetodeid.

Välja töötatud partnerivaliku metoodika hindab ettevõtteid SPN'i raames ning pakub efektiivseima variandi VE formeerimiseks, lähtudes otsustaja eelistustest. Samas jääb otsustajale võimalus analüüsida kõiki VE loomise alternatiivseid variante, et valida neist sobivaim konkreetsest juhtumist lähtuvalt.

Doktoritöös kirjeldataks väljatöötatud metoodika tõestamiseks reaalset olukorda, kus mitmed tootmisvaldkonna VKEd on ühinenud ühise eesmärgi saavutamiseks. Pakutav metoodika on kohandatav ka mis tahes muus valdkonnas, kus parima partneri valimine põhineb mitmetel kriteeriumidel.

Käesolev uurimistöö pakub alternatiivi praegu maailmaturul kehtivale suurettevõtete poolt reguleeritud turujaotusele, lahendades eelkirjeldatud probleemi SPN raamistiku kaudu.

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APPENDIX

Part A

Partner Network Questionnaire

(developed by using website https://www.surveymonkey.com/)

1. What are the business objectives of your company?

- ☐ Increase productivity of the personal
- ☐ Minimise the machines idle time
- ☐ Minimise number of defects
- ☐ Minimise number of reclamations

2. Which of the following business processes are described in your company?

- ☐ Design
- ☐ Sales
- ☐ Purchase
- ☐ Planning
- ☐ Manufacturing
- ☐ Quality control

3. What is your Company Location (address, office, workshop, etc.)

4. What operations are you ready to subcontract?

- ☐ Turning
- ☐ Milling
- ☐ Deep Boring
- ☐ Grinding
- ☐ Sawing
- ☐ Drilling

- ☐ Flame cutting
- ☐ Tooth-cuttings
- ☐ Mortising
- ☐ Bending
- ☐ Welding
- ☐ Pressing
- ☐ Short blasting
- ☐ Painting

5. What certificates does your company hold?

- ☐ ISO 9001
- ☐ ISO 14001
- ☐ OHSAS 18001

6. What diplomas or achievements does your company hold?

7. Means for communication with your company (phone, e-mail, fax, etc.).

8. Contact person at Collaboration Network (name, surname, contact phone, e-mail)

9. What is the expectation of your company of the Partner Network?

- ☐ Increase company profit
- ☐ Find new resources
- ☐ Project management
- ☐ Participate in collaborative projects

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Educational institution	Graduation year	Education (field of study/degree)
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Tallinn University of Technology	2003/2005	BSc in Engineering
Tallinn School of Informatics and Computing	1998/2001	Vocational education
Tallinn Vana-Kalamaja Gymnasium	1998/2000	Secondary education

4. Language competence/skills (fluent, average, basic skills)

Language	Level
Estonian	Fluent
Russian	Fluent
English	Fluent

5. Professional employment

Period	Organisation	Position
2002 –….	Densel Baltic OÜ	Production engineer
2006–2007	Agrico Eesti OÜ	Design engineer
2006–2006	Pioneer AS	Design engineer

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Tallinn Tehnikaülikool	2003/2005	Tehnikateaduste bakalaureusekraad
Informaatika ja Arvutustehnika kool	2000/2001	Kutseharidus
Vana–Kalamaja Gümnaasium	1999/2000	Keksharidus

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti keel	kõrgtase
Vene keel	kõrgtase
Inglise keel	kõrgtase

5. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2002–….	Densel Baltic OÜ	Tootmisinsener
2006–2007	Agrico Eesti OÜ	Arendusinsener
2006–2006	Pioneer AS	Arendusinsener

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-Bonded Hardmetals. 1992.

2. **Jakub Kõo**. Determination of Residual Stresses in Coatings &Coated Parts. 1994.

3. **Mart Tamre**. Tribocharacteristics of Journal Bearings Unlocated Axis. 1995.

4. **Paul Kallas**. Abrasive Erosion of Powder Materials. 1996.

5. **Jüri Pirso**. Titanium and Chromium Carbide Based Cermets. 1996.

6. **Heinrich Reshetnyak**. Hard Metals Serviceability in Sheet Metal Forming Operations. 1996.

7. **Arvi Kruusing**. Magnetic Microdevices and Their Fabrication methods. 1997.

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10. **Irina Hussainova**. Investigation of Particle-Wall Collision and Erosion Prediction. 1999.

11. **Edi Kulderknup**. Reliability and Uncertainty of Quality Measurement. 2000.

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