DECISION SUPPORT SYSTEM PROPOSAL FOR MANAGING FLEXIBILITY OF AUTOMOTIVE INDUSTRY SUPPLY CHAIN

(OTOMOTİV ENDÜSTRİSİ TEDARİK ZİNCİRİNDE ESNEKLİK YÖNETİM SİSTEMİ ÖNERİSİ)

by

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Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

M.SC.

in

INDUSTRIAL ENGINEERING

in the

INSTITUTE OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

May 2015

This is to certify that the thesis entitled

DECISION SUPPORT SYSTEM PROPOSAL FOR MANAGING FLEXIBILITY OF AUTOMOTIVE INDUSTRY SUPPLY CHAIN

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ACKNOWLEDGEMENTS

First of all, I would like to express my special thanks and gratitude to my supervisor and mentor, Assist. Prof. Dr. Mujde Erol GENEVOIS who supervised me to carry out this study.

It is my pleasure to express my special thanks and sincere appreciations to my friends Özcan Armağan AYAN and Gökberk YILDIRIM for their cooperation and support. I would like thank to all my instructors in the university who helped me during my education.

Finally, a very special note of appreciation and thanks to my mother Güler GÜRE, my father Halit GÜRE for their help and support throughout my education and life. I would like to express my special thanks to Öyküm Bahar ESEN, for her patience, encouragement, support.

May 2015
Uğur GÜRE

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LIST OF SYMBOLS

AHP : Analytic Hierarchy Process
ANP : Analytic Network Process
WSM : The Weighted Sum Model
WPM : The Weighted Product Model
ELECTRE : Elimination and Choice Translating Reality
AISC : Automotive Industry Supply Chain
MCDM : Multi-Criteria Decision Making
TOPSIS : Technique for Order Preference by Similarity to Ideal Solution
BOCR : Benefits, opportunities, costs, and risks

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RÉSUMÉ

Compte tenu des développements technologiques et le profil de l'évolution des clients, pour les producteurs de ne pas perdre des clients a été très difficile jour après jour et études ont été faites pour cette question de fait. Le terme de flexibilité élevé afin de répondre à l'évolution des demandes des clients et de se conformer aux conditions de marché incertaines.

La flexibilité est définie comme la capacité d'une entreprise à se adapter à des incertitudes et types de flexibilité sont décrits dans un certain nombre d'études. Le but de cette étude est de déterminer et définir des types de flexibilité dans l'industrie automobile, pour modéliser les flexibilités qui sont difficiles à atteindre et coûteux, à budget limité, et de créer et d'offrir un système d'aide à la décision déterminer quels types de flexibilité sont plus importants.

Les définitions ont été créés avec un examen approfondi de la littérature, multi critères décisionnels systèmes ont été analysés pour le modèle de solution et la méthode ELECTRE III favorable et critères pèse dans la matrice de performance qui sont nécessaires pour l'utilisation de ce modèle est combinée avec la méthode ANP. Pour la création de tableaux, je travaillais avec les experts de l'industrie.

Les types de flexibilité qui ont été choisis en raison des résultats, des suggestions pour la chaîne de l'industrie automobile et de leurs difficultés d'approvisionnement sera le sujet principal des prochaines études.

Mots-clés : ELECTRE, ANP, MCDM, flexibilité

ABSTRACT

Considering the technological developments and the changing customers' profile, for the producers not to lose customers has been very difficult day by day and studies have been done for this matter of fact. The term flexibility raised in order to answer the clients' changing demands and complying with the uncertain market conditions.

Flexibility is defined as a company's ability to adapt itself to uncertainties and flexibility types are described in a number of studies. The aim of this study is to determine and define flexibility types in automotive industry, to model flexibilities which are hard to reach and expensive, in limited budget, and create and offer a decision support system determining which of the flexibility types are more important.

The definitions were created with an extensive literature review, multi criteria decision making systems were analyzed for solution model and favorable ELECTRE III method and criteria weighs in performance matrix which are necessary for using this model is combined with ANP method. For creating tables, I worked with the experts from the industry.

The flexibility types which were chosen due to the results, suggestions for the supply chain of automotive industry and their difficulties will be the main subject of the next studies.

Keywords: ANP, ELECTRE, MCDM, flexibility

ÖZET

Teknolojik gelişimler ve müşteri profilinin değişmesiyle üreticiler için müşterilerini kaybetmemek her geçen gün daha da zorlaşmakta ve bunu başara bilmek için de çalışmalar yapılmaktadır. Bu konuda, değişen müşteri taleplerine cevap vermek ve belirsiz piyasa koşullarına uyum sağlamak için esneklik kavramı ortaya atıldı.

Esneklik, bir şirketin belirsizliklere karşı uyum gösterebilme yeteneği olarak tanımlandı ve çeşitleri birçok çalışmada tanımlandı. Bu çalışmanın amacı, otomotiv sektöründeki esneklik çeşitlerinin tespiti ve tanımlarını yaparak, ulaşılması zor ve maliyetli olan esneklikleri modelleyip, sınırlı bütçe ile hangi esnekliklerin daha önemli olduğunu tespit edecek karar destek sistemini oluşturmak ve çözmektir.

Tanımlar geniş bir literatür taraması ile oluşturulmuş, çözüm modeli için tüm çok kriterli karar destek sistemleri incelenmiş ve uygun olan ELECTRE III metodu, ve bu modeli kullanabilmek için performans matrisinde gerekli olan kriter ağırlıkları için ise ANP metodu ile kombine edilmiştir. Tabloların doldurulmasında sektörün içinden experler ile çalışılmıştır.

Sonuçlara göre seçilen esneklikleri, otomotiv endüstrisi tedarik zincirine uygulama önerileri ve zorlukları bundan sonra yapılacak olan çalışmaların ana konusu olacaktır.

Anahtar kelimeler : MCDM, ELECTRE, ANP, esneklik

1. INTRODUCTION

Rapid technological advance had a great impact on life. Customers started to desire more than it is offered and so competition is severely evolved. This competition is a marathon of endurance, power and wisdom. To ensure an efficient organization, investments, such as new tech equipment, adaptation of new business models, experienced and talented human resources, marketing etc. are required. In the competitive market, dynamics are changing fast.

To reach the evolution of the demand, flexibility approach is created. Flexibility can be easily defined as, the ability to cope with uncertainties. These uncertainties are generally created from customers, internal and external processes, suppliers, legislations or from the environment itself. An industrial nation’s economic future may lie in flexible systems (Gerwin, 1993). When the expectations were limited, having flexible systems wouldn’t be a primal target. 1960’s Ford type production was just responding to the customers who want to buy a standard. Now customers are not the same. New terms are created such as customization. Customized products even determine a nation’s economic future and also are important for efficient and sustainable development in the market. Integrating flexibility into an industry facilitates a true competitive advantage and long-term sustainable gain.

Automobile manufacturers today compete in an increasingly global environment. An important part of the equation for competing in today's automotive industry is flexibility. Cadences are tightening to respond to market demands, but manufacturers need to be even more flexible than that. Inflexibility equals lost opportunities. Today's manufacturing line needs to be flexible and agile, which has come about through configurability, distributed control and plug-and-play capabilities. Obviously, the flexibility is deployed more often in segments with higher proportion of flexible competitors. The association between flexibility and competition is particularly strong in the automotive sector in which manufacturers use flexibility as a competitive weapon (Fine and Pappu, 1990). Euro-Car segmentation has nine segments:

- A - Basic - Economy car - City car
- B - Small
- C - Lower Medium
- D - Upper Medium
- E - Executive
- F - Luxury
- S - Sports
- M - Multipurpose cars
- J - Sport utility cars

This study is focused on passenger cars and on segments which are most preferred by customers according to sales numbers. Only four segments will be investigated; A-Basic, B-Small, C-Lower Medium, D-Upper Medium. For a clear understanding, Ford Ka is an example to A class, Volkswagen Polo is an example to B class, Toyota Auris is an example to C class and BMW 3 series is an example to D class cars.

In this paper customer expectations satisfaction via adapting automotive industry supply chain (AISC) flexibility will be studied. Flexibility is defined as the capacity of responding against uncertainties created by various causes in the environment. Possible actions to ensure flexibility are called as levers of flexibility and their performance evaluation tools are called metrics of flexibility. First automotive industry and AISC will be briefly presented via its three actors expectations; supplier, producer, customer (Genevois et al., 2013). Second the concept of flexibility and its importance in AISC will be investigated. Third the methodology including the analytic network process (ANP) and ELECTRE III techniques for prioritizing evaluated flexibility levers will be presented. Finally the outcome will be discussed according to the results, and possible investments will be proposed.

2. AUTOMOTIVE INDUSTRY

Automotive industry is composed of organizations and companies which are involved in design, development, manufacturing, marketing and selling of motor vehicles. The automotive industry plays an important role in overall business cycle developments. The status of automotive industry is a key indicator for a nation's development. It is one of the biggest economic sectors in the world by revenue. Automotive industry is also highly dependent to energy sector which designates a nation's global politics. Compounded annual growth rate of the industry is more than 4%. Automotive industry has a multinational portfolio of suppliers, producers and customers.

2.1. Automotive Industry Supply Chain

Supply chain is the flow of materials (Figure 2.1), financials and services from the first supplier to the final consumer (Figure 2.2). Globally, all industry's supply chain costs as a percent of sales is 52%, but in automotive sector this ratio is about 67% (Heizer and Render, 2008). An automobile is composed of twelve thousand components by average. That's why automotive industry's ratio exceeds the average. Every supply chain has three aspects which are customer, producer and supplier. In AISC, all these three aspects have distinctive and also some common expectations; such as cost-minimizing, efficiency, technological advance, sustainability, environmentally friendly production, endurance, reliability etc...

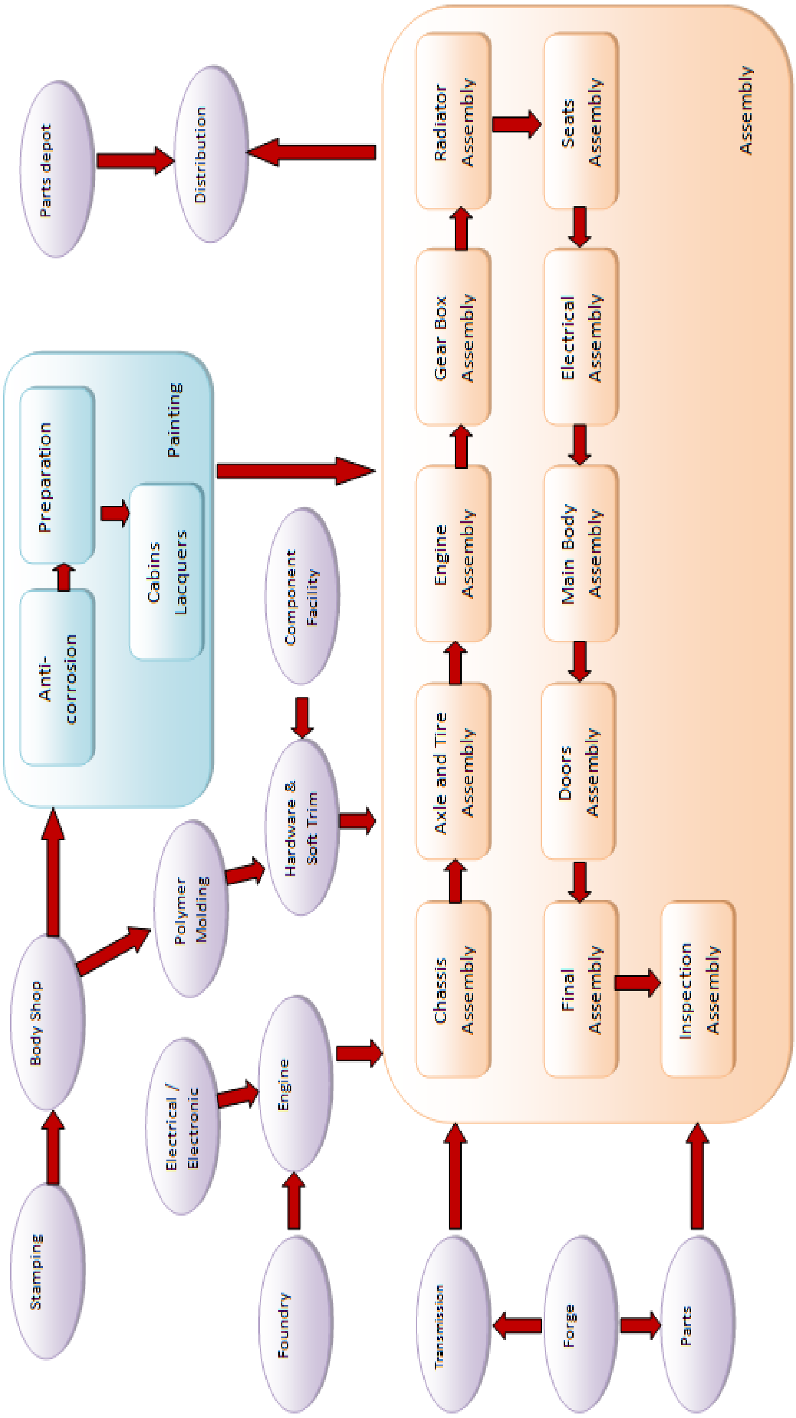


Figure 2.1: Material flow chart for automotive industry

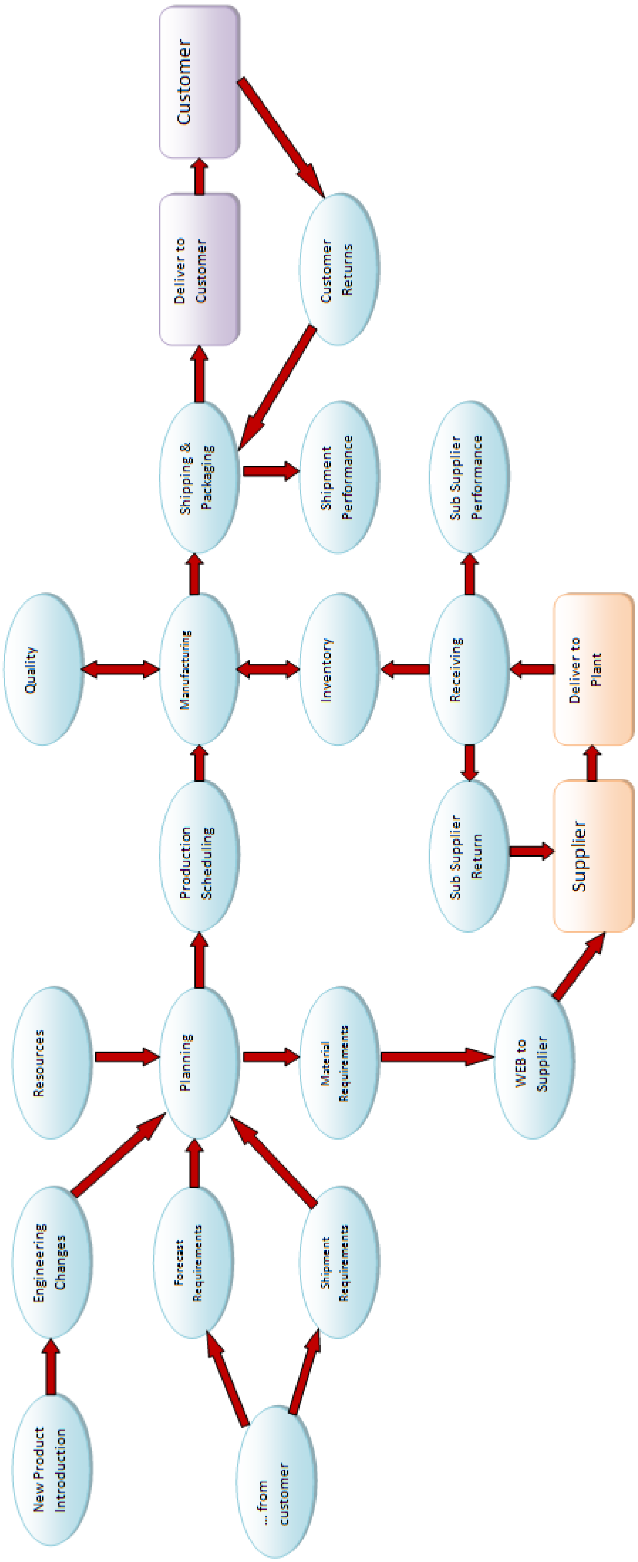


Figure 2.2: Information flow chart for automotive industry

Customer expectations from AISC are considered as; customization, high responsiveness, delivery reliability, right quality, after sales services.

Customization is to provide individually designed products and services to meet customers' diverse and changing needs. The concept has emerged in the late 1980s and may be viewed as a natural follow up to processes that have become increasingly flexible and optimized regarding quality and costs (Silveira et al. 2001).

Responsiveness can be defined as the "ability to react purposefully and within an appropriate time-scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage" (Holweg, 2005). To keep this feature up companies are obliged to construct flexible systems and manage them with strategic behavior.

Delivery reliability is the capacity of meeting the true demand in scheduled time interval. As a competitive advantage delivery reliability is a key factor which affects the entire supply chain. Many approaches are generated; as short delivery cycles, superior quality and reliability (Skinner, 1974). Delivering process is being observed mostly multiple times in a supply chain.

Right quality is a must and integrated part of efficiency. Right good, right time, right customer, right place compose other components of efficiency.

After-sales service, in firms manufacturing and selling durable goods has a strategic relevance in its potential contribution to company profitability, customer retention and product development (Saccani et al. 2007). After-sales service's industry and income is multiple times higher than the original product's. After sales service is a key business sustaining longer product life cycle and higher brand reliability to customer.

Manufacturing firms aim to achieve the highest levels of performance along areas such as quality, flexibility, delivery and costs (Sarmiento et al. 2010). In this study main producer and supplier expectations from AISC are considered as; process optimization, supply reliability, loyal customer, minimum consumption of resources, effective risk management.

Process optimization is a tangible gain for optimizing the operations of supply, manufacturing and distribution activities of a company to reduce costs and inventories. The key features of process optimization are integration of the information and the decision-making among the various functions that comprise the supply chain of the company (Grossmann, 2005).

Supply reliability is compulsory for fewer late orders, and a decrease in problems with delivered quality, quantity, or mix (Walton and Marucheck, 1997). Supply reliability depends on the relation with suppliers. One of the most common methods to generate supply reliability is procurement contracts. Various types of deals exist and procurement contracts are vital for the debut of the supply chain process.

Loyalty brings the sustainability of the provided business. More customers are satisfied, more products are being repurchased. The development, maintenance, and enhancement of customer loyalty represent a fundamental marketing strategy for attaining competitive advantage (Ellinger, 1999).

Minimum consumption of resources brings economic advantage; every firm desires to maximize their profit, so we have the equation minimum input for maximum output. Nature, all other market participants, even all internal activities cause risk and uncertainty. A firm must be ready for unexpected situations such as supply problems, breakdowns, unpredictable increase or decrease of demand, new governmental regulations etc.

3. FLEXIBILITY

We defined flexibility as the capacity of adaptation under the double constraint of uncertainty and the urgency. This uncertainty can come from the providers (rupture, problems of transport), from the customers (variation of the request) or from the company itself (breakdowns of the equipment, problems of provisioning) (Genevois and Ulukan, 2012).

Investment channels of the automotive sector are broad and multinational. Also automotive sector has a high ratio of supply chain cost to revenue. Various drivers should cooperate to ensure efficiency in a supply chain. A key dimension of supply chain performance is flexibility; the ability to be adapted to internal and external capabilities or a reaction to environmental uncertainty (Vickery et al., 1999).

In literature, it is easy to find various previous studies on flexibility in automotive sector. Barad and Sapir in 2003 studied logistics flexibility. They presented flexibility types and quantitatively investigated one of the dimensions.

Sanchez and Perez in 2005 studied supply chain flexibility and firm performance. They clearly defined supply chain flexibility and its subdivisions. Then they made a survey between suppliers of automotive sector to determine which of supply chain flexibility levers is the most favorable. Finally they defined supply chain evaluation metrics and concluded with the correlation matrix of levers and metrics.

Erol Genevois and Gurbuz in 2009 studied flexibility in automotive sector and utilized fuzzy hierarchical process method to determine flexibility levers which can best meet the customer satisfaction.

Gerwin in 1987 used mix, changeover, modification, rerouting, volume, material and sequence flexibilities as flexibility types. Browne's original taxonomy of flexibility types are in 1984; machine, process, product, routing, volume, expansion, operation and production flexibility. In 1990, Sethi added market and program flexibility to Browne's taxonomy.

Beach et al. in 2000, defined and studied machine flexibility, labor flexibility, material handling flexibility, routing flexibility, operation flexibility, expansion flexibility, volume flexibility, mix flexibility, new product flexibility, modification flexibility.

3.1. Flexibility Types and Levers

In this study, automotive industry supply chain flexibility is examined in two main aspects. First is process flexibility and this is only focusing to product manufacturing process. Second one is logistics flexibility and this is related to the different logistics strategies which can be adopted either to release a product to a market or to procure a component from a supplier. (Sánchez and Pérez, 2005)

Five main flexibility types are; mix flexibility, adaptation flexibility, quick design change flexibility, delivery flexibility and volume flexibility. Mix flexibility is adopted to deal with uncertainty about the products that will be demanded by customers at a particular period (Gerwin, 1993). Volume flexibility of a manufacturing system is its ability to be operated profitably at different product overall output levels (Narain et al., 2000). Mix Flexibility and Volume Flexibility studied by (Slack, 1988), (Suarez et al. 1991, 1996), (Chambers, 1992), (Chen et al., 1992), (Olhager, 1993), (Gerwin, 1993), (Upton, 1994), (Nilsson and Nordahl, 1995) and (Olhager and West, 2002) in the literature. Quick design change flexibility is required to ensure company's continuous competitiveness in the market. Adaptation flexibility is the capability of a manufacturing system that enables it to adapt rapidly and inexpensively to changes in its internal and external operating environment. For example, if a manufacturing system can make rapid and inexpensive implementation of engineering design changes for a particular product, it possesses adaptation flexibility (Paul M. Swamidass, 2000).

Delivery flexibility (Nilsson and Nordahl, 1995), (Suarez et al. 1991, 1996), (Slack, 1988) is the company's capability to adapt lead times to the customer requirements (Sánchez and Pérez, 2005).

The possible behaviors of the company to increase flexibility are called levers of flexibilities. Twelve levers of flexibility respect to literature will be decision making, planning/scheduling, sequencing, material, labor, changeover, design/development, financial resources, machine/equipment, expansion, transport/shipping and routing flexibility.

Sequencing flexibility is a measure of alternate feasible sequences that can be used to schedule the operations of a job in a manufacturing system (R. Rachamadugu, U. Nandkeolyar and T. Schriber, 1993).

Material flexibility is the ability of the production function to handle unexpected changes in inputs. The appearance of the range includes the number of different types of significant variations in their amplitudes and setting. The temporal aspect reflects how long it takes to make an adjustment. Material flexibility helps to reducing defects; therefore, it facilitates the strategic objective of product quality (Gerwin, 1993) also, reduces pressures on upstream activities to eliminate quality problems (Nevins et al., 1989).

It is well known that the organization team of the workforce can promote economic efficiency of the enterprise and skill levels of workers have a great effect on the productivity of the company. Labor flexibility is the ability to change the number of workers, the tasks performed by workers, and other responsibilities of workers (Narain et al., 2000). The idea of using a multifunctional labor is called labor flexibility; this is achieved by cross-training operators in different tasks (Cesani and Steudel, 2005). The working time is a suitable index to reflect this ability. A skilled worker completes a specific task in a short period, but the unskilled does not. Therefore, we use the time and effort needed by operators to complete tasks as a factor affecting flexibility to reflect the labor flexibility (Gong, 2008).

Changeover flexibility, ability to quickly replace new products for those currently offered, is required in the manufacturing process. A company manages this type of uncertainty through the strategic objective of product innovation (Gerwin, 1993).

Machine flexibility is defined as the ease with which a machine can change between the different process jobs (J. Browne et al., 1984).Research on the flexibility of the machine includes the setup time of the machine and built a model whose objective is to optimize the machine setup time (P. Chandra, M.T. Mihkel, 1992). Machine flexibility is the most fundamental flexibility lever.

The size range Machine flexibility is measured as the aggregate of the different tasks, it is able to perform. This measure, also known as the versatility of the machine, can be normalized as the ratio of all the tasks that the manufacturing system can perform. On the dimension of response is measured by the length of its preparation tasks. These can be related to the time required for changing tools in a tool store, the time of a positioning tool, etc. (Barad and Sapir, 2003).

Expansion flexibility of a manufacturing system is how easily the quality and the capacity can be increased if necessary (Narain et al. 2000).

Routing flexibility is defined as the ability to manufacture a product via several alternative routes in the same facility (Das, S. and Nagendra, P. 1997). This flexibility reduces the negative impact of environmental uncertainty and unforeseen inefficiencies in the production process (Gupta and Buzacott, 1989). For a given number of machines in the system, the flexibility of routing will increase the individual versatility of the set of machines. The logic of routing flexibility is to cope with short-term disruptions, such as breakdowns and changes in the requirements for alternative manufacturing options. To achieve these options not only versatile machines are necessary, also the flexible material handling and flexible transportation network are necessary (Barad and Sapir, 2003).

Flexibility types and levers are chosen according to automotive industry supply chain needs from the literature. Aim of this study is building a new model for managing flexibility in automotive industry. Measuring flexibility and its gains are very hard and with today's knowledge level, we cannot give exact values for flexibility and their importance for the company. In our model, flexibility types and levers ranked in order to multiple criteria and objectives like "increasing flexibility" and "satisfy expectations of supply chain elements". For solving this model, -with multiple criteria and not exact data-, Multiple Criteria Decision Making (MCDM) methods are most suitable methods. Three experts from the automotive industry worked on this model.

4. MULTI-CRITERIA DECISION ANALYSIS

Multi-Criteria Decision Analysis has seen a huge amount of use in last years. Its role in different application domains has increased significantly, especially as developing new methods and improving old methods.

Multi-criteria decision making (MCDM) is problem areas which is one of the fastest growths for the past decades. In business, decision making process has developed from one person and the profit as a single criterion to multi-person, multi-criteria situations. In practice, the awareness of this development has been increasing and in theory, many methods have been proposed and developed to solve decision problem in various ways.

Majority of MCDM problems cannot be solved by mathematical programming and discrete mathematics. Choosing the best methods for MCDM is most difficult and important thing to solve the problem. In this paper, we will review the methods for identify which methods are most suitable in case of managing flexibility in supply chain (Triantaphyllou, 2000).

The most significant challenge for engineers is how to get optimal solution or make decisions for defined problems. This has been the most significant challenge from ancient Egypt or classical Greece to present and probably in future. In history, old methods have been replaced with modern science, scientific disciplines such as computer science, operations research, statistics etc. developed. These disciplines aid people to make the best decision for a given problem. Dynamic and linear programming, multi-criteria decision making, hypothesis testing etc. are for searching For an optimal decision. Multi-criteria decision making (MCDM) is most popular class of methods which has alternatives, decision criteria and finding the best alternative.

Multi-criteria decision making has different forms. The criteria, the alternatives or related data may not be well defined. In some cases, problem structure can be multi-level hierarchy; some data can be fuzzy or stochastic.

In this paper, we will review weighted sum model, the analytic hierarchy process, the weighted product model, TOPSIS and ELECTRE methods for choosing right method for supply chain flexibility problem (Zimmermann, H., and L. Gutsche., 1991).

General Overview

Multi-criteria decision making (MCDM) is one of the most popular and well-known subject for decision making. MCDM methods have common notions;

-Alternatives:
Alternatives are defined as different choices of action to the decision maker.

-Multiple Attributes:
Attributes are referred to as “goals” or “decision criteria”. Attributes represent different dimensions from which the alternatives can be viewed. If the number of criteria is more than ten for example, they may be in a hierarchical structure. It means some of the criteria are major and they possibly have sub-criteria. Also sub-criterion could have sub-sub-criteria.

-Incommensurable Units:
This is nature of MCDM problems. Some criteria have different units of measure so it is hard to compare and solve a specific decision problem. For instance, in case of buying car, cost may be measured in dollars, but safety or emission values will be measured with different units.

-Decision Weights:
All the criteria have different importance for the decision problem, usually the weights of criteria normalized.

-Decision Matrix:

The matrix which has performance of alternatives can be built in most of MCDM problems (Triantaphyllou, 2000).

	Criteria				
	C_1	C_2	C_3	…	C_n
Alts.	(w_1	w_2	w_3	…	w_n)
A_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
⋮	⋮	⋮	⋮	⋮	⋮
A_m	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}

Figure 4.1: A Decision Matrix

4.1. Multi-Criteria Decision Making Methods

There are three steps in the use of any decision making methods involving numerical analysis of alternatives:

a) Define the criteria and alternatives

b) Attach numerical measures of the relative importance of the criteria and the impact of options on these criteria.

c) Determine a ranking for each alternative

4.1.1. The WSM Method

The weighted sum model (WSM) is mainly used in single dimensional problems. In single dimensional cases, where all the units are identical (e.g., dollars, seconds), the WSM can be used easily. Complication with this method however, emerges when it is applied to multi- dimensional MCDM problems. For this case, in combining different dimensions and consequently different units, the additive utility assumption is violated and the result becomes equivalent to "adding apples and oranges"(Triantaphyllou 2000).

Assume that a particular problem is defined MCDA on m alternatives and n decision criteria. Furthermore, we assume that all the criteria are criteria for benefits, that is, the higher the values are, the better.

Next assume that w_j is the relative weight and importance of the criterion C_j and a_{ij} is the value of the performance of the Ai when evaluated in terms of the criterion Cj.
Then, the total importance of A_i, noted as $A_i^{\text{WSM-score}}$ is defined as:

$$A_i^{\text{WSM-score}} = \sum_{j=1}^{n} w_j a_{ij}, \text{ for } i = 1, 2, 3, \ldots, m.$$

In the case of maximization, the best alternative is one that gives the total maximum value of the performance.

Strengths of WSM

- Like all MCA methods, weighted summation helps structuring a problem. By classifying the problem in a variety of objectives, criteria for measuring objectives and alternative options weighted summation provides a structured approach to address the problem. Weighted summation accommodates quantitative and qualitative information.
- Provides transparency of the evaluation process, because of its simple, easy to explain methodology. It is very suitable for use in the participatory process.
- If used in a participatory way, WSM can integrate diverse perspectives of stakeholder groups to build the tree of criteria, developing alternative solutions for the problem and prioritize the criteria. In addition, stakeholders can use the method of reasoning tool to support and improve the negotiations.
- To apply a WSM effective, good software support is essential. Much software is available to implement WSM. An advantage of using software is using sensivity analyses for test the robustness.

Weaknesses of WSM

- The hypothesis of compensability between the criteria and the loss of information due to standardization. Furthermore, the allocation of weights is a difficult task, especially if the number of criteria is big and the criteria are very different in character.
- WSM can be applied only if the attributes are additive.

4.1.2. The WPM Method

The Weighted Product Method (WPM) was introduced by Bridgeman. The method has a sound logic and the calculation is simple, but has not been widely used.

The weighted product model (WPM) is very similar to the WSM. The main difference is instead of addition, in this model, there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion.

The best alternative is the one that is better than or at least equal to all other alternatives. The reason why the WPM is sometimes called dimensionless analysis is that its structure eliminates any units of measure. Thus, the WPM can be used in single- and multi-dimensional MCDM. Instead of the actual values, using relative ones is an advantage of this method (Triantaphyllou 2000).

4.1.3. The Analytic Hierarchy Process

The analytic hierarchy process (AHP) (Saaty, T.L., 1980) decomposes a complex MCDM problem into a system of hierarchies. The importance of the AHP, its variants, and the use of pairwise comparisons in decision making is best illustrated in the more than 1,000 references cited in (Saaty, T.L., 1994). A number of special issues in refereed journals have been devoted to the AHP and the use of pairwise comparisons in decision making.

The similarity between the WSM and the AHP is clear. The AHP uses relative values instead of actual ones. Thus, it can be used in single or multi-dimensional decision making problems (Triantaphyllou 2000).

Many applications of the AHP have been made since 1970s. It has been used in Finland for analysis of nuclear vs non-nuclear energy, whether to construct a new nuclear power plant or not.

Application areas of the AHP:

- Accounting and finance
- Architecture and design
- Capital investment
- Conflict analysis
- Economics
- Decision Support
- Energy
- Group decision making
- Marketing
- Optimization
- Portfolio selection
- Risk analysis etc.

4.1.4. The Analytic Network Process

Some decision making issues cannot be structured hierarchically. Interactions and dependencies could be between all elements. Means, not just importance of criteria cause the importance of alternatives like in a hierarchy; also importance of alternatives causes the importance of criteria (Bottero et al. 2011). For modeling real world issues, Saaty proposed the Analytic Network Process (ANP). ANP is a Multi Criteria Decision Making (MCDM) tool considered to be an extension of Analytic Hierarchy Process (AHP) (Saaty, 2005). The ANP represents decision problems as a network of alternatives and criteria. All elements should be grouped into clusters. Figure 4.2 shows an example of networks between clusters. Network between C_4 and C_3 is an outer dependence of the elements in C_3 on the elements in C_4; loop in a C_3 or C_1 indicates inner dependence of the elements in that cluster with respect to a common property.

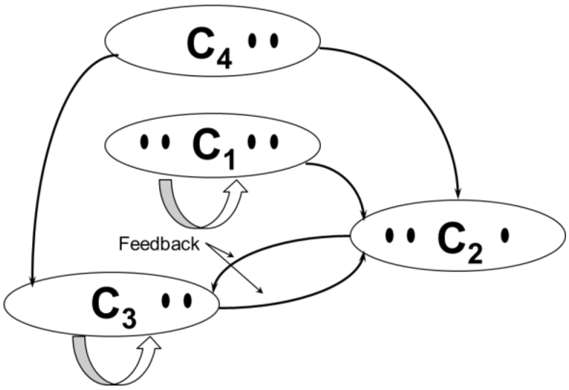


Figure 4.2: ANP networks and feedbacks

The power of analytic network process (ANP) is its use of rate scales to capture all kinds of interactions and make accurate forecasts and more, make better decisions. So far it has proven to be successful when expert knowledge has been used it to predict sports results, economic turns, commercial, social and political events.

ANP is the first mathematical theory that allows us to deal systematically with all kinds of dependence and feedback. The reason for its success is the way it raises judgments and uses the measurement of draw ratio scales. Priorities that ratio scales are so fundamental kind of number ready to perform basic arithmetic operations of addition in the same scale and multiplying significantly different scales as required by the ANP. Main steps of ANP:

Step I: Development of the structure of the decision-making process
Step II: Assessment of pairwise comparison
Step III: Supermatrix formation
Step IV: Final Priorities

In literature, there are many real world applications, for instance, used for supplier selection process in an automotive company (Kasirian et al., 2010), for evaluating Turkish mobile communication operators (Tosun et al., 2008), for environmentally conscious construction planning (Chen et al., 2005), for product mix planning in semiconductor fabricator (Chung et al., 2005), in process models like strategic planning (Cheng et al., 2007) etc.

4.1.5. ELECTRE

The ELECTRE (Elimination and Choice Translating Reality) method is based on dealing with "outranking relations". In other words it compares the alternatives by using pairwise comparisons among alternatives separately. We denote the outranking relationship of the two alternatives (A_iA_j) as $A_i \rightarrow A_j$, which signifies "even when the *i-th* alternative does not dominate the *j-th* alternative quantitatively". We can accept the alternatives as dominated which are surpassed by one or more criteria and which matches the remaining criteria. Under each criterion the ELECTRE method exerts the pairwise comparisons and by the help of physical or monetary values and threshold levels for the difference of these values the decision maker is able to show that he/she

- is indifferent between the alternatives
- has a weak/strict preference for one or two
- is not able to show any of these preference relations

Therefore, it is possible that the outranking relations, in other words, a set of binary relations of alternatives, be complete or incomplete. After it is asked to the decision maker to convey the relative importance of the factors by assigning weights and importance factors. Sometimes the ELECTRE method is not able to define the most preferred alternative because it is possible for it to be incomplete but it always gives us a bunch of leading alternatives. Therefore, as it eliminates the less favorable alternatives, it permits us to have a more clear view over alternatives. We use this method when there are some decision taking problems because of insufficient criteria with a large number of alternatives (Lootsma, 1990).

The method includes the five main steps (Triantaphyllou, 2000):

Step 1: Normalizing the Decision Matrix

In this procedure by the help of the following equation, we transform the elements of the decision matrix into "dimensionless comparable entries":

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}}$$

Therefore, the normalized matrix X where m is the number of alternatives, n is the number of criteria, and x_{ij} is the normalized preference indicator of the *i-th* alternative tested by the *j-th* criterion becomes:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 2: Weighting the Normalized Decision Matrix

In the second step, we multiply the importance weight factors of the corresponding decision criterion which are denoted as (w_1, w_2, w_3, ... , w_n) with each column of the X matrix.

Therefore, the weighted matrix Y becomes:

Y = XW

$$Y_{ij} = \begin{bmatrix} w_1x_{11} & w_2x_{12} & \cdots & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & \cdots & w_nx_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1x_{m1} & w_2x_{m2} & \cdots & w_nx_{mn} \end{bmatrix}$$

Where:

$$\mathbf{W} = \begin{bmatrix} w_1 & 0 & 0 & \dots & 0 \\ 0 & w_2 & 0 & \dots & 0 \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ 0 & 0 & 0 & \dots & w_n \end{bmatrix} \quad and \quad \sum_{i=1}^{n} wi = 1$$

Step 3: Determine the Concordance and Discordance Sets

The concordance set C_{kl} ofA_k and A_l for m≥k and l≥1 can be considered as the set of all the criteria which respects that A_k is preferred to A_l.
That is, the following is true:

$$C_{kl} = \{j, y_{kj} \geq y_{lj}\}$$

for j = 1,2,3, ... , n.

The complementary subset which can be shown as follows is called the discordance set:

$$D_{kl} = \{j, y_{kj} < y_{lj}\}, \quad \text{for } j = 1, 2, 3, \dots, n.$$

Step 4: Construct the Concordance and Discordance Matrices

The sum of the weights associated with the criteria taken from the concordance set forms the concordance index c_{kl} . In this step by the help of concordance index, the relative value of the entries in concordance matrix is calculated.

Here, the relative importance of alternative A_k with respect to alternative A_l is indicated by the concordance index. Apparently, 0 ≤c_{kt} ≤1.

$$c_{kl} = \sum_{j \in C_{kl}} w_j$$

for j = 1, 2, 3, ... , n.

We note that the entries of matrix C are not defined when k = I. The concordance matrix C can be shown as follows:

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \dots & c_{1m} \\ c_{21} & - & c_{23} & \dots & c_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ c_{m1} & c_{m2} & c_{m3} & \dots & - \end{bmatrix}$$

We show the level that a certain alternative A_k is worse than a rival alternative with discordance matrix D. We calculate the elements d_{kl} of the discordance matrix as follows:

$$d_{kl} = \frac{\max\limits_{j \in D_{kl}} \left| y_{kj} - y_{lj} \right|}{\max\limits_{j} \left| y_{kj} - y_{lj} \right|}$$

The discordance matrix can be shown as:

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \dots & d_{1m} \\ d_{21} & - & d_{23} & \dots & d_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \dots & - \end{bmatrix}$$

As with C matrix, the entries of D matrix are not defined when k=l and these two matrices are non-symmetric.

Step 5: Determine the Concordance and Discordance Dominance Matrices

While constructing concordance dominance matrix we respect the rule that alternative A_l can be dominated by A_k only if its corresponding concordance index c_{kl} is superior to a certain threshold value c.

The average concordance index indicates the threshold value f, so we can say that the following relation could be true:

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl}$$

And the elements of concordance dominance matrix determined as follows:

$$f_{kl} = 1, \quad \text{if } c_{kl} \geq \underline{c},$$
$$f_{kl} = 0, \quad \text{if } c_{kl} < \underline{c}.$$

In addition to this the threshold values (d) which are used in defining the discordance dominance matrix G could be defined by the following equations:

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl}$$

$$g_{kl} = 1, \quad \text{if } d_{kl} \geq \underline{d},$$
$$g_{kl} = 0, \quad \text{if } d_{kl} < \underline{d}.$$

Step 6: Determine the Aggregate Dominance Matrix

The elements of the aggregate dominance matrix E:

$$e_{kl} = f_{kl} \times g_{kl}.$$

Step 7: Eliminate the Less Favorable Alternatives

Looking at the aggregate dominance matrix we can derive a partial preference relation between alternatives. By using both the concordance and discordance criteria we can say that if $e_{kl} = 1$, then alternative A_k is preferred to alternative A_l.

We can simplify the matrix by eliminating any column(s) which have an element equal to one because we call the column of the aggregate dominance matrix is "ELECTREally" dominated by the corresponding row if matrix has at least one element equal to 1. So by doing this, we will get the best alternative which dominates all other alternatives.

Strong Features

● By the help of this method we are able to take into account the original data with respect to qualitative criteria.

● We are able to conserve the original performances of the actions no matter what are their nature of scale is. Thus, they let us to handle heterogeneous scales for modelling so many different subjects such as noise, delay, cost etc.

● As the weights cannot be interpreted as substitution rates we can conclude that the compensatory effects are not appropriate. From the beginning of the application due to the non-relevance of compensatory effects in ELECTRE method we are not obliged to use identical and adequate scales.

● The imperfect knowledge and arbitrariness caused by the construction of criteria can be found by the help of the indifference and preference thresholds modeled.

Some Applications Areas

- Agriculture and Forest Management
- Energy
- Environment and Water Management
- Finance
- Medicine
- Military
- Project selection
- Transportation

Real World Applications

- Sorting cropping systems (Arondel and Girardin, 2000).
- Land-use suitability assessment (Joerin et al., 2001).
- Greenhouse gases emission reduction (Georgopoulou, 2003).
- Participatory decision-making on the localization of waste-treatment plants (Norese, 2006).

- Assisted reproductive technology (Matias, 2008).
- Sustainable demolition waste management strategy (Roussat et al., 2009).

For different types of decision problems, different types of ELECTRE methods exist. Table 3.1 shows decision problems and methods.

ELECTRE I, ELECTRE Iv and ELECTRE Is are for choice problem, ELECTRE-Tri-B and ELECTRE-Tri-C are for sorting problem.

ELECTRE II, ELECTRE III and ELECTRE IV are ranking methods. ELECTRE III is the most used ranking method in the ELECTRE methods (Ishizaka et al. 2013). In this study, ELECTRE III is used with ANP for ranking flexibility levers.

4.1.6. The TOPSIS Method

TOPSIS (for the Technique for Order Preference by Similarity to Ideal Solution) was developed by Yo and Hwang as an alternative to the ELECTRE method. The basic of this method is selected alternative should have the shortest distance from the optimal solution and the farthest distance from the negative-ideal solution (Triantaphyllou 2000).

The steps of the TOPSIS method are presented:

Step 1: Construct the Normalized Decision Matrix
Step 2: Construct the Weighted Normalized Decision Matrix
Step 3: Determine the Ideal and the Negative-Ideal Solutions
Step 4: Calculate the Separation Measure
Step 5: Calculate the Relative Closeness to the Ideal Solution
Step 6: Rank the Preference Order

4.2. Method Selection

As a summary, in our problem structure, we have 5 main flexibility types in process and logistics, and 3 main components and their expectations. We also have flexibility levers for choosing the best actions for companies in case of managing flexibility (will be presented in application part). For ranking levers, we have performance matrix from automotive industry experts. Most suitable MCDM method is ELECTRE III method, which is most popular in the ELECTRE methods for ranking alternatives. Our problem is adapted to software, which is developed by Université Paris Dauphine. But the problem for solving ELECTRE is that weights of criteria, which we do not have, are requested in performance matrix of ELECTRE.

The solution to this problem is to use another method for obtaining weights of criteria. In our problem structure, there is no exact hierarchy, and for some networks, we have feedbacks too. AHP is not suitable because of these limitations, but ANP contains all of our demands. With our application, we were able to rate the flexibility levers that are not easy to measure and compare by using ANP and ELECTRE together (Genevois and Gure 2014).

Although, in literature, there is not any research that ANP is used with ELECTRE, there are researches in which two MCDM methods are used together. For instance, Integrated Fuzzy AHP and ELECTRE method were used for environmental impact assessment (Kaya, 2011). Also, FAHP and ELECTRE were used for network selection problem (Charilas et al., 2014). Moreover, AHP and ELECTRE were used for assessment of de-desertification (Sadehgiravesh et al., 2014).

5. APPLICATION: ANALYTIC NETWORK PROCESS AND ELECTRE III

For ranking flexibility levers from the most important to the less important one according to automotive industry supply chain needs and to decide to invest on the more profitable levers, combination of two MCDM techniques ANP and ELECTRE methods are used. Figure 5.1 shows the process.

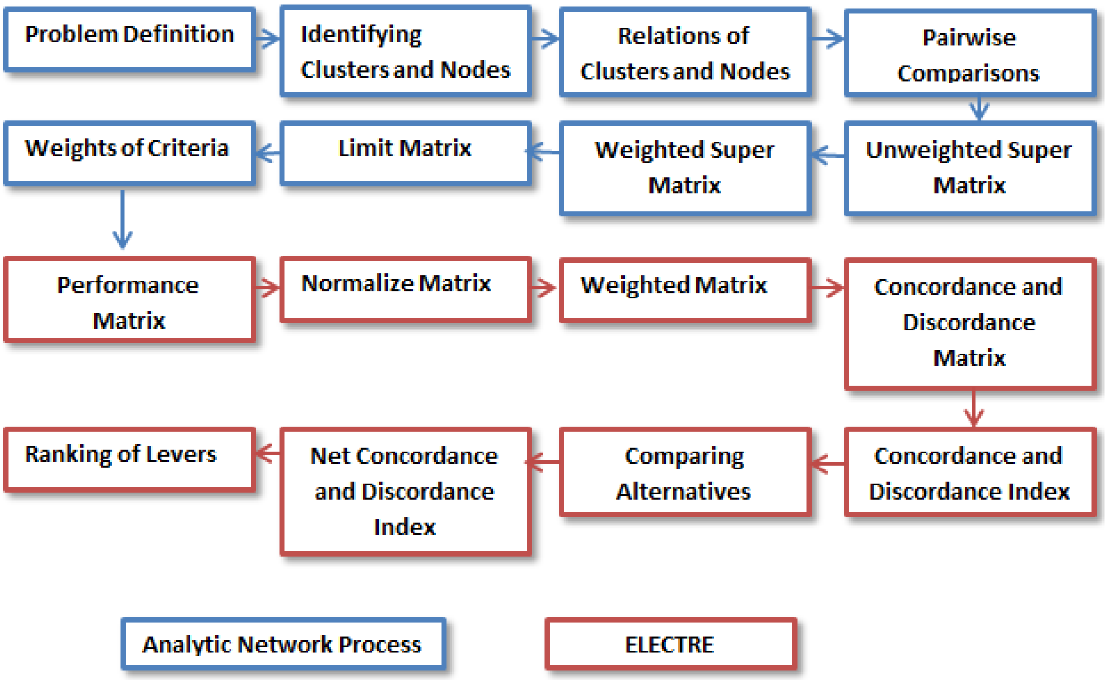


Figure 5.1: Application process

5.1. The Analytic Network Process

For first part, Super Decisions software is used for building the model and getting weights of criteria for ELECTRE method. This software can be downloaded for free from, http://www.superdecisions.com and tutorial from http://www.superdecisions.com/demos_tutorials.php3

Step I: Development of the structure of the decision-making process

Structure the problem is most important part for application. First all nodes should be listed and grouped into clusters. Secondly, the relationships between parts of the network have to be defined. Figure 5.2 shows nodes, clusters and all relationships between nodes.

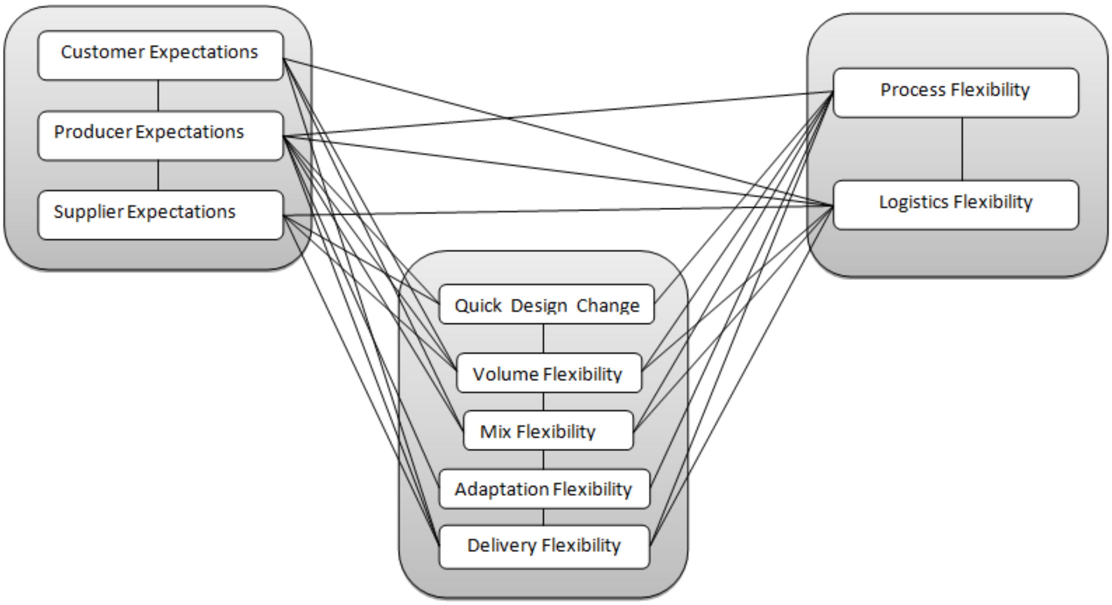


Figure 5.2: Problem structure

Step II: Assessment of pairwise comparison

All the nodes pairwise compared in the same cluster with respect to parent node and provide local priorities. In Super Decisions software; graphic, verbal, matrix, questionnaire and direct comparison modes are available. Examples of comparison matrices are below. Other comparisons in questionnaire mode are in appendices.

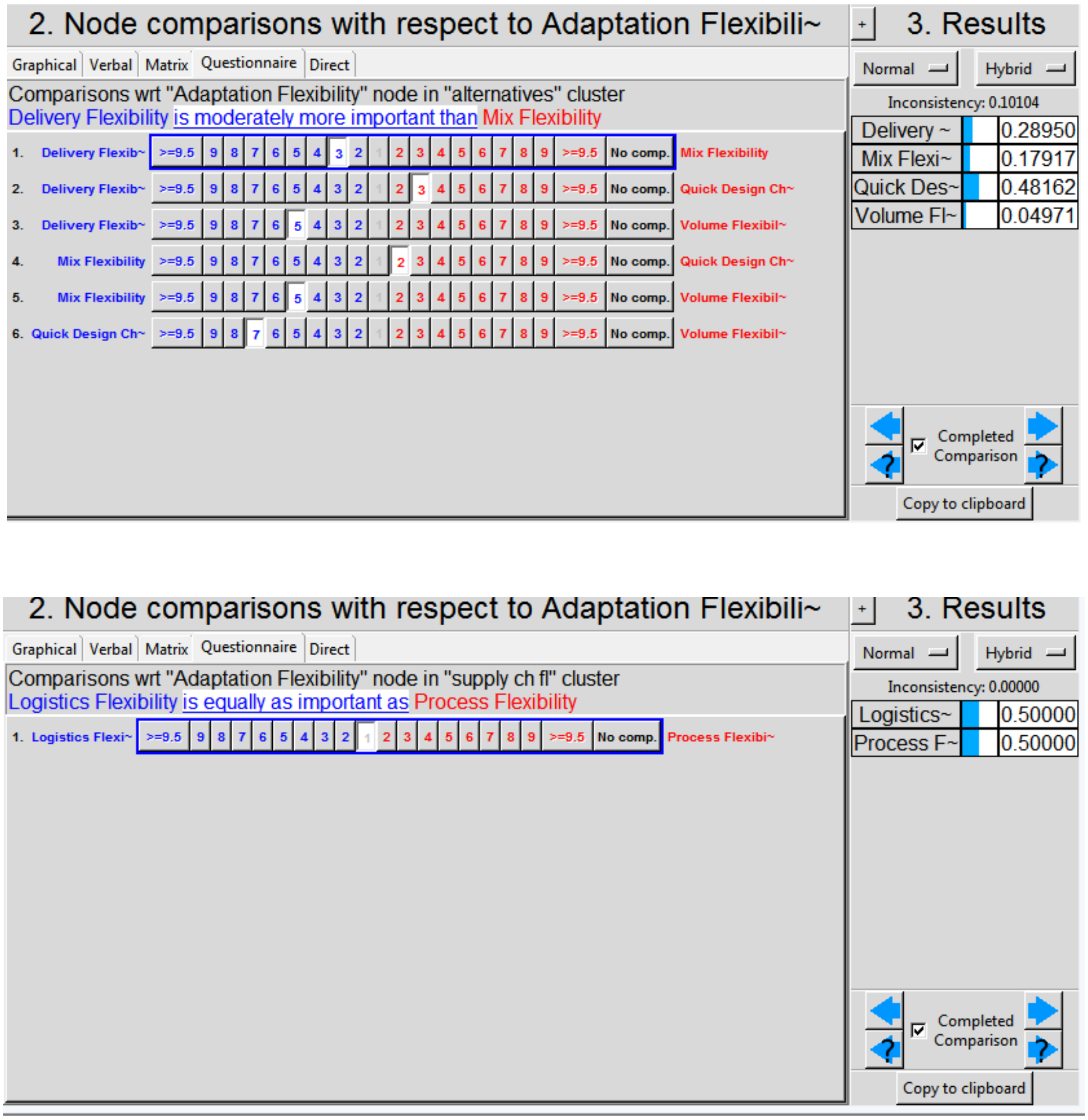


Figure 5.3: Examples of pairwise comparison

Maximize flexibility and satisfy expectations of all three elements in supply chain were our main objective. All comparisons made by respect to parent node and our objectives. To adapt rapidly and inexpensively to changes in its internal and external operating environment is called adaptation flexibility. For adapting internal or external changes to automotive manufacturing system, most important flexibility type is quick design change flexibility. Because it helps for change our process and taking advantage in competitive world. Biggest relation is between adaptation and quick design change flexibility. If we can increase it, adaptation flexibility will be increase too. In the other cluster, process and logistics flexibilities are both very important so we can say equally important.

Step III: Supermatrix formation

The supermatrix elements allow a resolution to be made of the interdependencies that exist among the elements of the system. It is a portioned matrix where each sub-matrix is composed of a set of relationships between and within the levels, as represented by the DM's model (Step I). The supermatrix obtained in this step is called the initial supermatrix and it contains all the eigenvectors that are derived from the pairwise comparison matrixes of the model. The eigenvector obtained from a cluster level comparison with respect to the control criterion is applied to the initial supermatrix as a cluster weight. This result is the weighted supermatrix.

	Adaptat~	Deliver~	Mix Fle~	Quick D~	Volume ~	Customer	Producer	Supplier	Logisti~	Process~
Adaptat~	0.00000	0.00000	0.15527	0.27969	0.25000	0.00000	0.38664	0.00000	0.00000	0.30155
Deliver~	0.28950	0.00000	0.29233	0.09362	0.75000	0.55842	0.08520	0.29696	0.69083	0.07193
Mix Fle~	0.17917	0.75000	0.00000	0.62670	0.00000	0.31962	0.18232	0.00000	0.14884	0.13404
Quick D~	0.48162	0.00000	0.49756	0.00000	0.00000	0.00000	0.23319	0.53961	0.00000	0.37052
Volume ~	0.04971	0.25000	0.05484	0.00000	0.00000	0.12196	0.11265	0.16342	0.16033	0.12196
Customer	0.00000	0.46154	0.83333	0.00000	0.54995	0.00000	0.80000	0.00000	0.59363	0.00000
Producer	1.00000	0.23077	0.13889	0.80000	0.20984	1.00000	0.00000	1.00000	0.24931	1.00000
Supplier	0.00000	0.30769	0.02778	0.20000	0.24021	0.00000	0.20000	0.00000	0.15706	0.00000
Logisti~	0.50000	0.83333	1.00000	0.14286	0.66667	1.00000	0.25000	1.00000	0.00000	1.00000
Process~	0.50000	0.16667	0.00000	0.85714	0.33333	0.00000	0.75000	0.00000	1.00000	0.00000

Figure 5.4: Unweightedsupermatrix

	Adaptat~	Deliver~	Mix Fle~	Quick D~	Volume ~	Customer	Producer	Supplier	Logisti~	Process~
Adaptat~	0.00000	0.00000	0.03882	0.06992	0.06250	0.00000	0.12017	0.00000	0.00000	0.14878
Deliver~	0.07237	0.00000	0.07308	0.02340	0.18750	0.17357	0.02648	0.09230	0.34085	0.03549
Mix Fle~	0.04479	0.18750	0.00000	0.15667	0.00000	0.09934	0.05667	0.00000	0.07343	0.06613
Quick D~	0.12041	0.00000	0.12439	0.00000	0.00000	0.00000	0.07248	0.16772	0.00000	0.18281
Volume ~	0.01243	0.06250	0.01371	0.00000	0.00000	0.03791	0.03501	0.05079	0.07910	0.06017
Customer	0.00000	0.11539	0.20833	0.00000	0.13749	0.00000	0.15664	0.00000	0.18451	0.00000
Producer	0.25000	0.05769	0.03472	0.20000	0.05246	0.19580	0.00000	0.19580	0.07749	0.31081
Supplier	0.00000	0.07692	0.00694	0.05000	0.06005	0.00000	0.03916	0.00000	0.04881	0.00000
Logisti~	0.25000	0.41667	0.50000	0.07143	0.33333	0.49339	0.12335	0.49339	0.00000	0.19580
Process~	0.25000	0.08333	0.00000	0.42857	0.16667	0.00000	0.37004	0.00000	0.19580	0.00000

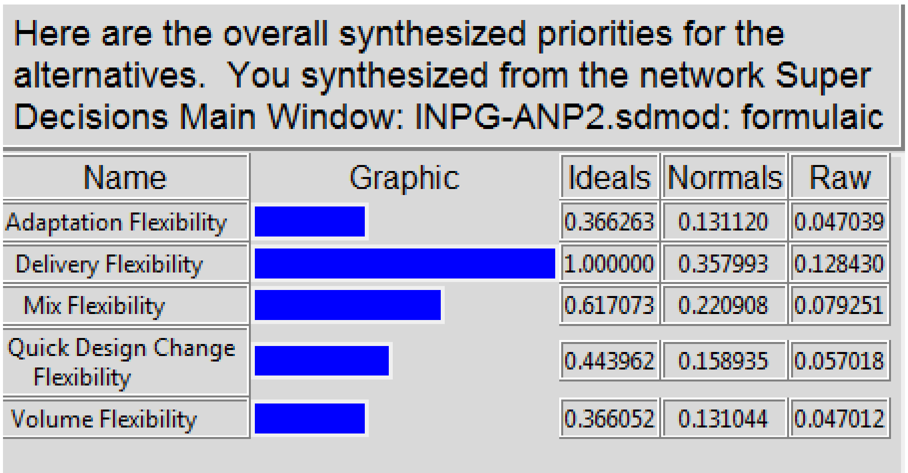
Figure 5.5: Weighted supermatrix

Step IV: Final priorities

In the final step, the weighted supermatrix is made to converge to obtain a long-term stable set of weights. The supermatrix is raised to a limiting power to obtain a matrix where all the columns are identical and each gives the global priority vector.

In the case of the complex network, it is necessary to synthesize the outcome of the alternative priorities for each of the BOCR structures in order to obtain their overall synthesis; for this operation different aggregation formulae are available (Saaty, 2005).

As for the AHP, a sensitivity analysis can be performed in order to improve the quality of the final results of the evaluation (Saaty, 2003).


Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: INPG-ANP2.sdmod: formulaic

Name	Graphic	Ideals	Normals	Raw
Adaptation Flexibility		0.366263	0.131120	0.047039
Delivery Flexibility		1.000000	0.357993	0.128430
Mix Flexibility		0.617073	0.220908	0.079251
Quick Design Change Flexibility		0.443962	0.158935	0.057018
Volume Flexibility		0.366052	0.131044	0.047012

Figure 5.6: Synthesized priorities

Delivery flexibility is provides biggest importance for satisfying expectations in automotive industry supply chain. Pairwise comparisons with respect to volume, logistics flexibility and customer expectations are shows that this type is most important flexibility. Because in automotive industry, if we want to work with high delivery flexibility, like “just in time”, we should bring right quantity, right quality at right time to right place. Also it helps to decrease inventory costs. If we have materials more than we need in stock or not enough material, this will be decrease our production rate, customer satisfaction and will increase our expenses.

Here are the priorities.

Name	Normalized by Cluster	Limiting
Adaptation Flexibility	0.13112	0.047039
Delivery Flexibility	0.35799	0.128430
Mix Flexibility	0.22091	0.079251
Quick Design Change Flexibility	0.15894	0.057018
Volume Flexibility	0.13104	0.047012
Customer	0.38902	0.100828
Producer	0.48561	0.125865
Supplier	0.12537	0.032494
Logistics Flexibility	0.61451	0.234783
Process Flexibility	0.38549	0.147280

Figure 5.7: Priorities

5.2. ELECTRE III

For ranking levers, ELECTRE III-IV software is used. Software is available at Lamsade- Université Paris-Dauphine for free and no limitation on the alternatives and criteria.

Step I: Performance Matrix

First steps for using ELECTRE III method are; identifying criteria and the alternatives, performance of alternatives and thresholds for criteria. Table 5.1 shows criteria, alternatives and performances.

Table 5.1: Performance matrix

Alternatives/Criterias	Adaptation Flexibility	Delivery Flexibility	Mix Flexibility	Quick Design Change Flexibility	Volume Flexibility
Decision Making Flexibility	8	4	5	7	4
Planning/Scheduling Flexibility	3	6	7	5	5
Sequencing Flexibility	3	5	6	5	5
Material Flexibility	2	2	6	4	4
Labor Flexibility	6	3	6	6	6
Changeover flexibility	3	5	6	5	6
Design/Development Flexibility	5	4	6	8	3
Financial Resources Flexibility	6	6	5	7	5
Machine/Equipment Flexibility	4	5	6	6	7
Expansion Flexibility	8	3	3	6	3
Transport/Shipping Flexibility	4	8	5	3	5
Routing Flexibility	3	4	6	4	5

Nonnumerical values were scaled from 1 to 9, where

Excellent = 9,

Very good = 8,

Good = 7,

More or less good = 6,

Indifferent = 5,

Somewhat bad = 4,

Bad = 3,

Very bad = 2,

Awful = 1

The indifference threshold indicates the largest difference between the performances of the alternatives on the criterion considered such that they remain indifferent for the decision maker. The preference threshold indicates the largest difference between the performances of the alternatives such that one is preferred over the other on the considered criterion.

For thresholds;

α-indifference coefficient = 0,

β-indifference coefficient = 0,

α-preference coefficient = 0;

β-preference coefficient = 1 and veto is disabled.

Table 5.1 shows that, respect to our most important flexibility type (delivery flexibility); transport/shipping flexibility has very good performance with 8 points. For good delivery flexibility or just in time, planning/scheduling, machine/equipment flexibility also very important but if customers can't get their automobile at right time, other flexibilities are not important.

For second important flexibility type (mix flexibility) planning/scheduling flexibility has best performance. To adopt changes in to automobile, according to customers' demands, we need a good planning team to organize new requests quickly for achieving competitive advantage.

Step II: Concordance Matrix

Matrice de concordance

	A0001	A0002	A0003	A0004	A0005	A0006	A0007	A0008	A0009	A0010	A0011	A0012
A0001	1	0.29	0.29	0.78	0.65	0.29	0.62	0.51	0.29	1	0.51	0.65
A0002	0.71	1	1	1	0.58	0.87	0.71	0.71	0.58	0.71	0.51	1
A0003	0.71	0.42	1	1	0.58	0.87	0.71	0.35	0.58	0.71	0.51	1
A0004	0.35	0	0.22	1	0.22	0.22	0.35	0.22	0.22	0.35	0.38	0.38
A0005	0.35	0.42	0.64	1	1	0.64	0.48	0.48	0.51	0.87	0.64	0.64
A0006	0.71	0.42	1	1	0.71	1	0.71	0.35	0.58	0.71	0.51	1
A0007	0.74	0.29	0.51	0.87	0.74	0.51	1	0.38	0.51	0.87	0.51	0.87
A0008	0.87	0.78	0.78	0.78	0.65	0.65	0.62	1	0.65	0.87	0.64	0.78
A0009	0.71	0.42	1	1	0.87	1	0.71	0.35	1	0.87	0.64	1
A0010	0.13	0.29	0.29	0.65	0.65	0.29	0.26	0.13	0.29	1	0.29	0.29
A0011	0.71	0.62	0.62	0.62	0.36	0.49	0.49	0.71	0.49	0.71	1	0.62
A0012	0.71	0.26	0.48	1	0.58	0.35	0.71	0.35	0.22	0.71	0.51	1

Figure 5.8 : Concordance matrix

Step III: Matrix final preorder

Matrice du préordre final

	A0001	A0002	A0003	A0004	A0005	A0006	A0007	A0008	A0009	A0010	A0011	A0012
A0001	I	P^-	R	P	P^-	R	P^-	P^-	P^-	P	R	P
A0002	P	I	P	P	P	P	P	P	R	P	P	P
A0003	R	P^-	I	P	R	I	R	P^-	P^-	P	R	P
A0004	P^-	P^-	P^-	I	P^-	P^-	P^-	P^-	P^-	P^-	P^-	P^-
A0005	P	P^-	R	P	I	R	P^-	P^-	P^-	P	R	P
A0006	R	P^-	I	P	R	I	R	P^-	P^-	P	R	P
A0007	P	P^-	R	P	P	R	I	P^-	P^-	P	R	P
A0008	P	P^-	P	P	P	P	P	I	R	P	P	P
A0009	P	R	P	P	P	P	P	R	I	P	R	P
A0010	P^-	P^-	P^-	P	P^-	P^-	P^-	P^-	P^-	I	P^-	P^-
A0011	R	P^-	R	P	R	R	R	P^-	R	P	I	R
A0012	P^-	P^-	P^-	P	P^-	P^-	P^-	P^-	P^-	P	R	I

Figure 5.9: Matrix final preorder

What P^- means on the table is that the alternative on the left side is worse than on the alternative up. It ranks as lower than other alternative on both descending and ascending distillation tables.

What P means is that the alternative on the left side is better than the one on the up side and it ranks on the higher level on both descending and ascending distillation tables.

R is for the situations that cannot be decided which one is better. On one of the descending and ascending distillation tables, the first alternative is on higher level whereas on the other table the second one is on higher level.

Step IV: Distillation

The second phase consists of exploiting these pairwise outranking degrees: the ascending and descending distillation procedures lead each to a complete (i.e. transitive) pre-order. Each pre-order takes into account respectively the outranking and outranked behavior of an alternative with regard to the others. Since these procedures may lead to two different procedures, a final ranking is generated as the intersection of the two pre-orders.

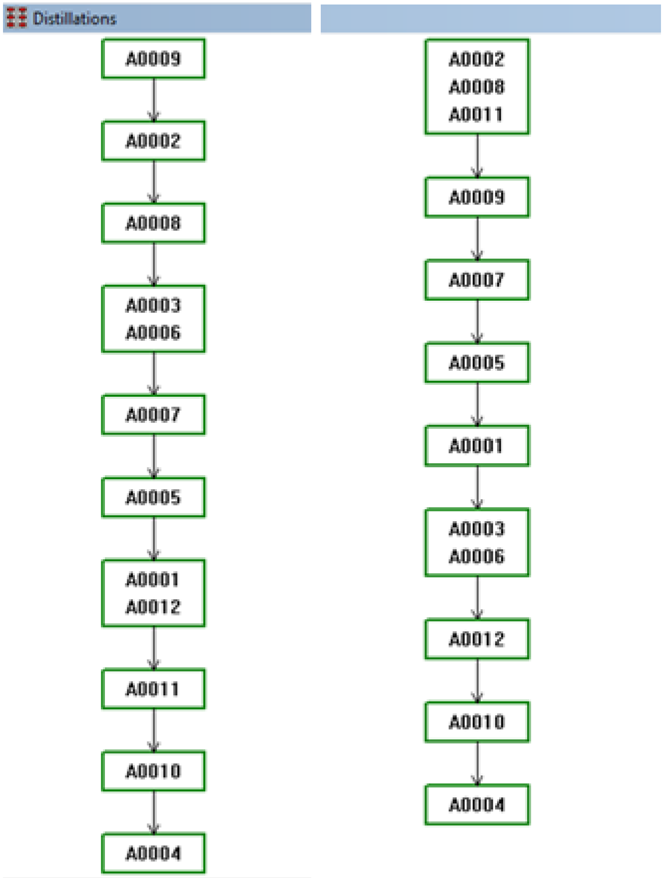


Figure 5.10: Descending and ascending distillation

The meaning of the arrows is that they state the alternative on the up side is better than the one below. We cannot state that one of the alternatives is better than the other when we compare the alternatives on the same box; we accept them to be on the same level.

Step V: Results

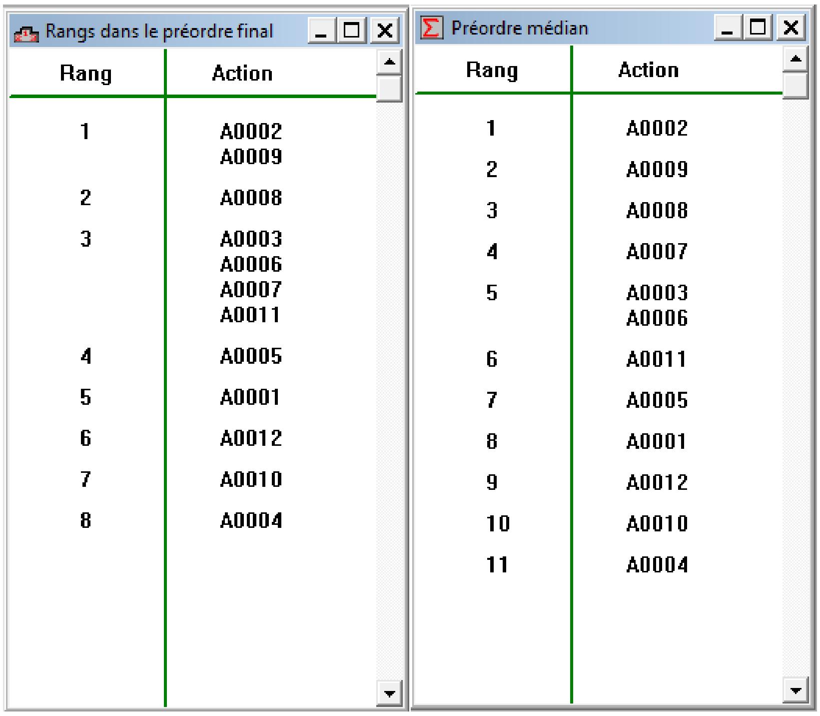


Figure 5.11: Results

The final ranking, as illustrated in Figure 5.12, we can see that the best alternative in descending distillation is A9; A2, A8 and A11 is best for ascending distillation. In the final ranking, A2 and A9 is the best alternatives. These alternatives are incomparable in the final graph (Figure 5.12): there is no arrow (and thus no preference relation) between the two alternatives. This is the result of the fact that A2 has a different ranking (compared to A9) in the descending distillation than in the ascending distillation. A2 is ranked second in descending distillation and first in ascending distillation, whereas A9 respectively first in the descending distillation and second in the ascending distillation.

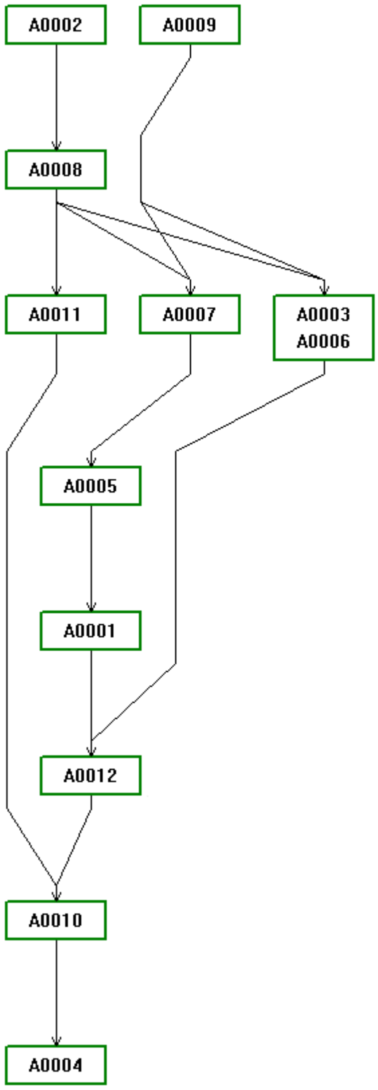


Figure 5.12: Final graph

6. CONCLUSION

In this study, a decision making model, based on ANP and ELECTRE III is developed. The reason of combining two methods is, ELECTRE III needs the weights of criteria for first performance matrix but we don't know the weights in the beginning. So idea was using ANP for obtain weights of flexibility types, which are alternatives for ANP model and criteria for ELECTRE III method.

To take advantage in an increasingly competitive global environment, flexibility is the most important competitive weapon. If the company has higher flexibility than the competitors, it means that uncertainties and urgencies in the market will be great advantage for that company and also could be means big benefits. Customers and their requests always changing and for don't lose them, manufacturers should keep up with customers. Times have changed and now customers do not have to buy whatever we produce. They have a lot of options, different models and brands so satisfying customer expectations are extremely important.

According to our results, Planning/Scheduling Flexibility and Machine/Equipment Flexibility have highest priority. These flexibility levers are helping to satisfy expectations like; delivery reliability, customization etc.

In the second level, Financial Resources Flexibility and in third level, Transport Shipping Flexibility, Design/Development Flexibility, Sequencing Flexibility and Changeover Flexibility are more important than the others for be flexible.

Being flexible is always good if you are not a brand which has very luxury and expensive cars and selling just hundreds of cars per year. For other companies, adapting high flexibility to supply chain is could be very expensive and one of the objectives of this study is to identify flexibility levers which could be increase our flexibility more than the others and to invest our limited budget to these levers.

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APPENDICES

APPENDIX A. PAIRWISE COMPARISONS

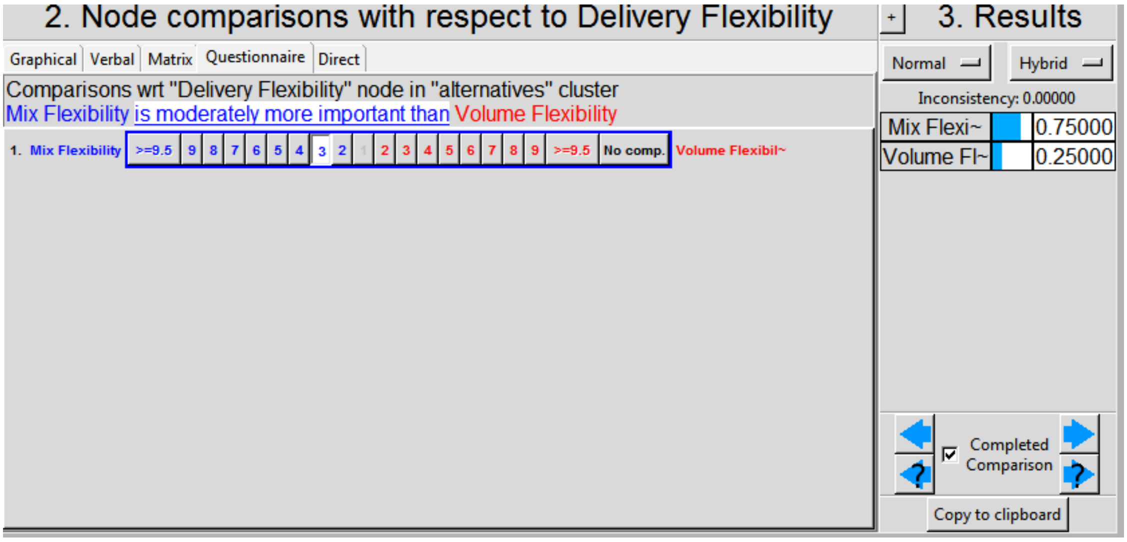

Figure A.1: Comparisons of "Delivery Flexibility" node in "alternatives" cluster

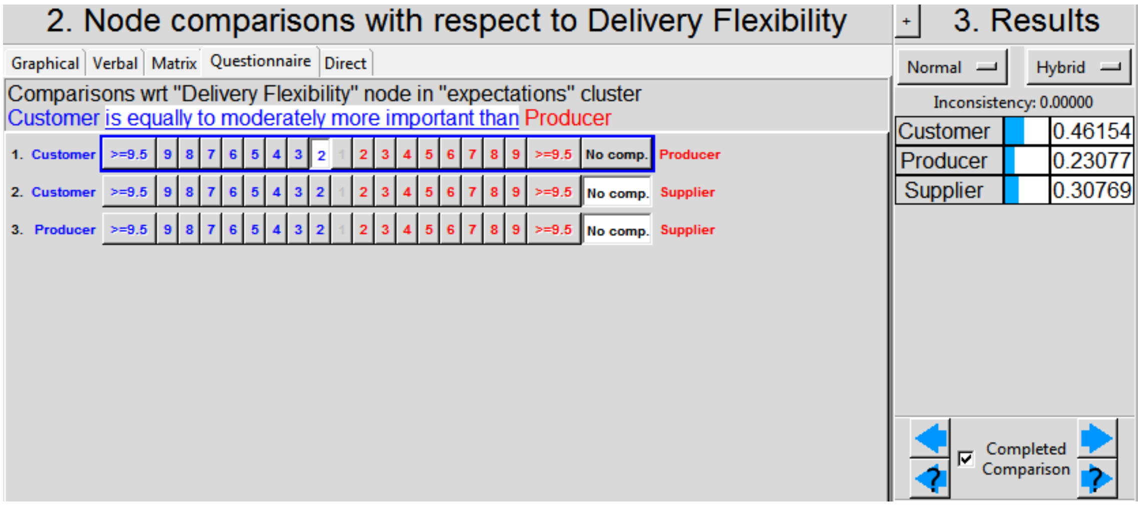

Figure A.2: Comparisons of "Delivery Flexibility" node in "expectation" cluster

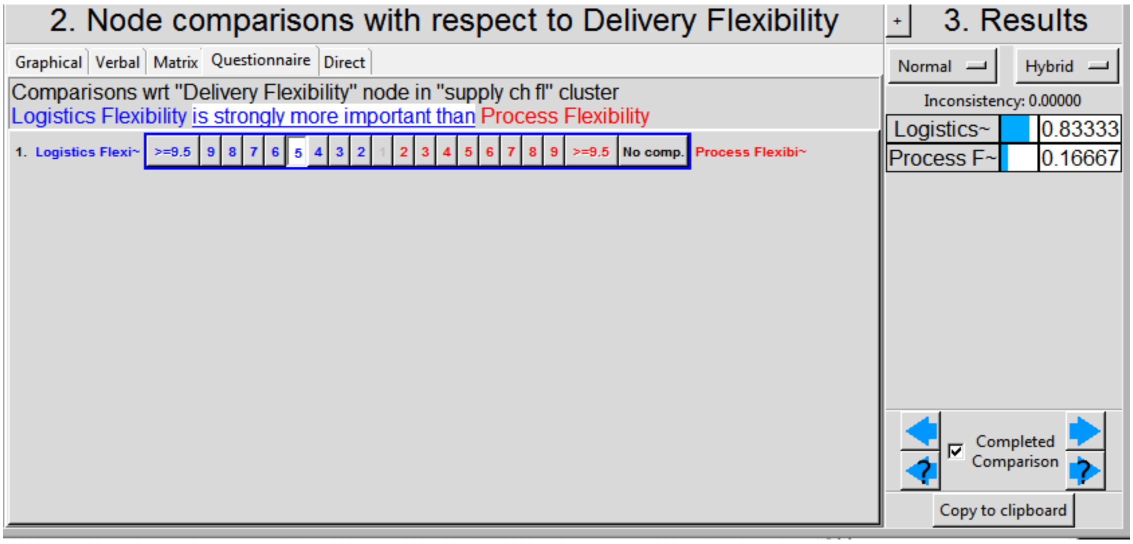

Figure A.3: Comparisons of “Delivery Flexibility” node in “supply chain flex.” cluster

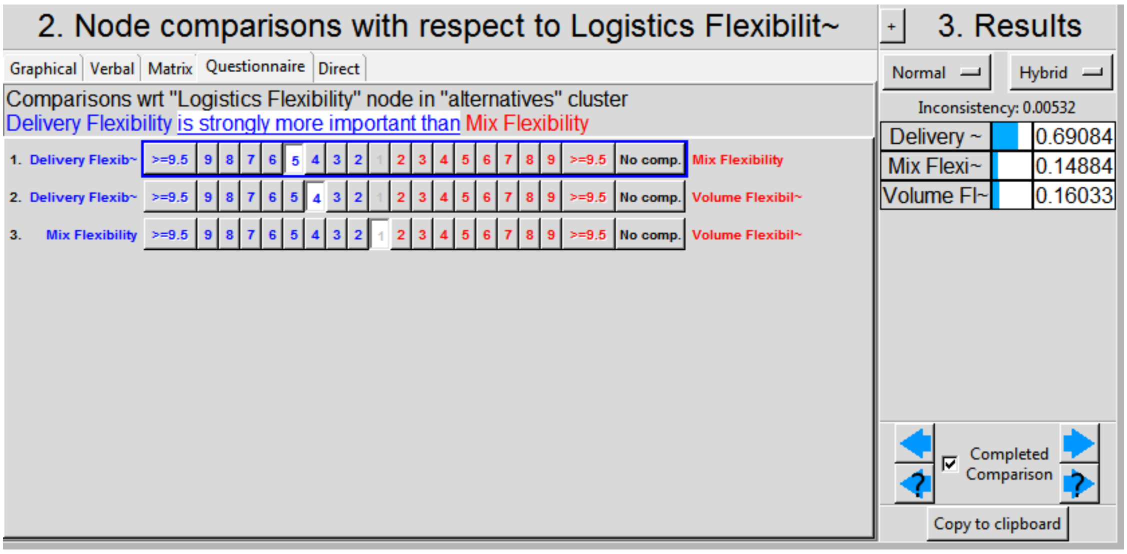

Figure A.4: Comparisons of “Logistics Flexibility” node in “alternatives” cluster

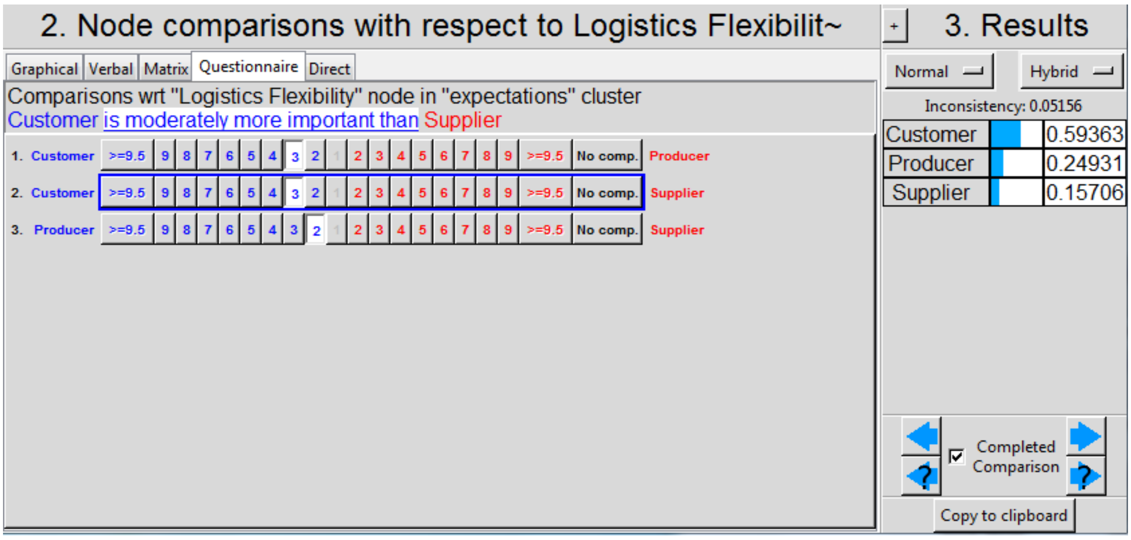

Figure A.5: Comparisons of "Logistics Flexibility" node in "expectations" cluster

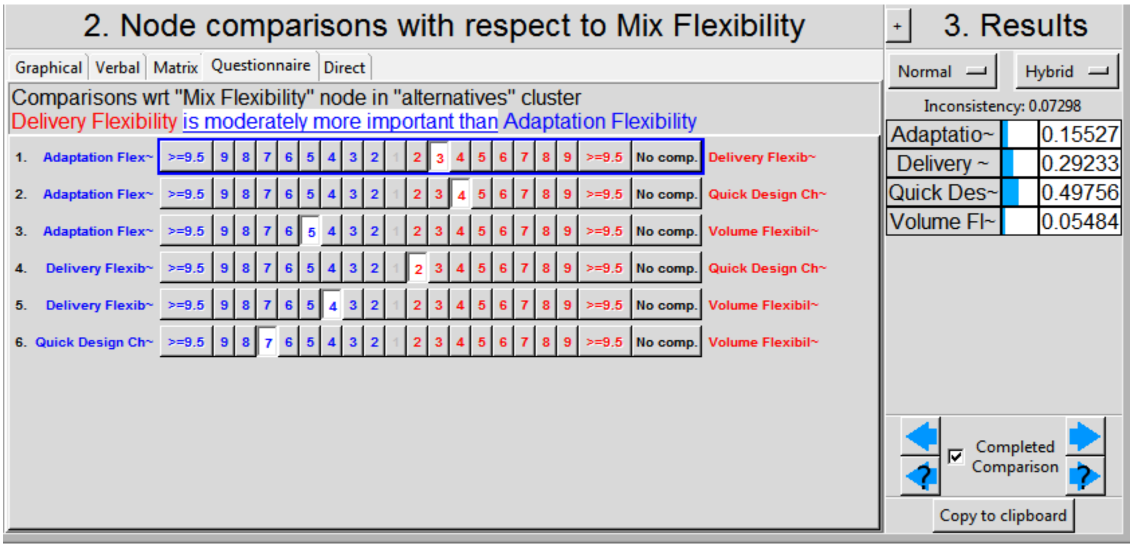

Figure A.6: Comparisons of "Mix Flexibility" node in "alternatives" cluster

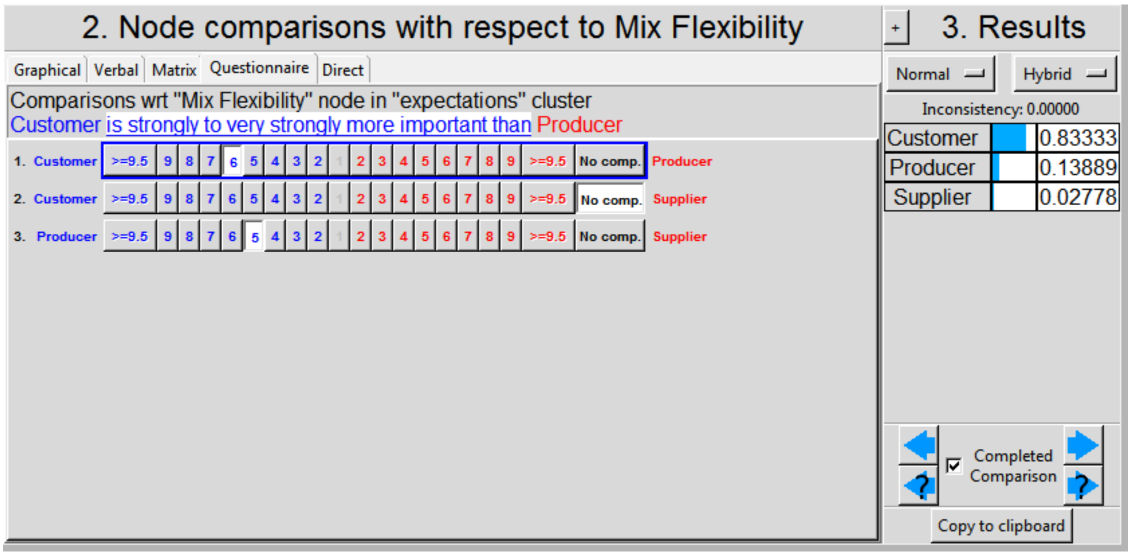

Figure A.7: Comparisons of "Mix Flexibility" node in "expectations" cluster

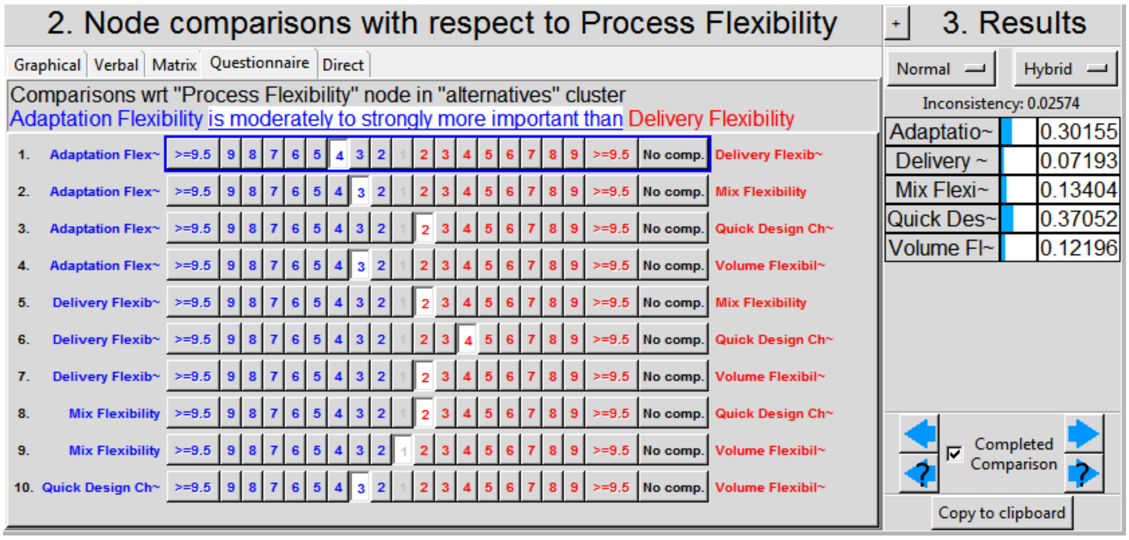

Figure A.8: Comparisons of "Process Flexibility" node in "alternatives" cluster

Figure A.9: Comparisons of “Producer” node in “alternatives” cluster

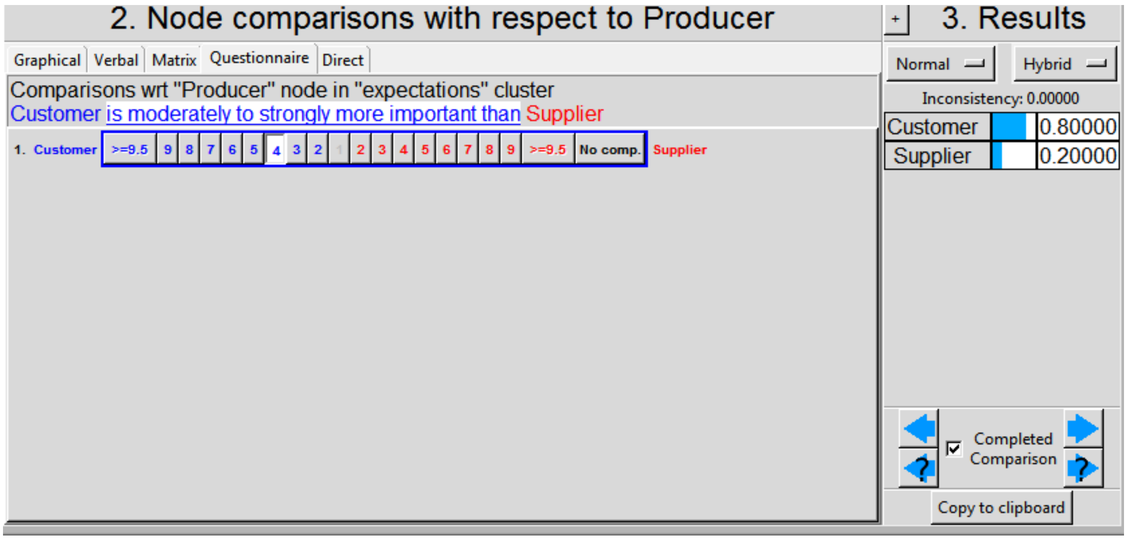

Figure A.10: Comparisons of “Producer” node in “expectations” cluster

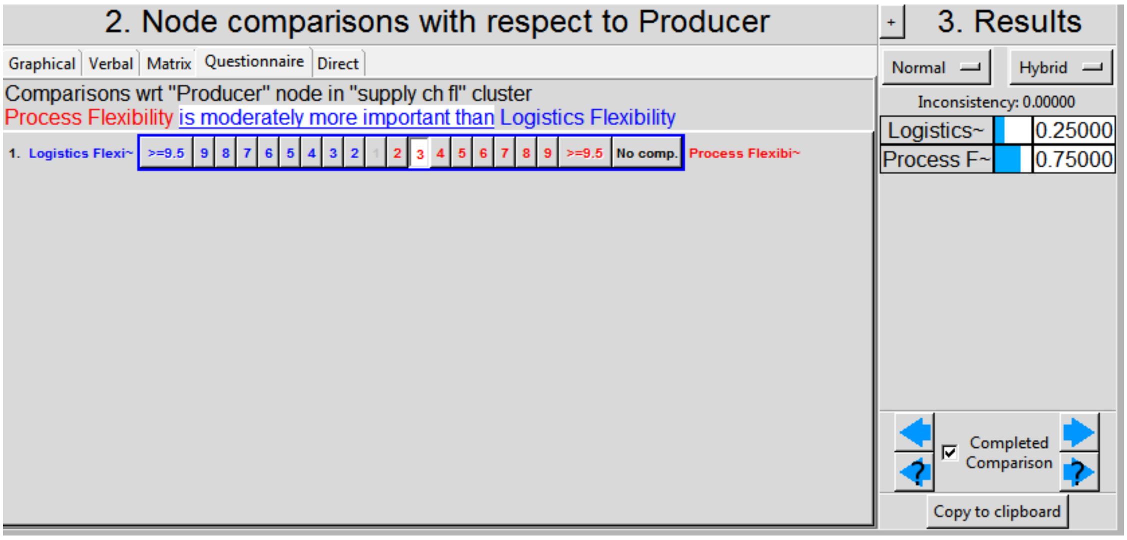

Figure A.11: Comparisons of "Producer" node in "supply chain flex." cluster

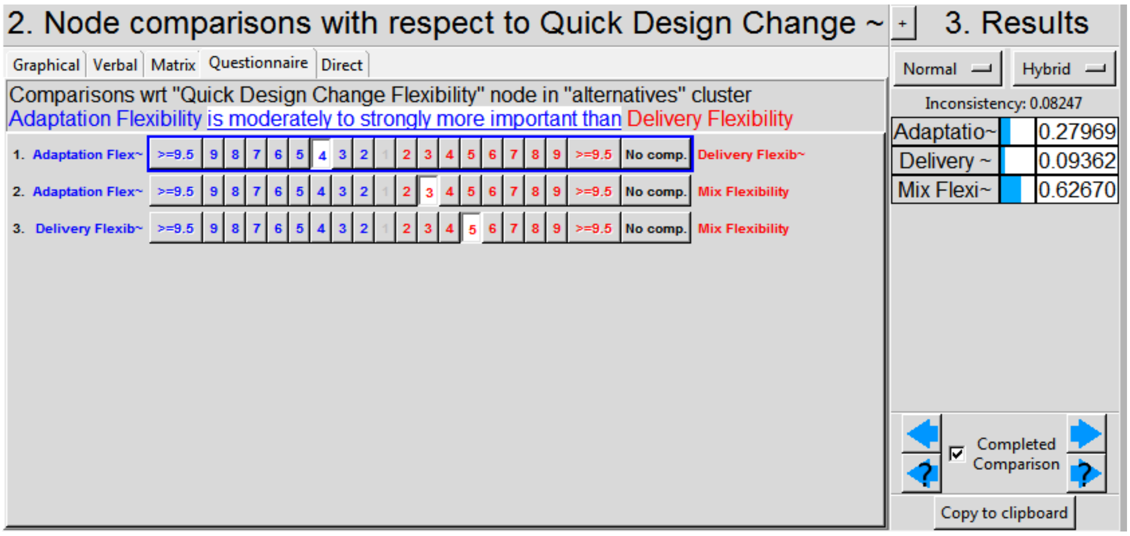

Figure A.12: Comparisons of "Quick Design Change Flex." node in "alternatives"

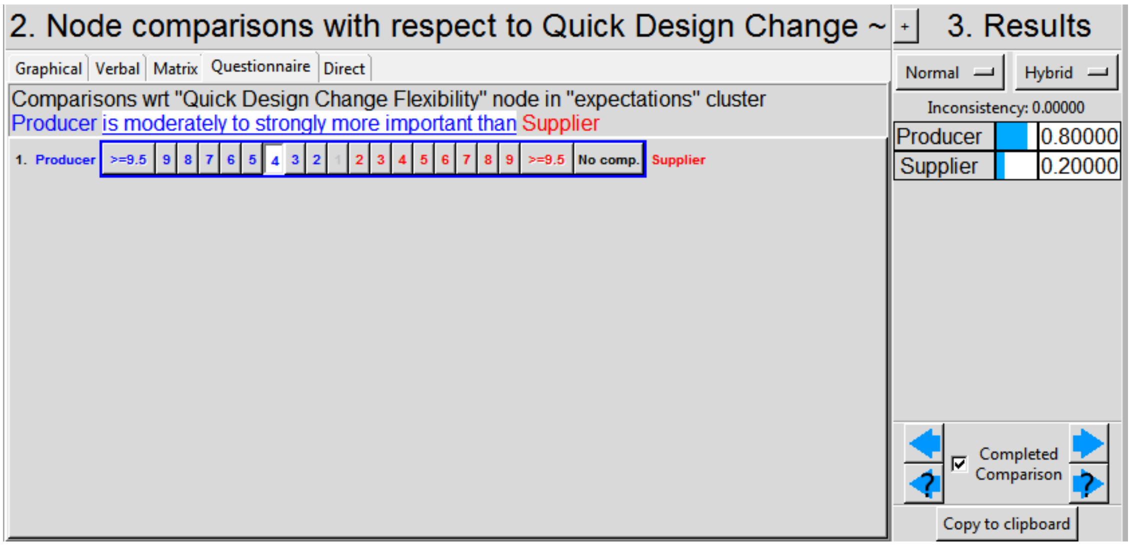

Figure A.13: Comparisons of "Quick Design Change Flex." node in "expectations"

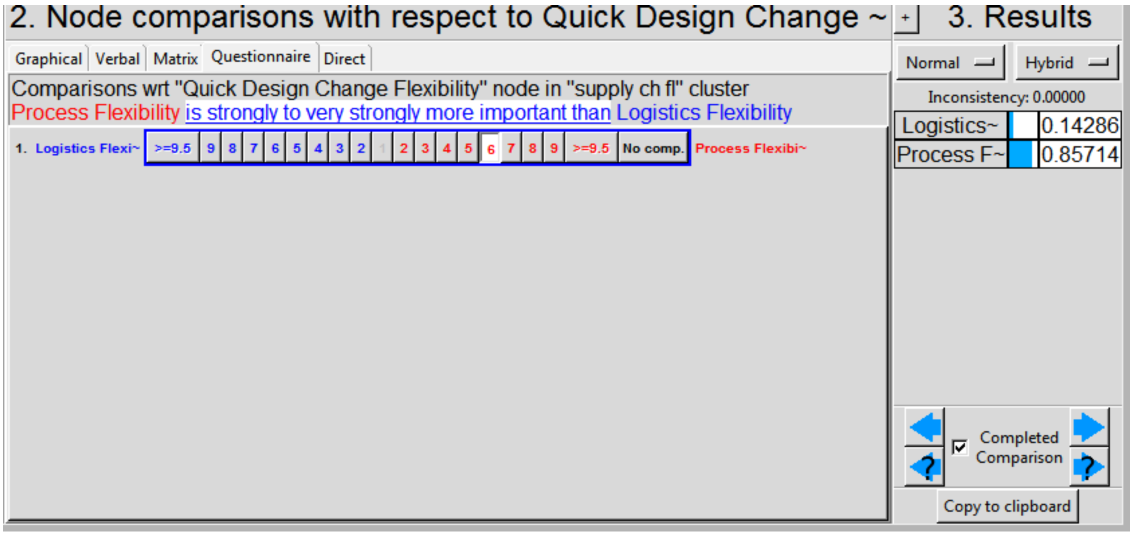

Figure A.14: Comparisons of "Quick Design Change Flex." node in supply chain flex.

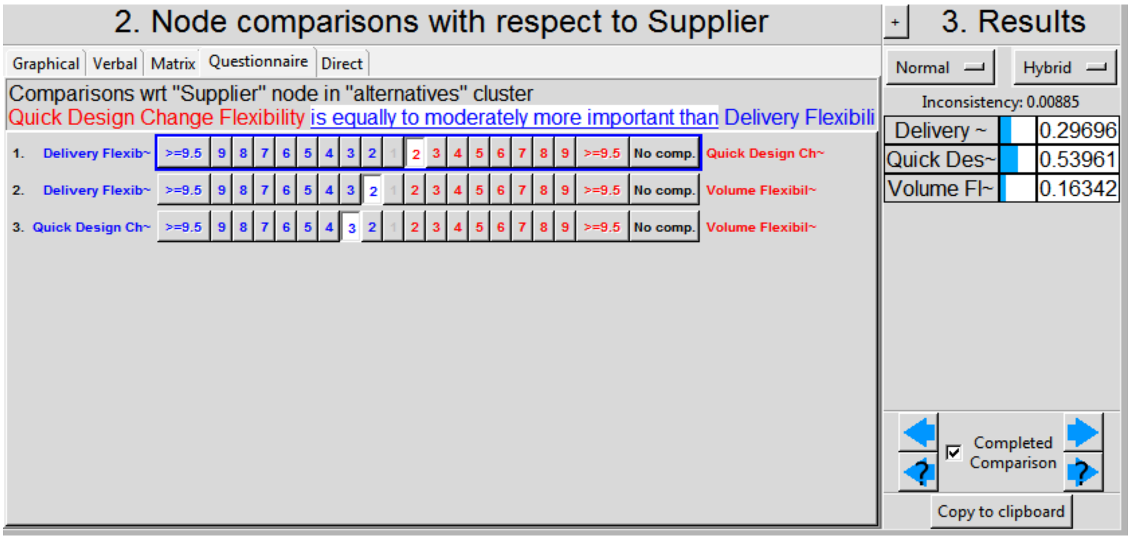

Figure A.15: Comparisons of “Supplier” node in “alternatives” cluster

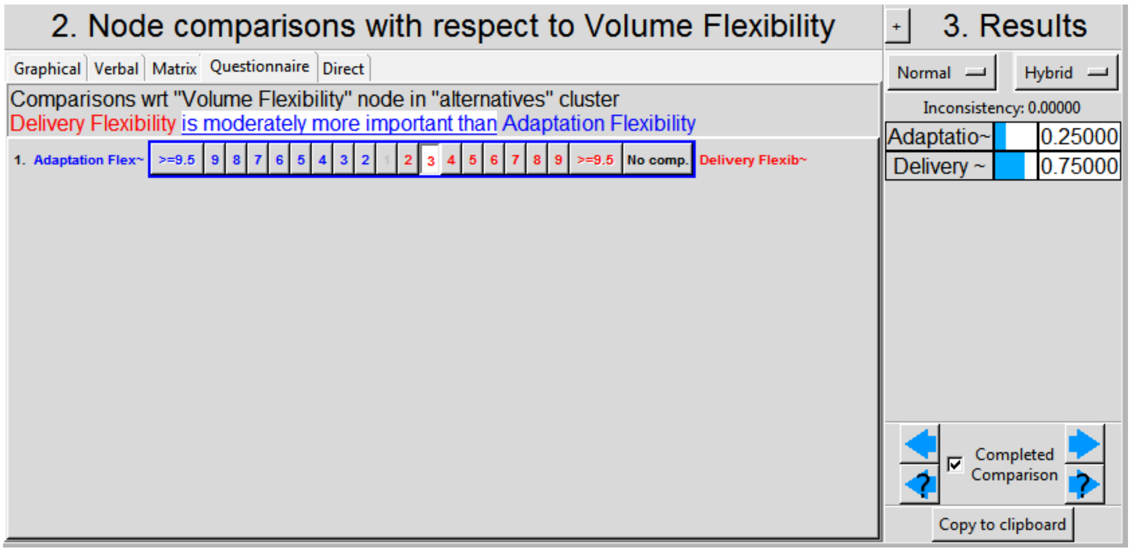

Figure A.16: Comparisons of “Volume Flexibility” node in “alternatives” cluster

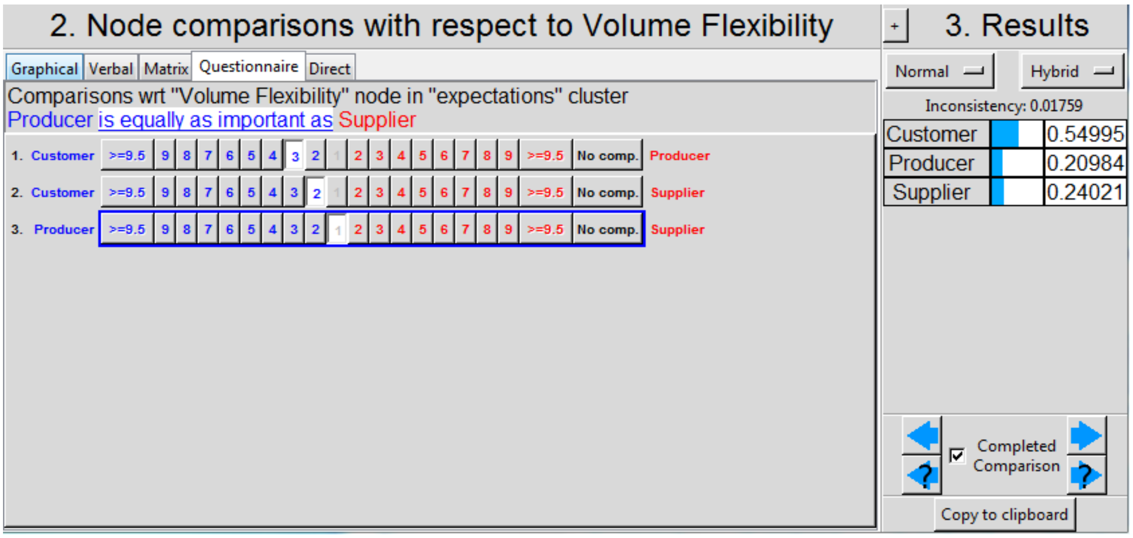

Figure A.17: Comparisons of “Volume Flexibility” node in “expectations” cluster

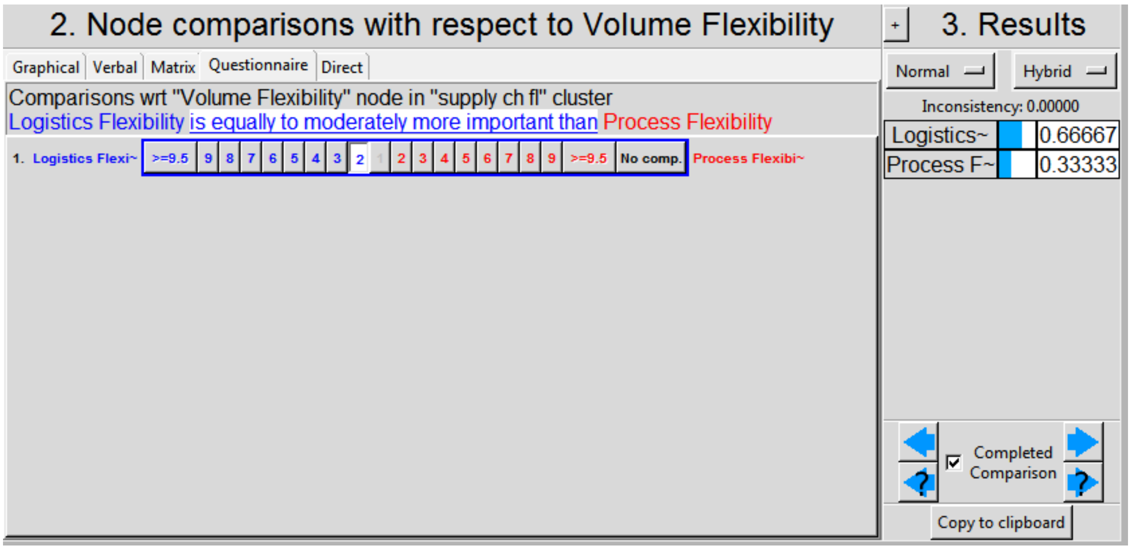

Figure A.18: Comparisons of “Volume Flexibility” node in “supply chain flex” cluster

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2013	Supply Chain Flexibility Metrics Evaluation (AMMCS)