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Providing A Hybrid Model To Control And Evaluate Time Uncertainty In Dynamic Supply Networks Of Oil Companies

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Abstract

Delivery speed and accuracy in dynamic supply networks (SNs) are the main challenges ahead of managers due to the short-time nature of it. Therefore, uncertainty, couldn't be ignored. Network structure and relevant complexities are one of the main factors of uncertainty in SNs. M easuring the uncertainty in the network regarding to these causes is one of the issues covered by this study. On the other hand, it is indispens able to identify suppliers with the highest contribution to the uncertainty in order to be able to improve network performance. Therefore, in t his study a hybrid methodology is presented to solve and cover these gaps. Which is created by the combination of three adapted methods. T o show the applicability, it applied in three scenarios to accumulate the DTU of the network.
Finally, the validation of this methodology is performed by the 10-fold cross validation. The results proved the ability, highest accuracy and speed.

Keywords: Logistic network; complex supply network; time uncertainty; dynamics

1. Introduction

Today's competitive market conditions are changing rapidly. As a result, managers need to use innovative strategies in decisi-on making to survive in these dynamic markets.
Companies are increasingly recognizing the effective role of supply chain networks (SCNs), in enhancing their compe titive edge in the global marketplace and its impact on the economy. Stepping up to maximize customer satisfaction has become one of the most important success factors in today's dynamic markets. Increasing customer demands, a s well as rising expectations and diversification, have forced organizations to increase flexibility in service delivery, w hile simultaneously controlling costs. One of these flexibilities, for example, can be the creation of flexible structures in supply networks, and the ability to reconfigure, based on network goals.

Traditional SCNs are no longer capable of meeting today's market demands and are doomed to failure. Therefore, it is imperative for the organization to move towards the creation of dynamic SCNs, with the aim of meeting dynamic and short-term customer demands.(Ari-Pekka & Antti, 2005). Proper response to the varied and short-term demands of customers in the shortest time is one of the main goals of such networks.

In such networks, due to their dynamic and short-term nature, traditional decision-making techniques (used in traditional SCNs), and consistent with continuous improvement, are no longer capable of operation. One of the most prominent features to consider when designing new techniques used in dynamic networks is the high speed, together with the high accuracy in decision making.

A review of the literature in this study shows that researchers' interest in considering the uncertainty factor in the three parameters of time, cost, and quality has increased (see Fig.1).

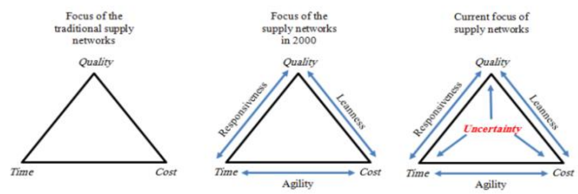

Fig. 1. The main focus area of SCNs management, over time (Micheli, et al., 2008; Norrman & Jansson, 2004).

Today, uncertainty in SCNs can be identified as a major management challenge. In designing the network structure, the two factors of the complexity of the structure and the type of relationship between suppliers are the factors affecting the uncertainty. Figure 2 shows the basic structure of a network.

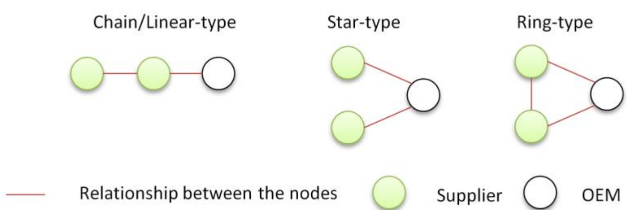

Fig. 2. Possible types of elementary network structures

The entire network structure is created by combining the basic networks mentioned in Figure 2. This is illustrated in Figure 3. All network structures are classified as complete and partial communications (Zhao, et al., 2011; Safaei, et al., 2014).

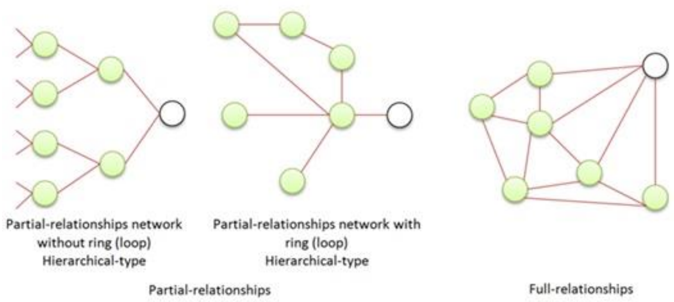

Fig. 3. Complex networks in two categories: complete and partial communication

One of the most important causes of uncertainty is the complexity of network structures (Cheng, et al., 2013). Most of the models used in this domain have focused more on controlling and reducing uncertainty, based on the internal variables of member firms (machine breakdown and the external factors like demand uncertainty, which most of them are created by the customers), and external variables (such as demand flactuations (Käkia, et al., 2013; Subramanian, et al., 2014)), in SCN or in traditional long-term networks. The first thing to consider is adapting established models to the methods required in dynamic networks (Pishvaee, et al., 2009). Also, the measurement, control and reduction of uncertainty resulting from network structure is still recognized as a research gap.

An important issue that can drive innovation in this research is to find the suppliers that have the most potential to influence the uncertainty of the network. In this way, according to Pareto's law, those members of the network, which should implement the models of network uncertainty reduction, will first be identified. This will increase performance and effectiveness, as well as speed up response to the model.(Safaei & Thoben, 2014; Hu, et al., 2013).

Most scholars in the field agree with the role of time in enhancing customer satisfaction, and the importance of this issue in dynamic networks is undeniable. This research has put all its focus on this issue.

The uncertainty in the response time in a network is caused by the uncertainty in the response time of each network member (Zimmer, 2002). In order to correctly estimate this uncertainty, in a dynamic environment, one must first understand the issue of how sensitive the network is to each member's structural position. This is entirely related to the shape and structure of the network. The level of position of each member in the network can produce an effect similar to the bullwhip effect shown in Figure 4.

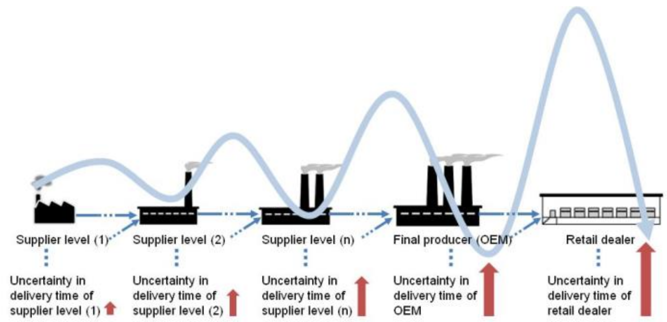

Fig. 4. The effect of time uncertainty on the network, than the time uncertainty on each network member

1020/5000

Given that most quantitative models have used complex optimization models in the research literature, as well as a nalyzing and solving in an unknown location for application, as a result, it is very difficult for managers to understan d such models. Therefore, the need to use a comprehensible model, which combines both quantitative and qualitati ve methods, based on exploratory research, seems necessary. Other goals of this study are to introduce a hybrid mo del, using simple mathematical, probabilistic and simulation techniques, to reduce the complexity of the network str ucture first, and then calculate the final network uncertainty. Finally, the other application of this model is the simpli city of implementation by managers and the sensitivity analysis of their structural strategies on the uncertainty of n etwork response time.

Following the introduction, and a brief discussion of the aims of the research, the research problem and model expr ession will be discussed. Then the research methodology will be examined. Next, the validity of the model will be ev aluated by the "10-
folds cross validation" technique. Finally, the performance of the model will be examined in several numerical exam ples.

2. Mathematical explanation of uncertainty

In general, as shown in Figure 5, all quantitative uncertainty modes are usually represented by one of three method s, linear interval, fuzzy membership functions, and probability density function(Safaei, et al., 2013).

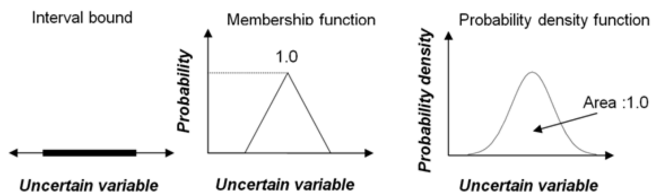

Fig. 5. Possible qualitative states, to show uncertainty (Safaei, et al., 2011)

In most of the studies, both fuzzy and probabilistic approaches have been favored more than linear distance appr oach because of their higher accuracy (Yen, 2009). The fuzzy technique has a greater error because of the many assumptions (such as membership degrees), but the reason for using this technique further is the computational limitations of the probability density function (pdf) technique(Montgomery, 2008). However, the pdf technique has characteristics that cannot be easily overcome, and it is the ultimate adaptat ion to real-world situations. In this technique, there are no estimated assumptions, and all calculations are based on real-world data(Zhao, et al., 2011).

Given the strengths and weaknesses of both techniques, it can be argued that if a method, other than using estim ation and hypothesis, is found to solve the pdf constraints in defining uncertainty, it can be considered the best tech nique. For this purpose, in this study, this technique is used to define time uncertainty.

3. Methodology

The three main steps for the methodology of this research are:

1. Uncertainty Definition Phase for Each Member: Identifying the most appropriate pdf for each member's respons e time
2. Phase II, which identifies the members that will have the greatest impact on the uncertainty of the network.
3. Final Phase: Calculate the accumulated uncertainty over the whole network

The first phase will be done using sampling, and past data of each member, using EasyFit software.

In the second phase, using the PERT (Program Evaluation and Review Technique) technique, the network will be sim plified and ready for calculation.

Then, And, using the uncertainty calculation methods in laboratory equipment calibration, GUM (Guide to the Expre ssion of Uncertainty in Measurement), and the Monte Carlo Simulation Method (MCM), the uncertainty of the netw ork will be calculated.

This method is called the hybrid method because of the use of three different methods from three different work ar eas and their matching to the scientific domain of SCNs management. Then, in the discussion of the methodology, a n improved PERT method will be discussed, and the method of applying it to the network will be shown.

3.1. Network Preparation

According to the graph theory, all possible bases for generating production networks are composed of six categories , linear, star, partial relation with loop and "without loop", and complete relation with loop and "without loop" (see

Fig. 6). These networks are intended for up to four nodes, and the reason for not counting more nodes is the ability to cover all possible states with four nodes, and if the node is added, only the number of iterations is added..

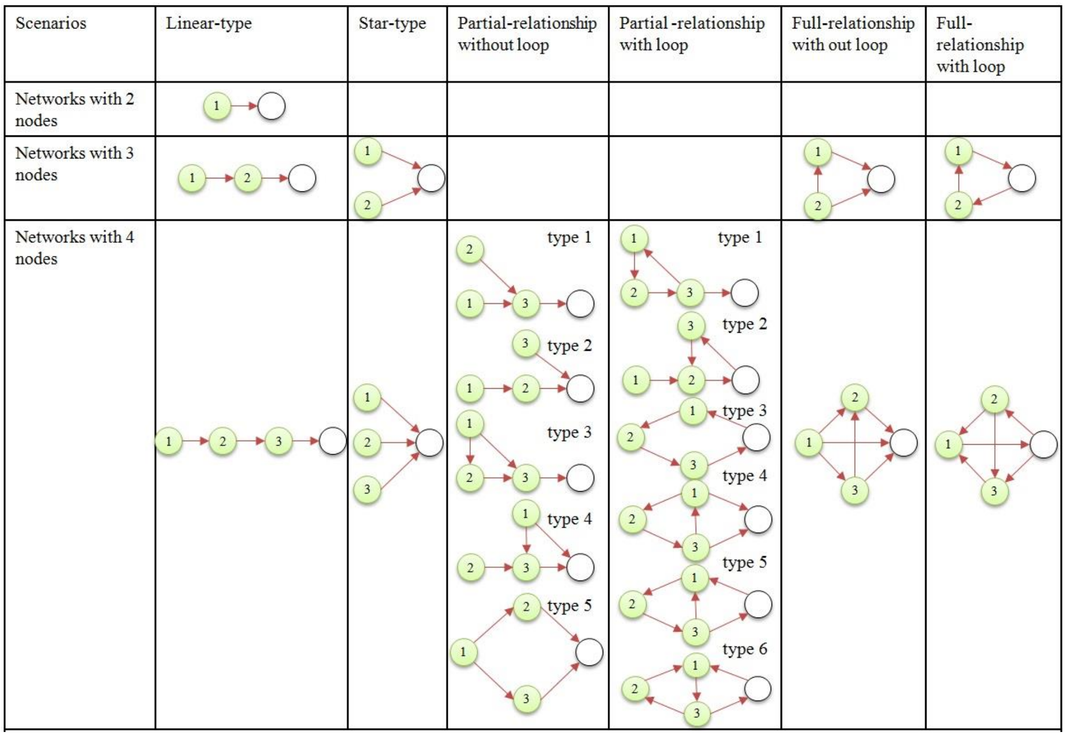

Fig. 6. Classification of basic manufacturing networks

It is now time to establish the mathematical relationships for each of the groups shown in Figure 6. As previously de scribed, all networks are created by combining the three basic foundations, consequently, it is sufficient to calculate the mathematical relationships for these three basic graphs, by combining them to derive the relationships of the ot her networks given in Fig. 6, as well as the relationships of each more complex network, as a mathematical model. In "Linear Type" (Fig. 7) the average combination of network response times to OEM (μ_c) is equal to the average res ponse time of both suppliers (μ_i) ($\mu_c = \mu_1 + \mu_2$). And the relationship function (f(y)) is equal to the sum of all pdfs of the network members (Equation 1).

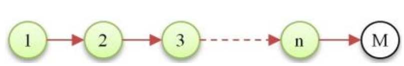

Fig. 7. Linear type

$$f(y) = f(T) = f(T_1) + f(T_2) + \cdots + f(T_n) \qquad (1)$$

In "Star Type" (Fig. 8), the average network response time composition, up to OEM, is the maximum average time of both members ($\mu_c =$

max (μ_1, μ_2)). In this case, the relation function is equal to the maximum of the total pdfs of the suppliers (Equatio n 2).

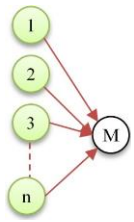

Fig. 6. Star type

$$f(T) = \max(f(T_1), f(T_2)) \quad (2)$$

And in the Ring type, first by introducing a virtual member, the network will become a simple linear type and then fo llow all the principles of linear relationships (i' is a dummy of the node i) (Safaei, et al., 2014).

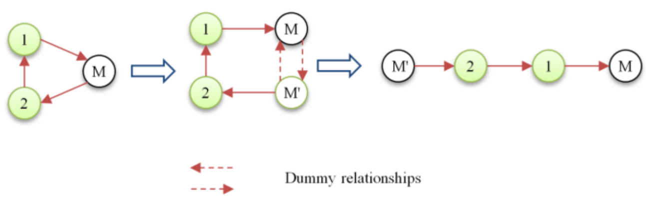

Fig. 9. Simplification process for loop

3.2. Methodology overview

As shortly stated before the introduced methodology for recognizing and analysis of DTU in SNs is a hybrid procedur e out of three individual statistical tools and techniques. The PERT is a method for simplifying complex networks by defining their critical path according to DTU. The guide to the expression of uncertainty in measurement GUM is a m athematical tool for calculating an aggregated uncertainty in an entity out of several sources of uncertainties in a sys tem. The MCM can be used as a simulation means to model and calculate uncertain systems (Calvet, et al., 2010). Furthermore, a combination of these three techniques is favourably developed to be adapted for solving com plex SNs. However, this combined framework offers two alternative combinations encountering alternative uncertai nty distributions within a network. If it is ensured that all distributions follow the normal or t-student distribution, the framework employs the combination of PERT and GUM as the developed solving tool. If alt ernative distributions other than normal are recognized in the network, then the combination of PERT and MCM has to be applied.

According to the literature, there are three basic methods to determine the critical path in the networks. The first one is CPM[1], the second one is PERT and the last one is GERT[2]. The CPM, is based on the networks and projects with fixed time, the PERT, is based on the networks and projects with uncertain time, and finally GERT, is based on the uncertain activity or projects (Institute standards committee, 2009). Since the considered networks in this research study have uncertain time, and the research problem is focused on the time, PERT is chosen.

To calculate the accumulated uncertainty in the network by a mathematical method, there are three basic methods. The first one is Markov theory, and the second one is Bayesian method and the third one is GUM. The first two methods, involve complex mathematical formulas, and are difficult to be applied for the networks with more than three nodes. Moreover, a considerable number of calculations are required. To avoid these shortcomings, GUM is applied. To support GUM, and in the cases which GUM is not useful or has difficulty in calculating the accumulated uncertainty, a simulation programming method based on MCM is applied.

3.3. Critical supplies and critical path

As explained in the previous section, to determine the critical path, PERT is chosen. PERT is a statistical tool for controlling and managing project activities in time space. But PERT has two limitations (Wiest & Levy, 1974):

1. It is not able to handle loops in the network.
2. PERT just considers the Beta probability distribution function and other distribution will estimate to the Beta.

In this paper, to remove these two limitations, adapted PERT is proposed. The purposes of applying adapted PERT are:

1. Simplifying the complex network to a linear network
2. Finding the critical suppliers in the network

By considering the mean of each pdf as the expected value of delivery time and additionally, attaching the preparing network's section to the PERT, the adapted pert overcomes these limitations. As a brief description of the adapted PERT, it is divided into five steps (Safaei, 2014):

1. Prepare the network
2. Calculating the expected value of delivery time for each supplier.
3. Calculating the forward pass
4. Calculating the backward pass
5. Determining the critical path and critical suppliers

[1] Critical Path Method
[2] Graphical Evaluation and Review Technique

To create a better understanding about the adapted PERT, the inputs, outputs, and its abilities are illustrated in Fig. 11.

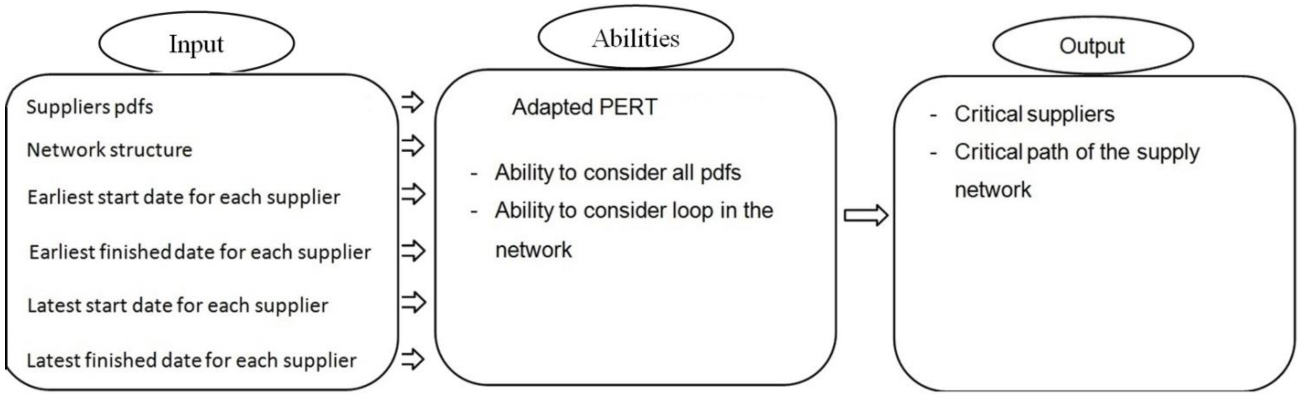

Fig. 7. Adapted PERT: inputs, outputs and abilities

For details, we refer to (Safaei, et al., 2014).

3.4. Calculating of accumulated uncertainty

Now, after determining the critical path and critical suppliers, the accumulated uncertainty of the delivery time mus t be calculated.

One of the method for calculating uncertainty in calibration field; which is widely applied in mechanical and electr ical systems, is "GUM". This is a guideline introduced by the JCGM member organizations (JCGM, 2008). GUM is recognized as an acceptable reference for measuring uncertainty in calibration laboratories, and it is a mathematical tool for calculating uncertainty in a system. Whereas an SN can be considered as a system, this met hod is transferred and adapted to the field of SN management. To read more about the algorithm and process of th e adapted GUM, we refer to (Safaei, et al., 2014). Fig. 12, is shown the inputs, outputs, and abilities of the adapted GUM in a simple way.

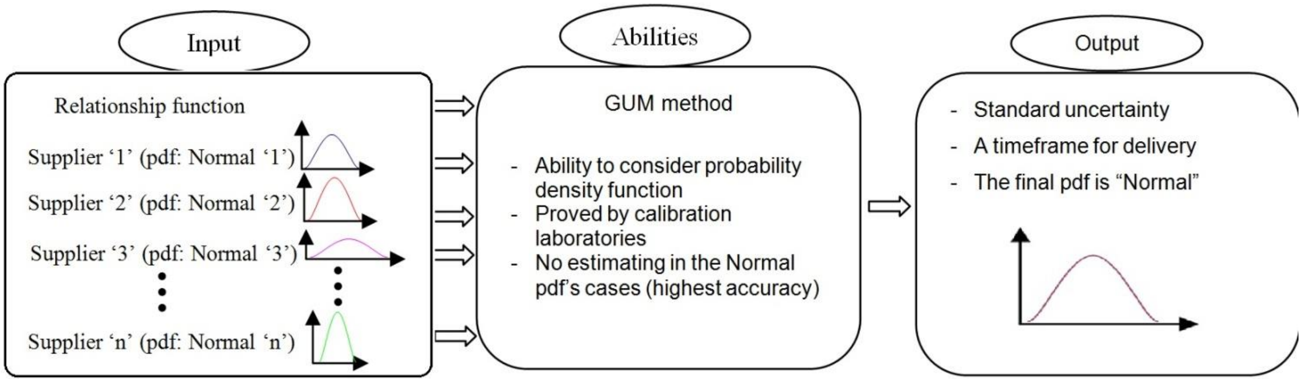

Fig. 8. Adapted GUM: inputs, outputs and abilities

As illustrated in Fig. 12, the relationship function of the network for DTU must be calculated by the given rules in se ction 4.1, and it is one of the inputs of the adapted GUM. To start the adapted GUM calculation, the pdfs of all critic al suppliers must be specified. Adapted GUM is a pdf based method, in the cases which the pdfs of delivery time for all critical suppliers where as Normal, there is no estimation in calculating process, and it has highest accuracy by co mparing to the other methods. But, adapted GUM has some limitations:

1. It is not possible to consider all kinds of pdfs. Some pdfs will be applied according to the Normal function b y considering the central limit theorem.
2. The final pdf is not sensitive to the entrance pdfs. And as shown in the Fig. 12, the final pdf will be Normal a nd it is not sensitive to the entrance pdfs.
3. The results are not accurate when at least one supplier has another pdf, because it must be estimated to th e Normal.
4. It is difficult to apply the method in complex SN with nonlinear relationship function.

To backup GUM, we are planning a simulation program based on the MCM. The inputs, outputs, and abilities of the adapted MCM is given in Fig. 13.

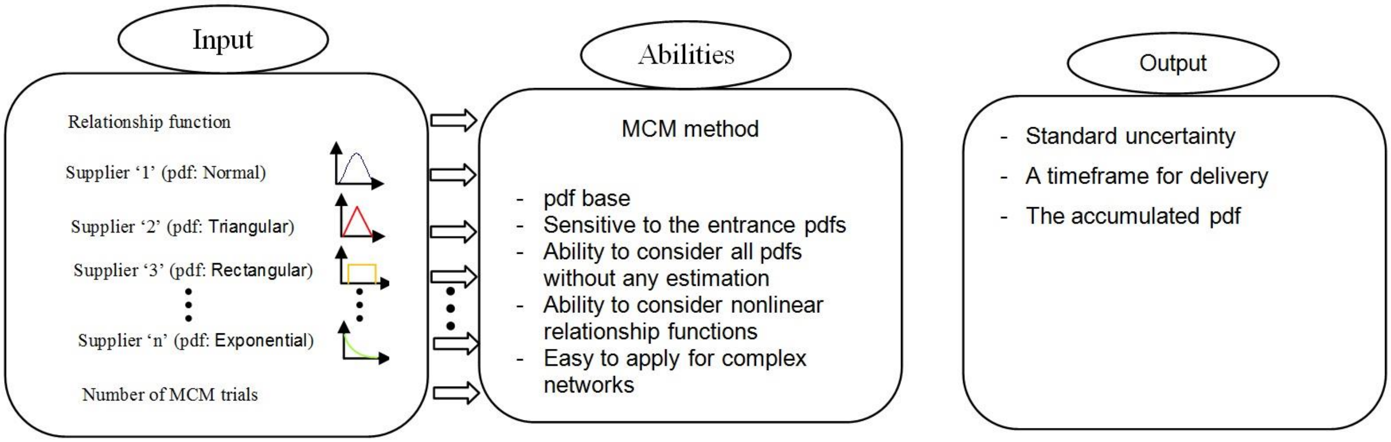

Fig. 9. Adapted MCM: inputs, outputs and abilities

In this study, MCM is a practical technique for substituting GUM in calculating uncertainty because the inputs of the MCM are the same as GUM. Moreover, the outputs of MCM are the same as GUM. In consequense, standard uncert ainty, a timeframe for delivery of the order, and the accumulated pdf of DTU of the network will be identified. As so me abilities of the MCM one can mention that it is a, pdf based method which is sensitive to the entrance pdfs with out any estimation. Moreover, different pdfs may be chosen (See Fig. 12). This method is able to consider nonlinear relationship functions and it is easy to apply for high complex networks. But, because MCM is a simulation method, the results of MCM must be qualified. To see the qualification of MCM, and algorithm of the process of MCM refer t o (Safaei, et al., 2014).

3.5. Hybrid methodology

In this section, the algorithm of the hybrid methodology and its implementation process is described. As mentioned , this methodology is generated by transferring and coordinating of three different methods, and adapted them to t he SN management. The process of hybrid methodology is divided into four steps illustrated in Fig. 14.

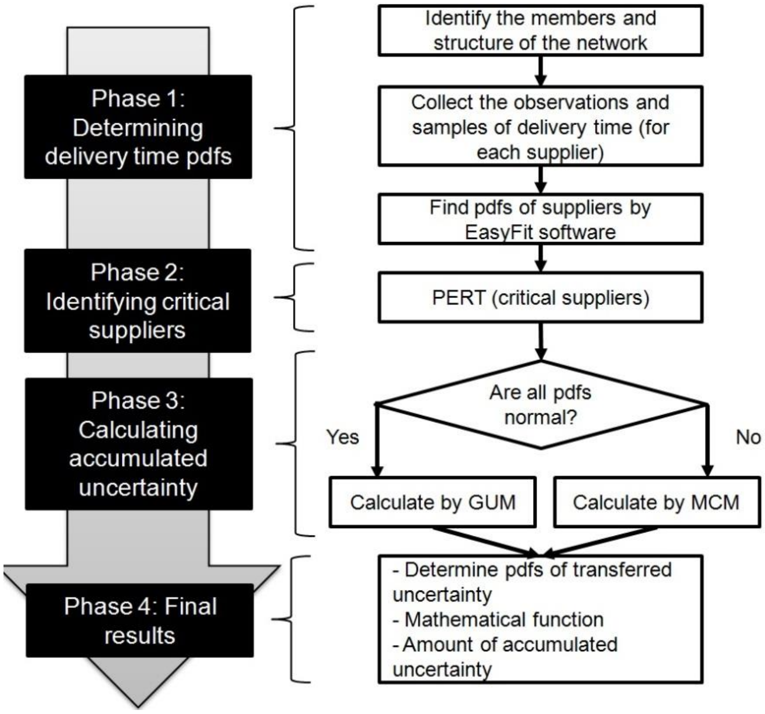

Fig. 10. Hybrid methodology

The procedure of this methodology is as follows:

1. **The SN structure, and the pdfs of delivery time for each supplier should be determined for the specific orde r.**

   To this aim, samples and observations related to the delivery time regarding to the past projects must be colle cted. These data are the delivery time of past projects for every supplier who are involved in the network. Aft erward, put all the collected data into the EasyFit software, for each supplier separately. Therefore, the EasyFi t software by using the MLE (Maximum Likelihood Estimates) method find the best fitted pdf for each supplier (Mathwave,

   2013). The EasyFit software has a capacity to conform the samples to 65 existing pdfs in mathematics and the real world, that is an exclusive feature, and then by prioritizing from 1 to 65, the nearest pdf function could be identified.

2. **The critical path must be determined.**

   The PERT method is able to find the critical path of the network. This critical path is contains of several supplie rs who are bottlenecks in the network. These critical suppliers have highest influences on the DTU of the netw ork, because each small change in the mean or standard uncertainty of them can change the mean and standa rd uncertainty of the whole network. Then, by using the adapted PERT method, find the critical suppliers. The links between critical suppliers are drawn and hereafter the critical path through the network can be determin ed.

3. **The accumulated uncertainty must be calculated.**
   For some cases of pdfs, there is no mathematic formula to find the summation several different pdfs (except t he Normal pdf). Therefore, the GUM is unable to find the delivery time accumulation of several suppliers with different pdf. For this reason, if all the members of the critical network have a normal distribution, GUM could be selected as the calculating engine. Otherwise, when there is another pdf is considered or if the relationshi p function is complex or nonlinear, the MCM is a proper replacement. It is needed to mention that, the numb er of trial runs of the MCM in the hybrid method is chosen as 10000.
4. **The final results of hybrid methodology.**
   This hybrid methodology can calculate and expand every complex network with any number of suppliers. In th is methodology, PERT is presented to challenge complexities of the networks, and GUM and MCM are the algo rithm calculation engines.

The qualification of the adapted MCM, and verification of the hybrid methodology are done in the previous paper (s ee (Safaei, et al., 2014)). In this paper, ability of implementing of the methodology in three real-life case studies will be discussed, and finally this methodology will be validated by 10-folds cross validation methods.

4. Applicability of the methodology in real-life case studies

This section introduces three real-life SNs and applies the hybrid methodology to them in order to measure the efficiency of this methodology in the r eal world. To this end, three different networks from three scenarios are discussed. The data of these case studies a re taken from the literature. These three scenarios of SNs are as follows:

1. Case study for custom products SNs
2. Case study for SNs with more than one OEM
3. Case study for SNs with more than one critical path

4.1. Case study for the custom products SNs

To challenge the proposed hybrid methodology, the first SN to which the methodology is applied is a notebook SN e xtracted from studies conducted by Graves and Willems (2005) and Li and Womer (2008) (Li & Womer, 2008; Graves & Willems, 2005). This network supplied two types of notebooks dubbed here as notebook “A” (gray cover) and notebook “B” (blue cover), both of them assembled by the same OEM.

This SN is illustrated in Fig. 15.

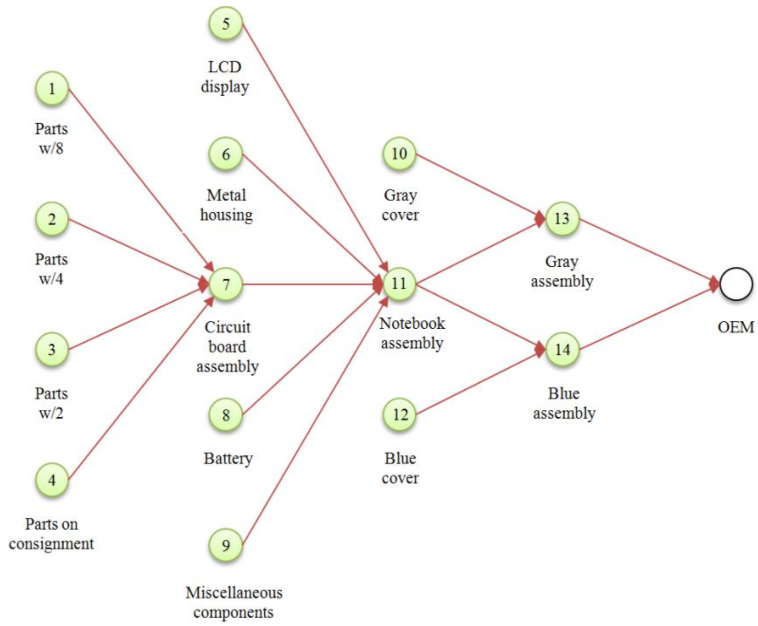

Fig. 11. Notebook computer SN

Since this SN has been designed to provide two products, it is necessary to demonstrate the SN of each product sep arately so as to be able to implement the hybrid methodology. Accordingly, the SN is illustrated into the separate SN s for each product (Fig. 16). The network on the left belongs to the blue-covered notebooks, while the one on the right belongs to Gary-covered notebooks.

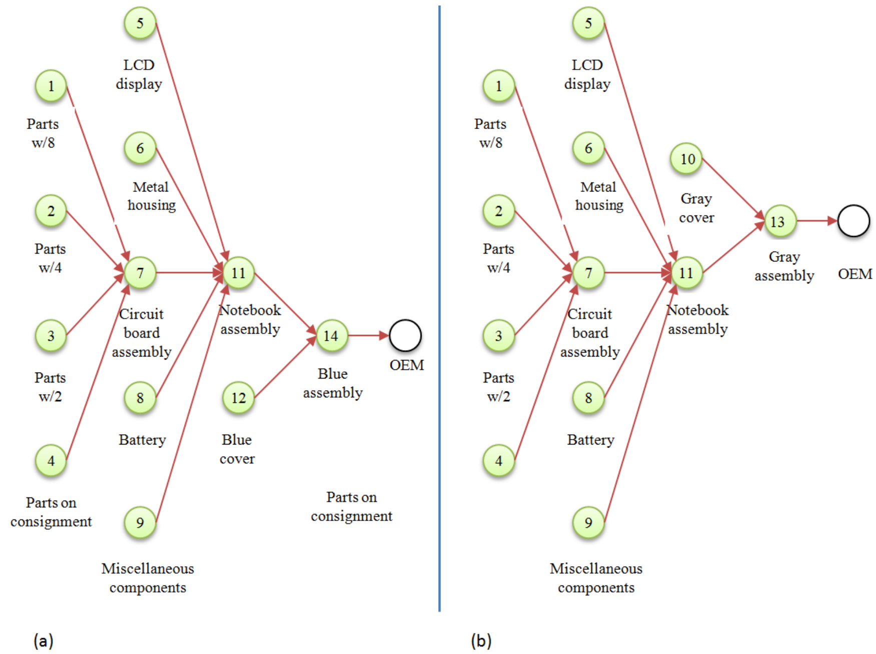

Fig. 12. Instance SNs for two variant notebook computers

The pdfs of all the suppliers have been presented in Table 1 based on the delivery times for the suppliers in this case study as well as the delivery time observed by Graves and Willems (2005).

Table 1. The pdfs of suppliers in notebook computer SN (Graves & Willems, 2005)

Node	Stageiname	pdf	Meani(μ_i) = $EXP(DT_i)$i(Day)	Variancei(u_i^2)(Day)
Supplier 1	Parts w/8	Normal	40	6
Supplier 2	Parts w/4	Normal	20	8
Supplier 3	Parts w/2	Normal	20	4
Supplier 4	Parts on consignment	Normal	5	0
Supplier 5	LCD display	Normal	60	3
Supplier 6	Metal housing	Normal	70	2
Supplier 7	Circuit board assembly	Normal	20	4
Supplier 8	Battery	Normal	60	5
Supplier 9	Miscellaneous components	Normal	30	4
Supplier 10	Gray cover	Normal	40	5

Supplier 11	Subassembly	Normal	5	2
Supplier 12	Blue cover	Normal	40	5
Supplier 13	Gray assembly	Normal	1	0
Supplier 14	Blue assembly	Normal	1	0
		*DT: Delivery Time		

Then, the hybrid methodology is applied to the above-
mentioned SN to calculate its DTU. Since the mean of delivery time, standard uncertainty, and pdfs are equal for suppliers 12, 13 and 14, which produce two different products, the level of uncertainty will be equal for both products. Hence, calculate the uncertainty of one of them only, namely the blue-covered notebooks will be calculated. Critical SNs whose delivery time fluctuations have the highest impact on their uncertainty are identified after the $E(DT)$ and pdf of each network is determined. The network is simplified and prepared for further calculations by identifying these suppliers through the use of the adapted PERT and data extracted from Table 1. Forward pass and backward pass calculations for network (a), illustrated in Fig. 16, are presented in Table 2. Suppliers 1, 2, 3, 4, 5, 6, 8, 9 and 12 are identified as beginner nodes since they enjoy the lowest input degree and are not preceded by any suppliers, while the OEM is considered the last node in the network. The input degree of each supplier is the number of suppliers, which are prerequisites of the specified supplier.

Table 2. Calculation of forward and backward in notebook computer SN

	Calculation of forward pass		Calculation of backward pass	
Node	$ES_i = \max(Ef_1, Ef_2, \ldots, Ef_k)$	$Ef_i = ES_i + EXP(DT_i)$	$LF_i = \min(LS_1, LS_2, \ldots, LS_K)$	$LS_i = LF_i - EXP(DT_i)$
Supplier 1	ES_1=0	40	50	10
Supplier 2	ES_2=0	20	50	30
Supplier 3	ES_3=0	20	50	30
Supplier 4	ES_4=0	5	50	45
Supplier 7	40	60	70	50
Supplier 5	ES_5=0	60	70	10
Supplier 6	ES_6=0	70	70	0
Supplier 8	ES_8=0	60	70	10
Supplier 9	ES_9=0	30	70	40
Supplier 11	70	75	75	70
Supplier 12	ES_{12}=0	40	75	35
Supplier 14	75	76	76	75
OEM (15)	76	-	-	LS_{15}=ES_{15}=76
*DT: Delivery Time				

In this stage, the critical path must be determined. The results of calculations related to the critical path, obtained through the use of the PERT algorithm illustrated in (Safaei, et al., 2014), have been presented in Table 3.

Table 3. Calculation of the critical path in notebook computer SN

Node	$LS_i - ES_i$
Supplier 1	10
Supplier 2	30
Supplier 3	30
Supplier 4	35
Supplier 7	10
Supplier 5	10
Supplier 6	0
Supplier 8	10
Supplier 9	40
Supplier 11	0
Supplier 12	35
Supplier 14	0
OEM (15)	0

As shown in Table 3, suppliers for which the difference between the earliest and latest start times is zero are consid ered critical suppliers of the network. The path of the critical suppliers has been drawn in Fig.17.

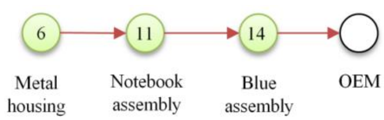

Fig. 13. Critical path network for notebook computer

At the next stage, the computational engine of the algorithm should be determined. The GUM method is employed to conduct the calculations since all the suppliers in the critical network enjoy Normal pdfs, the number of suppliers is low, and the network's form and structure are the linear one. Regarding the adapted GUM illustrated in (Safaei, et al., 2014), the calculations are as follows:

First, the relationship function of the suppliers is defined as follows since the critical network of notebooks has been turned into a single line:

$$f(y) = f(DT_6) + f(DT_{11}) + f(DT_{14})) \qquad (3)$$

In other words, the uncertainty for suppliers 6, 11 and 14, will have the highest effect on the DTU of the whole netw ork.

Given the relationship function, the assumptions and equation, the standard uncertainty for the notebook network (u_c) is calculated as follows (equation 4):

$$u_c^2(Y) = u(DT_6)^2 \times (\frac{\partial f}{\partial DT_6})^2 + u(DT_{11})^2 \times (\frac{\partial f}{\partial DT_{11}})^2 + u(DT_{14})^2 \times (\frac{\partial f}{\partial DT_{14}})^2 = 4 \text{ days}$$

$$u_c = 2 \text{ days} \quad (4)$$

Whereas $\frac{\partial f}{\partial DT_6} = \frac{\partial f}{\partial DT_{11}} = \frac{\partial f}{\partial DT_{14}} = 1.$

The standard uncertainty of delivery time for this network is 2 (equation (4)), namely a numerical range with the ma ximum tolerance of 2 days. Because of the normalcy of delivery time for all network members, the delivery time of t he whole network is also normal, with its mean of delivery time being determined by adding up the mean delivery ti mes of all the members since the critical network is a linear one (equation (5)).

$$EXP(DT_c) = \mu_c = EXP(DT_6) + EXP(DT_{11}) + EXP(DT_{14}) = \mu_6 + \mu_{11} + \mu_{14} = 76 \text{ days} \quad (5)$$

Whereas EXP(DT_i), is the expected value of delivery time of supplier i.

The expanded uncertainty with a confidence coefficient=95.4% and coverage factor=2 have been calculated as show n below. This expanded uncertainty indicates that the managers of the notebook networks are able to deliver noteb ooks within the pre-determined delivery time range, by 95% of confidence equation (6).

$$U = k \times u_c = 2 \times 2 = 4 \quad (6)$$

As a result for $\beta = 95.4\%$ timeframe of delivery time up to OEM is 76 ± 4 days.

The final diagram of the delivery time pdf and its uncertainty has been illustrated in Fig. 18.

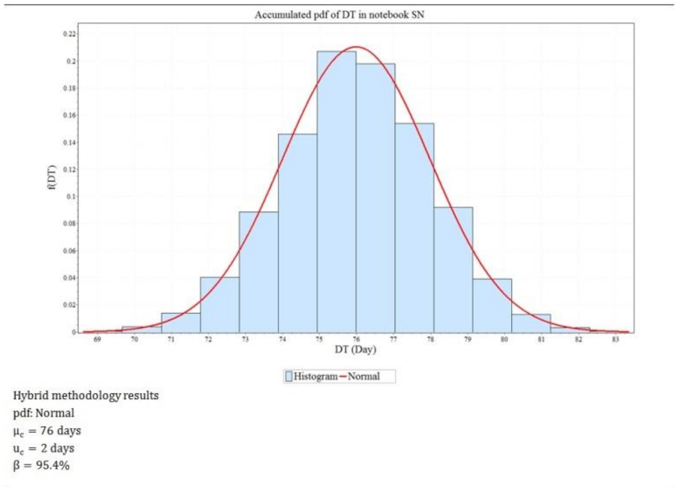

Fig. 14. Accumulated pdf of DTU in notebook computer SN

In the other scenarios, the details of the calculations will not be considered.

4.2. Case study for SNs with more than one OEM

In the real world, not all of the SNs have a single OEM, and some networks provide goods based on orders placed by several OEMs. The hybrid methodology is applied to the SN of Noramco's spray nozzles here in order to see how it works for such networks. This case study has been taken from a study conducted by (Kumar, et al., 2001).

The SN of these products is illustrated in Fig. 19.

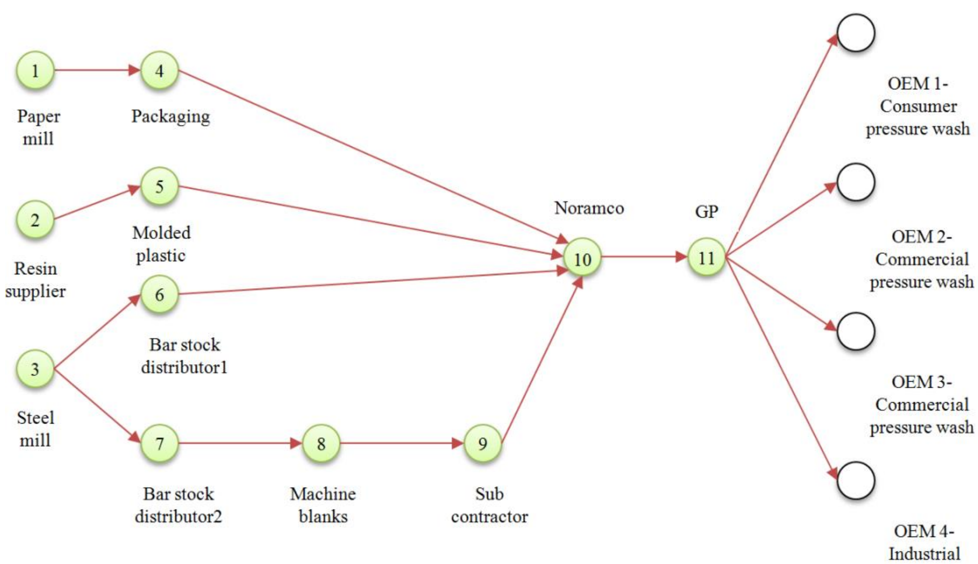

Fig. 15. Noramco's spray nozzles SN (Kumar (2001))

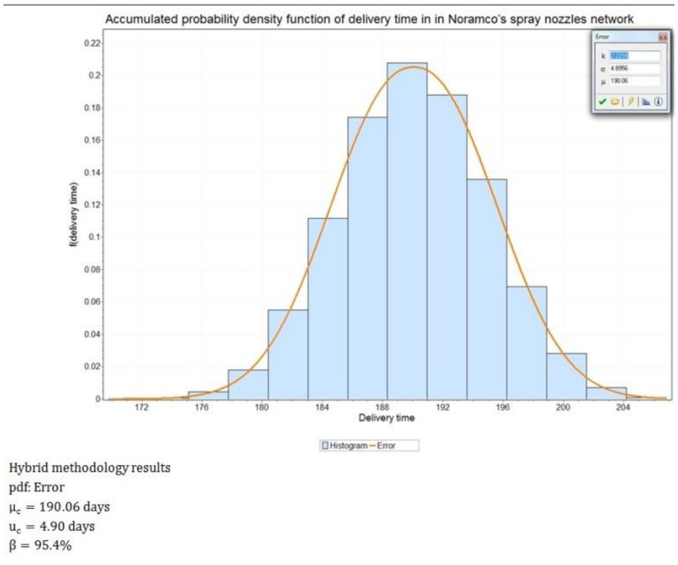

Fig. 16. Accumulated pdf of DTU in Noramco's spray nozzles SN

The results indicate that the standard uncertainty is equal to 4.90 days ($u_c = 4.90$ day), the expected delivery time is equal to 190.06 days ($\mathrm{EXP(DT)} = 190.06$ day), and the best fitted pdf for calculating accumulated uncertainty for this network, which has an Error dis tribution function, has the following features: k=2.2634, u=4.935, and m=189.99.

4.3. Case study for SNs with more than one critical path

In this section, the supply, assembly and production network of bulldozers presented by Graves and Willems (2003) will be examined (Graves & Willems, 2003). Graves and Willems have combined the small suppliers with the main suppliers due to the importance of the main processes in the SN and in order to avoid complexity and confusion, introducing the final SN illustrated in Fig. 2 1.

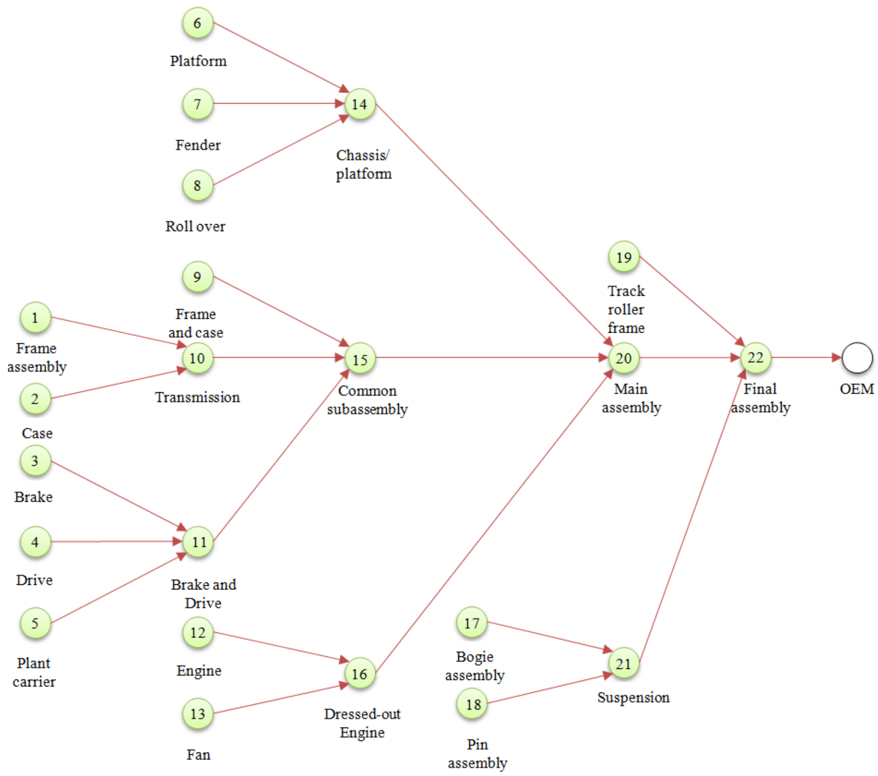

Fig. 17. Bulldozer SN (Nepal, et al., 2012; Wilhelm, et al., 2013)

After the calculation process related to the determining the critical path, two critical path is determined (see Fig. 22)
.

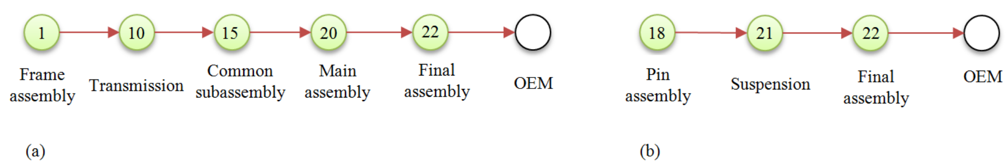

Fig. 18. Two critical paths of bulldozer SN

Hence, the standard uncertainty should be calculated separately for both critical paths in order to select the maxim um uncertainty as the standard uncertainty for the whole network.

First, the standard uncertainty of the critical path (a) will be calculated. Since this critical network is a linear one, the relationship function of the suppliers will be a summation of the suppliers pdfs. The relationship functions of path (a) and (b) are demonstrated in the form of equation (7) and (8).

$$f(y) = f(DT_1) + f(DT_{10}) + f(DT_{15}) + f(DT_{20}) + f(DT_{22}) \quad (7)$$

$$f(y) = f(DT_{18}) + f(DT_{21}) + f(DT_{22}) \quad (8)$$

Then, the calculation of the standard uncertainty for the critical path (a) is as follows (equation (9)):

$$u_{ca}^2(Y) = u(DT_1)^2 \times (\frac{\partial Y}{\partial DT_1})^2 + u(DT_{10})^2 \times (\frac{\partial Y}{\partial DT_{10}})^2 + u(DT_{15})^2 \times (\frac{\partial Y}{\partial DT_{15}})^2 + u(DT_{20})^2 \times (\frac{\partial Y}{\partial DT_{20}})^2 + u(DT_{22})^2 \times (\frac{\partial Y}{\partial DT_{22}})^2 = 20 \text{ days}$$

$$u_{ca} = 4.47 \text{ days} \quad (9)$$

The accumulated pdf for this network is Normal since the pdf of all the critical suppliers is Normal, and its standard uncertainty is 4.47 days. The expected DT is calculated through the use of the following relation (10):

$$\begin{aligned} EXP(DT_{ca}) = \mu_{ca} \\ &= EXP(DT_1) + EXP(DT_{10}) \\ &+ EXP(DT_{15}) + EXP(DT_{20}) \\ &+ EXP(DT_{22}) = \mu_1 + \mu_{10} \\ &+ \mu_{15} + \mu_{20} + \mu_{22} \\ &= 59 \text{ days} \end{aligned} \quad (10)$$

Also, the expanded uncertainty with β= 95.4% and k=2 is calculated as follows (11):

$$U = k \times u_{ca} = 2 \times 4.47 = 8.94 \text{ days} \quad (11)$$

As a result for $\beta = 95.4\%$ time frame of delivery time up to OEM is 59 ± 8.94 days.

The final diagram of the pdf for delivery time and the relevant uncertainty has been illustrated in Fig. 23.

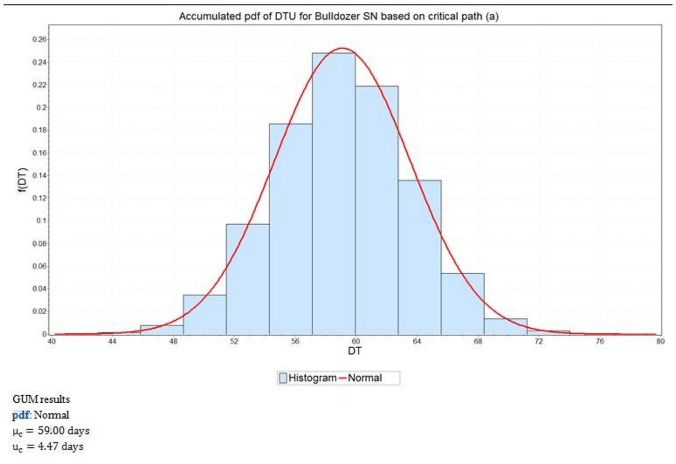

Fig. 19. Accumulated pdf of DTU for Bulldozer SN, according to the critical path (a)

In the next step, the same calculations will be applied to the critical path (b). To avoid repeating the above process, only relevant calculations and equations are mentioned here.

$$u_{cb}^2(Y) = u(DT_{18})^2 \times (\frac{\partial Y}{\partial DT_{18}})^2 + u(DT_{21})^2 \times (\frac{\partial Y}{\partial DT_{21}})^2 + u(DT_{22})^2 \times (\frac{\partial Y}{\partial DT_{22}})^2 = 15 \text{ days}$$

$$u_{cb} = 3.87 \text{ days} \quad (12)$$

$$EXP(DT_{cb}) = \mu_{cb} = EXP(DT_{18}) + EXP(DT_{21}) + EXP(DT_{22}) = \mu_{18} + \mu_{21} + \mu_{22} = 59 \text{ days} \quad (13)$$

$$U = k \times u_{cb} = 2 \times 3.87 = 7.74 \text{ days} \quad (14)$$

The accumulated pdf for this critical path is an Inverse Gaussian function with mean of delivery time= 59 days and ac cumulated uncertainty= 3.87 days. The relevant diagram has been illustrated in Fig. 24.

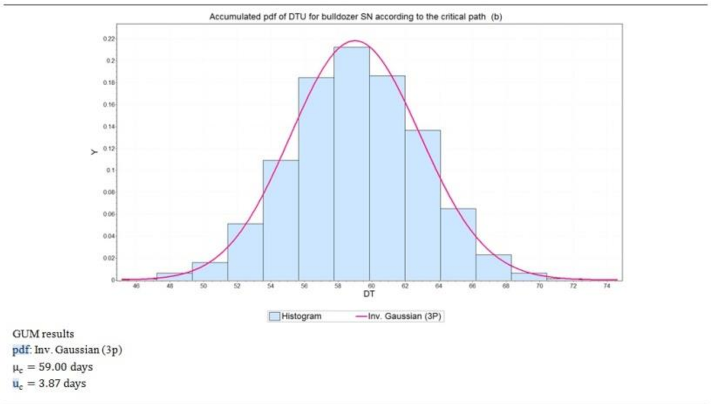

Fig. 20. Accumulated pdf of DTU for Bulldozer SN, according to the critical path (b)

Since the standard uncertainty for path (a) is higher than that of the path (b), it is considered as the uncertainty of the whole network.

5. Validation of hybrid methodology by cross –validation

Cross-validation is an evaluation technique that determines the generalizability of the outcome of a statistical analysis on a data set. This technique is usually applied to estimate the accuracy of a predictive model in practice. In general, one round cross-validation includes dividing the data into two subsets (training data and test data). It analysis on one of its subsets (training data) and validate this analysis by using the test data (Fig. 25).

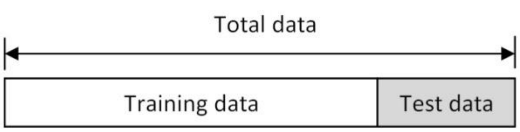

Fig. 21. A division of the data set into subsets (Borovicka, 2012)

To reduce variability, cross-validation procedure performs several rounds with different divisions, so that the validation results are averaged over the rounds. The cross validation technique is applied when the data collection is more difficult, costly or impossible (Fleet, 2012).

5.1. K-fold validation

In this case of validation, the data are randomly partitioned into K equal size subsets. From this K subsets, each time, a single subset is selected as the test data for validation and other (K-

1) subsets are used as training data. This procedure is repeated K times, and all data are used exactly once for traini ng and once for validation. The average of these K validations shows the final accuracy of the estimating model (Bro wne, 2000).

A single round of K-fold cross validation proceeds as follows:

1. Arrange the data in a random order
2. Partition the training data into K-folds (Fig. 26)

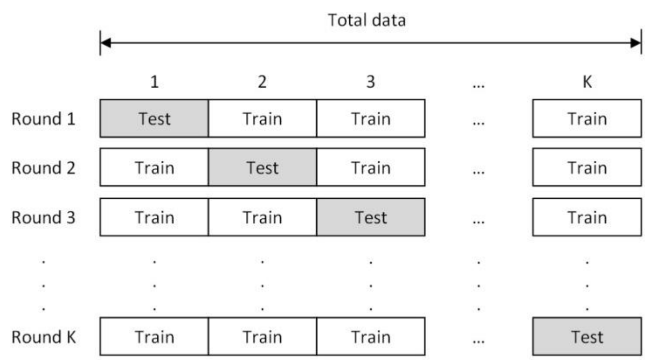

Fig. 22. K-folds cross-validation

3. For each K experiment, use (K-1) folds for training and the left one for testing and validating.
4. In each round ($i = 1,2,3, \dots, K$), fit the model according to the K-1 folds and test and validate the model by the test data. Find the error of each round (E_i).
5. Calculate Error of the model (E).

$$E = \frac{\sum_{i=1}^{K} E_i}{K} \qquad (15)$$

5.2. Validation of the hybrid algorithm by cross-validation technique

To validate the hybrid algorithm, we applied cross-validation technique to show the accuracy of the estimated pdf for the DTU of the SN. To this end, the error of the e stimated function for the Noramco's spray nozzles SN, is calculated by cross-validation technique.

In the calculations of the hybrid method for the presented case study, after simplification of the network the critical path was a linear network of the suppliers 3, 7, 8, 9, 10, and 11. The relationship function of this network regarding t he introduced strategies, is the same as equation (16).

$$f(y) = f(DT_3) + f(DT_7) + f(DT_8) + f(DT_9) + f(DT_{10}) + f(DT_{11}) \text{ and } Y = DT_3 + \qquad (16)$$

$DT_7 + DT_8 + DT_9 + DT_{10} + DT_{11}$

According to the introduced pdf of each critical supplier, by MCM, 10000 random data are generated and by relat ionship function 10000 times of Y are created. Then, by using the combination of MCM and EasyFit software the bes t pdf (f(y)) for Y is estimated. This function is the result of hybrid method, and all of the decisions after that (like calc ulating of the accumulated uncertainty) are made based on it. For this reason, calculating the error of this created p df can show the error of the hybrid algorithm. For details, see Table 4.

Table 4. Generated random numbers by adapted MCM

$f(Y) = f(DT_2) + f(DT_3) + f(DT_5) + f(DT_1) + f(DT_4) + f(DT_{5'})$ iandiY $= DT_2 + DT_3 + DT_5 + DT_1 + DT_4 + DT_{5'}$							
Row	DT_2 (Random number according to pdf)	DT_3 (Random number according to pdf)	DT_5 (Random number according to pdf)	DT_1 (Random number according to pdf)	DT_4 (Random number according to pdf)	$DT_{5'}$ (Random number according to pdf)	Y
1	Random number	Random number	Random number	Random number	Random number	Random number	Y1
2	Random number	Random number	Random number	Random number	Random number	Random number	Y2
3	Random number	Random number	Random number	Random number	Random number	Random number	Y3
	…	…	…	…	…	…	…
9998	Random number	Random number	Random number	Random number	Random number	Random number	Y9998
9999	Random number	Random number	Random number	Random number	Random number	Random number	Y9999
10000	Random number	Random number	Random number	Random number	Random number	Random number	Y10000

*pdf: Probability density function

**DT: Delivery time

As introduced before, the pdf of DTU of the proposed network in the case study was “Error distribution function” indicated by k=2.2634, u_c=4.935, and m=189.99. To validate the hybrid methodology, error of fitting the pdf is calculated by the 10-fold cross-validation technique.

Round 1	Train data $(Y_1, \dots, Y_{9000})$	Test data $(Y_{9001}, \dots, Y_{10000})$
Round 2	Train data $(Y_1, \dots, Y_{8000})$ and $(Y_{9001}, \dots, Y_{10000})$	Test data $(Y_{8001}, \dots, Y_{9000})$
Round 3	Train data $(Y_1, \dots, Y_{7000})$ and $(Y_{8001}, \dots, Y_{10000})$	Test data $(Y_{7001}, \dots, Y_{8000})$
Round 4	Train data $(Y_1, \dots, Y_{6000})$ and $(Y_{7001}, \dots, Y_{10000})$	Test data $(Y_{6001}, \dots, Y_{7000})$
Round 5	Train data $(Y_1, \dots, Y_{5000})$ and $(Y_{6001}, \dots, Y_{10000})$	Test data $(Y_{5001}, \dots, Y_{6000})$
Round 6	Train data $(Y_1, \dots, Y_{4000})$ and $(Y_{5001}, \dots, Y_{10000})$	Test data $(Y_{4001}, \dots, Y_{5000})$
Round 7	Train data $(Y_1, \dots, Y_{3000})$ and $(Y_{4001}, \dots, Y_{10000})$	Test data $(Y_{3001}, \dots, Y_{4000})$
Round 8	Train data $(Y_1, \dots, Y_{2000})$ and $(Y_{3001}, \dots, Y_{10000})$	Test data $(Y_{2001}, \dots, Y_{3000})$
Round 9	Train data $(Y_1, \dots, Y_{1000})$ and $(Y_{2001}, \dots, Y_{10000})$	Test data $(Y_{1001}, \dots, Y_{2000})$
Round 10	Train data $(Y_{1001}, \dots, Y_{10000})$	Test data $(Y_1, \dots, Y_{1000})$

Fig. 23. 10 rounds of designing cross-validation for hybrid methodology

In each round, a pdf according to the training data is fitted. After the pdf is created ($g(y_{Train})$), put the test data into the $g(y_{Train})$ and calculate the amount of pdf of test data $g(y_{Test})$ according to the pdf, which is created by training data and compare this number with the original pdf; $f(y)$, which is obtained by hybrid model for the test data; $f(y_{Test})$. Afterward, by equation (17), the error of each fitted function for each round (E_{round}), must be calculated individually. The final error of fitted pdf for the hybrid model is obtained by the average of the round errors (see equation (18)). Table 5, illustrates the process of error calculation for each round.

$$E_{round} = \sqrt{\frac{(g(y_{Test}) - f(y_{Test}))^2}{1000}} \quad (17)$$

$$E = \frac{\sum_{round=1}^{10} E_{round}}{10} \quad (18)$$

Table 5. Process of error calculation for each round

Round	$f(y)$	$g(y_{Test})$	E_{round}
1		Generalized extreme value (k= -0.30697, u= 5.0366, μ= 188.39)	0.047504589
2	Error (k= 2.2634, u=4.935, μ=189.99)	Lognormal (k= 0.03749, u= 4.8678, a= 59.976)	0.003033689
3		Generalized extreme value (k= -0.3244, u= 5.1739, μ= 188.33)	0.002083608

4	Generalized extreme value (k= -0.26428, u= 4.8419, μ= 188.11)	0.002280446
5	Weibull 3p (α=3.9331, β= 19.331.4, γ= 172.56)	0.00227037
6	Generalized extreme value (k= -0.24507, u= 4.8015, μ= 188.03)	0.003239487
7	Error (k= 2.1335, u=4.9923, μ=188.33)	0.001314435
8	Generalized extreme value (k= -0.23753, u= 4.9111, μ= 189.96)	0.002012467
9	Beta ($\alpha_1 = 3.9979, \alpha_2 = 4.4625,\ a = 175.69,\ b = 205.11$)	0.004332473
10	Normal (u= 4.8731, μ= 190.13)	0.003102529

$$E = \frac{\sum_{round=1}^{10} E_{round}}{10} = 0.00712 \qquad (19)$$

The calculation of the 10 folds cross-validation shows that the error of the fitted pdf is approximately 0.712%. This amount shows the function is fitted with high accuracy, and it validates the hybrid methodology results.

6. Conclusion

Customer-oriented production and manufacturing flexibility are the most elementary principles for survival in today's competitive market (Subramanian, et al., 2014). Customers' demands and needs change frequently, making traditional SNs with fixed structures uneconomical (Agus, 2011). Therefore, it is necessary to design an SN for each type of ordered product in order to reduce production costs, increase quality and flexibility, and improve the ability to meet customers' different requests. Therefore, an OEM might have different SNs in the short term. Today, managers have realized the importance of SNs with dynamic structures and are trying to adapt the decision making strategies in traditional networks to dynamic one with high speed and accuracy. High speed and accuracy are the most important features of these kinds of strategies, which must be adapted to the dynamic networks, since SNs are of short-term nature (Wilhelm, et al., 2013).

As stated, the importance of delivery time has been proved by literature. Furthermore, DTU could inflict irreparable damage on OEMs. Uncertainty in the SNs with fixed structures has been examined by many scientists (Cardoso, et al., 2013; Peidro, et al., 2009; You & Grossmann, 2008). However, the current study has focused on DTU in dynamic SNs.

The presented methodology is coordinating of three methods from three different fields and adaptation of them to the SN management field. The main aim of this methodology is monitoring and measuring of DTU of complex SNs . Moreover, the authors have tried to apply simple mathematical formulas to be more understandable for industrial managers and applicable in real-

life studies. Additionally, the hybrid methodology is able to consider loop, nonlinear relationship function, and all re al-

life pdfs in the network. This methodology can implement in the terms of the macro and micro views. However, this research study is focused on the macro view ability, that is to calculate internal DTU for every factory and supplier s eparately. Fig. 28 illustrates the internal networks of a supplier who is a member of an SN.

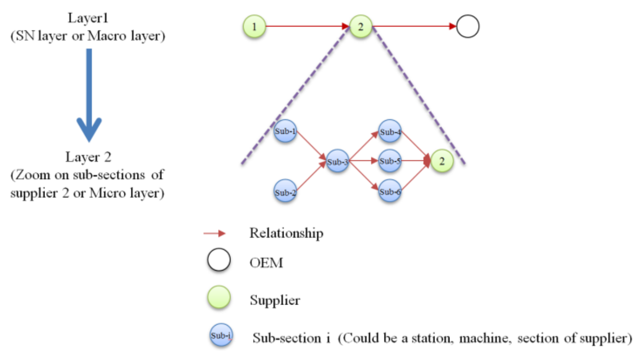

Fig. 24. An example of sub-sections network inside of a supplier in the SN

The further applications of the hybrid methodology are as follows:

1. Tool to find a proper structure for an SN
2. Performance indicator for SN regarding the uncertainty of the network
3. Assistance tool for supplier selection
4. Indicator to find suppliers with high/low performance
5. Tool to identify critical places of implementation of reducing strategies in the network

The researcher's suggestions regarding future research are:

1. Propose a fuzzy model for this research problem and compare results
2. Applying proposed methodology to calculate the internal accumulated uncertainty of each supplier
3. Modifying proposed methodology to be able to consider demand uncertainty

7. References

[1] Agus, A., 2011. The structural influence of supply chain management on product quality and business performance. International Journal of Trade, Economics and Finance, 2(4), pp. 269-275.

[2] Ari-Pekka, H. & Antti, P., 2005. Supply network dynamics as a source of new business. International Journal of Production Economics, 98(1), pp. 41-55.

[3] Borovicka, T. M. J. J. R. K. P. a. J. J., 2012. Advances in Data Mining Knowledge Discovery and Applications. In: Selecting Representative Data Sets. s.l.:InTech, pp. 43-70.

[4] Browne, M., 2000. Cross-validation methods. Journal of Mathematical Psychology, 44(1), p. 108–132.

[5] Calvet, S. et al., 2010. Ventilation rates in mechanically-ventilated commercial poultry buildings in Southern Europe: Measurement system development and uncertainty analysis. Biosystems engineering, 106(4), p. 423–432.

[6] Cardoso, S. R., Barbosa-Póvoa, A. P. F. D. & Relvas, S., 2013. Design and planning of supply chains with integration of reverse logistics activities under demand uncertainty. European Journal of Operational Research, 226(3), p. 436–451.

[7] Cheng, C. Y., Chen, T. L. & Chen, Y. Y., 2013. An analysis of the structural complexity of supply chain networks. Applied Mathematical Modelling, p. In Press.

[8] da Silveira, G. J. C. & Arkader, R., 2007. The direct and mediated relationships between supply chain coordination investments and delivery performance. International Journal of Operations & Production Management , 27(2), p. 140–158.

[9] Fleet, D., 2012. Machine Learning and Data Mining, s.l.: Lecture notes, Computer Science Department, University of Toronto.

[10] Graves, S. C. & Willems, S. P., 2005. Optimizing the supply chain configuration for new products. Management Science , 51(8), p. 1165–1180.

[11] Graves, W. & Willems, S. P., 2003. Supply chain design: safety stock placement and supply chain configuration. s.l.:Elsevier.

[12] Hu, F., Lim, C. C. & Lu, Z., 2013. Coordination of supply chains with a flexible ordering policy under yield and demand uncertainty. International Journal of Production Economics, 146(2), p. 686–693.

[13] Institute standards committee, P. m., 2009. In: 4. edition, ed. A Guide to the Project Management Body of Knowledge. s.l.:Project Management Institute.

[14] JCGM, 2008. Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM)-GUM 1995 with minor corrections. s.l.:JCGM member organizations.

[15]Käkia, A., Salo, A. & Talluri, S., 2013. Impact of the shape of demand distribution in decision models for operations management. Computers in industry, 64(7), p. 765–775.

[16]Kumar, S., Chandra, C. & Stoerzinger, M., 2001. Serve your supply chain, not operations- a case study. Industrial Management & Data Systems, 101(8), pp. 414-425.

[17]Li, H. & Womer, K., 2008. Modeling the supply chain configuration problem under resource constraints. International journal project management, 26(6), p. 646–654.

[18]Mathwave, 2013. Mathwave website (Easyfit help). [Online]
Available at: http://www.mathwave.com/help/easyfit/html/analyses/distributions/error.html

[19]Micheli, G. J. L., Cagno, E. & Zorzini, M., 2008. Supply risk management vs supplier selection to manage the supply risk in the EPC supply chain. Management Research News, 31(11), pp. 846 - 866.

[20]Montgomery, D. C., 2008. Introduction to Statistical Quality Control. 6 ed. s.l.:Wiley.

[21]Nepal, B., Monplaisir, L. & Famuyiwa, O., 2012. Matching product architecture with supply chain design. European Journal of Operational Research, 216(1), pp. 312-325.

[22]Norrman, A. & Jansson, U., 2004. Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. International Journal of Physical Distribution & Logistics Management, 34(5), pp. 434 - 456.

[23]Peidro, D., Mula, J., Poler, R. & Verdegay, J. L., 2009. Fuzzy optimization for supply chain planning under supply, demand and process uncertainties. Fuzzy Sets and Systems, 160(18), p. 2640–2657.

[24]Pishvaee, M. S., Jolai, F. & Razmi, J., 2009. A stochastic optimization model for integrated forward/reverse logistics network design. Journal of Manufacturing Systems, 28(4), p. 107–114.

[25]Safaei, M., 2014. Delivery time uncertainty in dynamic supply networks. 1st ed. Aachen: Shaker.

[26]Safaei, M. et al., 2013. A method to estimate the accumulated delivery time uncertainty in supply network. Bremen, Springer Berlin Heidelberg, pp. 337-347.

[27]Safaei, M., Mehrsai, A. & Thoben, K., 2014. A computational method in analyzing of delivery time uncertainty for highly complex supply networks. Measurement, Volume 55, pp. 549-563.

[28]Safaei, M., Seifert, M. & Thoben, K., 2011. Toward a better undrestanding of the network type impact on delivery time uncertainty in supply networks. Trondheim, Norway, Akademika Publishing, pp. 1-11.

[29]Safaei, M. & Thoben, K. D., 2014. Measuring and evaluating of the network type impact on time uncertainty in the supply networks with three nodes. Measurement, Volume 56, pp. 121-127.

[30]Simangunsong, E., Hendry, L. C. & Stevenson, M., 2012. Supply-chain uncertainty: a review and theoretical foundation for future research. International journal of production research, 50(16), pp. 4493-4523.

[31]Subramanian, N. et al., 2014. Customer satisfaction and competitiveness in the Chinese E-retailing: Structural equation modeling (SEM) approach to identify the role of quality factors. Expert Systems with Applications, 41(1), p. 69–80.

[32]Wiest, J. D. & Levy, F. K., 1974. A Management Guide to PERT/CPM. New Delhi: Prentice-Hall.

[33]Wilhelm, W., Han, X. & Lee, C., 2013. Computational comparison of two formulations for dynamic supply chain reconfiguration with capacity expansion and contraction. Computers & Operations Research, 40(10), p. 2340–2356.

[34]Yen, E. C., 2009. Is taking natural log superior to not? – Using a characteristics oriented fuzzy Hopfield neural network to identify probability density functions. Expert Systems with Applications, 36(3), p. 5094–5099.

[35]You, F. & Grossmann, I. E., 2008. Design of responsive supply chains under demand uncertainty. Computers & Chemical Engineering, 32(12), p. 3090–3111.

[36]Zhao, K., Kumar, A., Harrison, T. P. & Yen, J., 2011. Analyzing the resilience of complex supply network topologies against random and targeted disruptions. IEEE systems journal, 5(1), pp. 28-39.

[37]Zhu, A. X. et al., 2010. Construction of membership functions for predictive soil mapping under fuzzy logic. Geoderma, 155(3-4), p. 164–174.

[38]Zimmer, K., 2002. Supply chain coordination with uncertain just-in-time delivery. International Journal of Production Economics, 77(1), pp. 1-15.