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An Approach to Model and Manage Cost-Risk trade-off in Networked Manufacturing

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RÉSUMÉ

Le présent article introduit une évaluation du risque dans la planification des systèmes manufacturiers, impliquant différents acteurs travaillant séquentiellement pour réaliser un produit. Nous considérons ici un environnement dynamique virtuel, où différentes firmes soumissionnent pour des taches précises. L'approche traditionnelle est d'assigner des firmes à des taches pour minimiser les coûts d'utilisation de la chaîne. Cette approche néglige ainsi la notion de fiabilité et de risque. L'objectif de cet article est de proposer une façon d'incorporer la notion de risque au processus de planification de la chaîne. Nous avons identifié le risque comme une combinaison de trois principaux intrants, et nous l'évaluons grâce à une approche dérivée de la logique floue. Nous décrivons comment fonctionne notre programme, et comment le risque évalué est utilisé pour établir quelles firmes choisir afin d'optimiser le compromis coût-risque.

Mots-clefs: Risque, planification, aide à la décision, logique floue, chaîne logistique

ABSTRACT

This paper introduces elements of risk into supply-chain manufacturing systems that involve various actors acting sequentially to achieve an end-result. We consider a virtual dynamic environment, where different firms bid on sequential tasks. The traditional approach has been to assign tasks to firms, in order to realize production as cost-effective chains of activities. This approach neglects elements of risk, which we show how to incorporate. We have identified risk as a combination of three inputs, using a fuzzy logic approach. We show how a fuzzy controller can measure the risk involved in a supply-chain, which is constructed on an order-contract basis. We use this measure of risk to build a decision support environment that helps isolate alternative supply-chains that are potentially interesting from a cost perspective and compares them from a risk minimization stand point.

Keywords: Risk, planning, decision support system, fuzzy logic, supply-chain

1 INTRODUCTION

Globalization of the market as well as of manufacturing has increased the pressure to produce complex products of superior quality with shortened response times. Virtual and agile manufacturing enterprises have generated interest during the last few years as being capable of responding to these pressures (Goldman, Nagel, and Preiss, 1995). The virtual enterprise spans several traditional enterprises that come together for a short or long amount of time to realize an industrial mission. Global projects that involve a wide variety of manufacturing, transportation, and storage can than be undertaken rapidly. Even if only one firm is involved in its mission, it is quite likely that the virtual enterprise model adequately reflects its organization, since the firm is likely to be very complex and depends on strong partnership between its various competency units and its network of suppliers, subcontractors, and so on. We refer the reader to the book on the networked enterprise by Poulin and others (Poulin, Montreuil, and Gauvin, 1994) for an introduction to network manufacturing.

When many firms or many units of a single firm come together, like in any typical supply chain, it is natural that some risks to the success of the mission are involved. They happen due to a variety of reasons. Some are inherently due to factors like poor organization, poor coordination, and poor capacity management. Others are unforeseen, due to the intrinsic variability in nature, the infrastructure, and human nature. To get back to the supply chain example, the question we try to answer, is whether the risk involved in the chain can be measured, and if so, can we identify which chains satisfy the multiple objectives of lower risk and lower costs related to production and distribution.

This paper first presents a fuzzy logic approach to risk-measurement. We then present how measured risks can be used in configuring virtual supply chains that take into account both costs and potential risks. Finally, we conclude this paper by presenting an illustrative example of the proposed methodology.

1.1 MANUFACTURING CONTEXT

While we have tried to be very general in our approach to risk management, the context we had in mind was quite focussed. In this work, we consider the type of manufacturing cum transportation system discussed by D'Amours and others (D'Amours, Montreuil, and Soumis, 1996). In that paper, the authors present a symbiotic network modeling approach for the development of network manufacturing. Figure 1 shows the nature of the symbiotic network.

This network consists of manufacturing nodes, transportation nodes and storage nodes. Transportation nodes are the agents of material transfer. Nodes are defined in very general terms; they may represent unit entities like workstations, or composite entities like firms. In order to capture some of the features of virtual enterprise manufacturing, tasks are announced and bids assembled from the nodes capable of carrying out the tasks. Such bidding schemes are not uncommon in the literature. We will avoid a thorough literature search of this, but an excellent reference to ideas in shop-floor control realized through bidding mechanisms is the paper by Lin and Solberg (Lin and Solberg, 1992).

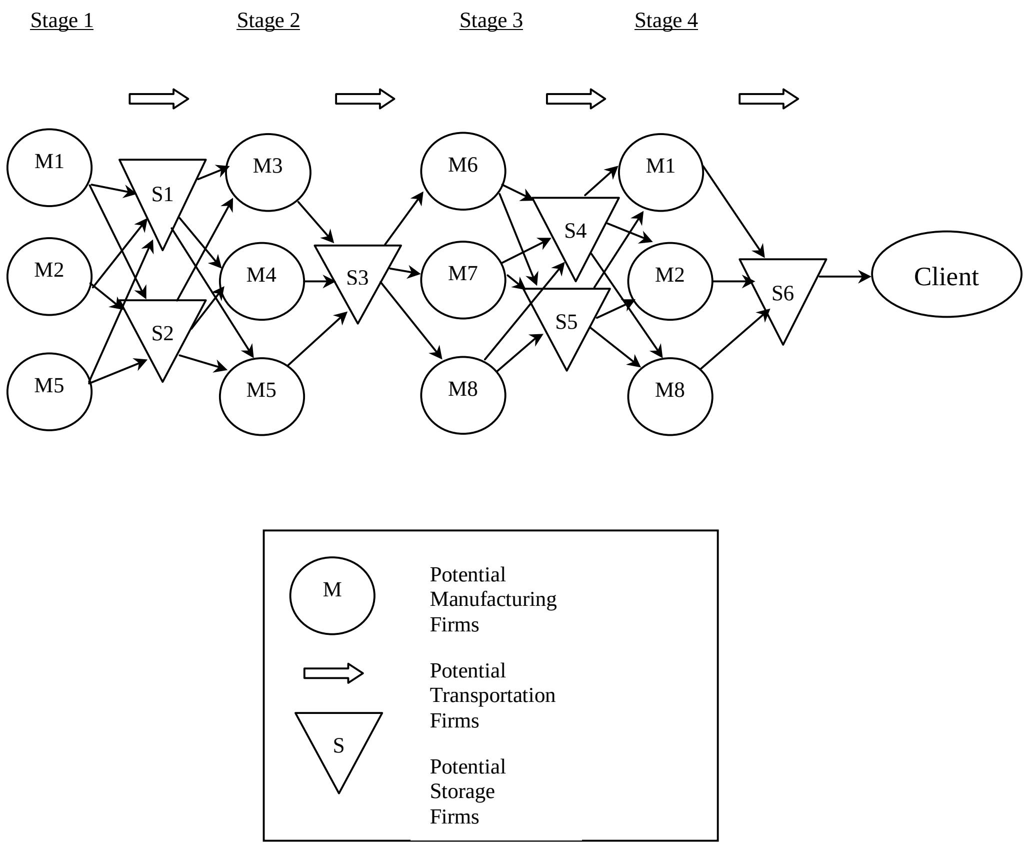
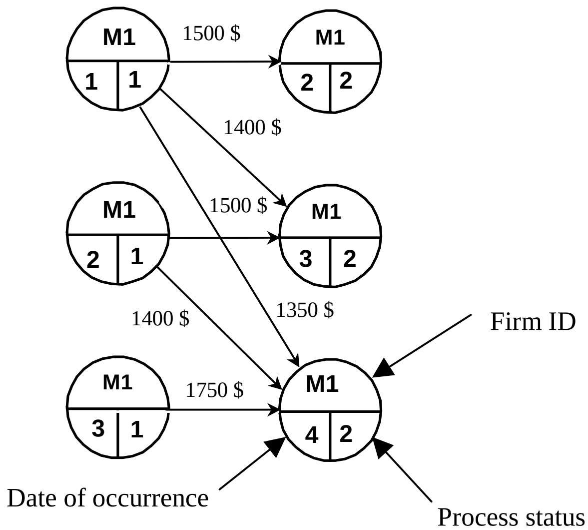


Figure 1: A potential network with all possible transfers (vector cross-product) allowed between stages

A task is defined as a transformation function on a product that changes product status, a numeric value that is assumed to have been pre-computed. In order to process a product through the network, a sequence of tasks needs to be defined, as assumed to be known beforehand.

In our setting, for each task (manufacturing, transportation and storage), bids are requested from potential firms. Figure 2 illustrates a typical manufacturing price-time bid, offering multiples alternative for realizing operation 1. This type of bidding process for the virtual manufacturing enterprise has been discussed in greater detail in D'Amours and others (D'Amours, Montreuil, and Soumis, 1996). We refer the reader to this paper for theoretical explanations of this practice.

Each received bid is then used to create an operational network used to optimize the configuration of the supply-chain. The authors take this basic model of a virtual enterprise and demonstrate how to optimally manage the operation of such a network through the construction of very large time-phased global networks. They show that determining the best sequence of manufacturers, transporters, and storage firms, is readily determined by solving a shortest-path algorithm. The strategy is tantamount to creating virtual manufacturing supply-chains as product demands arrive.



Start	Finish	Price
1	2	1500$
1	3	1400$
1	4	1350$
2	3	1500$
2	4	1400$
3	4	1750$

Operation 2
Subcontractor M1
Earliest start date = 1
Latest start date = 3
Earliest finish date = 2
Latest finish date = 4

Figure 2: Bid Description

What we attempt to do in this paper, is to introduce the element of risk. McDermott (McDermott,1996) on the other hand, takes the viewpoint that the virtual enterprise is in fact a manufacturing strategy to reduce risk. He makes the case by arguing that firms whose core is in fabrication or assembly tend to subcontract their manufacturing tasks more than firms whose core is in materials processing. This will be quite relevant to what we present in this paper. We were influenced by the ideas presented in Walhlstrom (Wahlstrom, 1994), though our modeling of risk does not involve hazards like chemicals, accidents, etc. Without loss of any generality, we will from now on call each node in the network, a firm. The general question is how to incorporate elements of non-conformity into such operating networks. That is to say, can we guarantee that the least cost virtual supply-chain is also the least risky? If not, how can we make the cost-risk compromise? Also, we are aware of the fact that this network is at the operational level. But answers to these questions may also help a supply-chain designer who works at the tactical level. If choices are to be made on how to configure a supply-chain manufacturing system consisting of closely working supplier firms (like it often is in JIT systems), the ideas presented in the rest of this paper may be useful.

1.2 INTRODUCTION TO RISK

In the contract bidding context, when global cost minimization is used as the configuration objective to design a supply-chain, certain risks inevitably arise; a manufacturing firm may not respect quality requirements, a storage firm may be delayed in retrieving an order, and a transport firm may find itself short of delivery trucks to get promised goods on time. Miles and Snow (Miles and Snow, 1992) discuss some causes of failure in network organizations. There are two reasons for which such situations arise; unforeseen events, like bad weather conditions, unexpected machine breakdowns, etc., and problems in either the firm's infrastructure, or in its management that lead to non-conformities from earlier promises. In the remainder of this paper, we will focus on non-conformities in time, i.e., delivery delays.

We would like to introduce the term *production planner* to continue with our illustration. The production planner is the manager of the virtual network, who oversees the bidding mechanism. Depending on outcome of bidding transactions, the planner assigns responsibilities to each node in the resulting supply-chain. These responsibilities are responsibilities on product delivery from supplier nodes to client nodes, which could be considered as contracts between the planner and each of the involved firms.

Now, there are two types of risks relating to such virtually constructed supply-chains. Risks for every firm in the chain arising from late delivery, and risks for the production planner who may have to modify a contract with a firm in the chain in order to modify either the start and finish times in the chain, or the nodes in the chain themselves.

1.3 VARIABLES AFFECTING RISK

We have identified five factors that influence the risk taken by the planner, who in order to absorb a delay in one or more participating firms in the contract, may have to modify the originally contracted supply-chain in order to accelerate the process.

<u>The reliability of the supplier firms</u>: Some suppliers are more reliable than others for a variety of reasons. From historical data, it may be possible to estimate the probability that a firm will respect the due-date in delivery.

<u>Average lateness</u>: Another factor is the average duration of a delay, if and when it does occur. This factor may or may not be independent of the previous factor.

<u>Firm capacity utilization</u>: Overloaded firms, working at close to 100% capacity utilization are more prone to delays. When a firm's facilities are under-utilized, there is generally less competition for resources, better queue management, fewer congestion effects, all resulting in improved delivery profiles.

These final two factors are not only firm dependent, but also chain-dependent. They relate to the fact that even if a firm delays an order, the overall supply-chain can deliver on time.

Position of the firm in the supply-chain: The first factor that is interesting to understand, is a firm's position in the supply-chain. When firms, early in the chain, experience delay, the result may be comparatively less serious to the planner than the situation where a firm located towards the end of the supply chain delivers late. The planner reaction time is naturally lower in this second situation and the probability of an overall delay is naturally higher.

Absorption capacity of firms downstream in the supply-chain: This factor relates to the fact that some firms have capacity to absorb delay through resource re-scheduling, quicker material movement, order-expedition through the use of overtime, etc. Thus each time delivery is delayed by one particular firm, firms downstream in the supply chain may be able to absorb the delay and prevent all or part of it from being passed on. The absorption capacity of these firms is therefore also a governing factor.

2 A FUZZY APPROACH TO COMPUTE RISK

When someone evaluates risk, some parts of the evaluation are very personal, but for a given problem, the rules involved in the evaluation risk are most of the time the same for everybody. For example, if the water is hot and I put my hand in it, I take the risk of burning my hand. The rule is the same for everybody, though what is hot and what is just warm is personal. This is the main reason why we choose to use a fuzzy logic approach to compute the risk. Fuzzy logic is a field that grew from fuzzy sets, a notion first introduced by Zadeh (Zadeh, 1965). Another reason why the fuzzy logic approach is natural, is the nature of the variables involved in risk. With such an approach, we can easily implement rules in a linguistic form. Zadeh (Zadeh, 1975) presents the notion of a linguistic variable and how it can be used in approximate reasoning, using very diverse variables.

We have been inspired by several applications of fuzzy logic in the manufacturing domain ((Azzaro-Pantelet al., 1991), (Chan, Kazerooni, and Abhary, 1997), and (Liu and Sahinidis, 1997)). The approach has been used in operation selection, process planning, production scheduling, etc. In all these cases, the applications involve inputs that are imprecise with a range of values. Examples are: jobs with a range of possible durations, multiple performance measures, some subjectively more important than others, etc.

2.2 VARIABLES INVOLVED COMPUTING RISK, AND FUZZYFICATION

In order to implement our fuzzy logic approach to compute risk, we use three variables. For a given supply-chain, we use the following data for each firm:

Firm reliability: The more a firm is reliable, the less this firm causes a risk. The firm reliability is used in our system through the percentage of delayed orders known for the firm. This information is independent of the given chain.

In order to be able to write the rules involved in evaluating the risk in linguistic form, we use three fuzzy sets to describe the universe of all possible reliabilities. Figure 3 describes these three fuzzy sets. For any possible percentage of delayed orders, we can assign a membership value to each of these sets. These membership values will be used according to Mamdani's (Mamdani and Assilian, 1975) approach to compute risk. The membership function of each fuzzy set used to describe the percentage of delayed orders is a parameter in the system, in order to allow the planner to implement a personal choice.

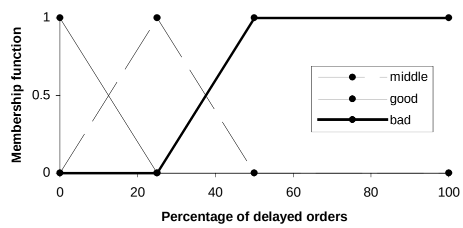


Figure 3: Fuzzyfication of the variable "percentage of delayed orders"

<u>The number of firms needed to absorb delay caused by one firm</u>: Supposing that a single firm in the supply-chain causes a delay of its average duration, how many firms will be needed to absorb this delay? This data is computed for each firm independently, in a given chain, knowing which firms follow the firm causing the delay. Here we consider the delay of only one firm at a time. This variable is used to translate the intensity of the modification required in re-planning in order to absorb delay.

As for reliability, we also use three fuzzy sets to describe the possible number of firms to absorb delay.

<u>The delay at the end of the logistic chain after absorption</u>: We need to know the order of the firms in the chain to compute this information. We once again consider delay one firm at a time. Then for supposed delay in each firm, the question is how long residual delay will be, considering absorption capacities of downstream firms?

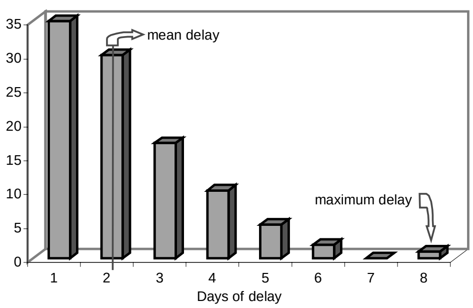
Here too, we use three fuzzy sets in the triangular form to describe all possible end delays. As before, the membership function of each set is a parameter in the system.

2.3 METHOD TO COMPUTE FUZZY INPUT

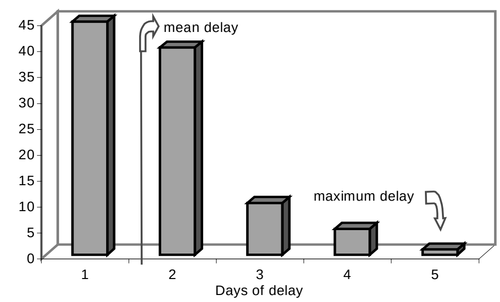
The two last variables used in our fuzzy approach are calculated for each potential firm of the supply-chain using input information on the firms.

This means that we need to know the possible delay for each firm. This is taken to be between the known mean and maximum delay for that firm, according to the planner's choice. If we choose the mean delay to compute risk, the probability of having a delay longer than the mean is 50%, which implies that the computed risk has a probability of 50% of being less than in reality. If we choose maximum delay, we may have a computed risk bigger than what is the most probable. So, we believe that a compromise between the two may be a good choice. See Case A and B in Figure 4, which suggests how to make a choice.

In Case A, 3 or 4 days may make an efficient probable delay. In the Case B, 2 days is the preferable delay since the distribution is closer to the mean than in the previous case.



Case A.



Case B.

Figure 4: Delay probability distributions

As for probable delay, we need to know the absorption capacity for each firm, information that is more complex to evaluate. What exactly is meant by the absorption capacity? It is the capacity of a given firm to accelerate its processes in order to absorb a delay caused by another firm, when processing tasks realized earlier in the process.

Because of delay, the duration and cost of a task may be changed. If we want a firm to absorb delay, the duration of its task needs to be shorter than if the delay had not occurred. While this is possible sometimes, it is not always possible. The capacity to absorb delay is a function of a lot of variables like production rates, quantity of products to make, etc. The first approach to evaluate this capacity consists in asking firms how often it can absorbs delay, something that can be known only when a close relationship is established between the planner and the firms.

Our second approach is to use all the different bids made by firms, like the bar graph like in Figure 5. On the X-axis we can see the beginning and the end of each alternative proposed by a firm in a bid. For the given alternative, we can see that there is one alternative to absorb a one day delay, and one alternative to absorb a two day delay. Neither would change the end date. We say that the absorption capacity of the given firm is two days.

Using the different bids allows us to evaluate the absorption capacity of a firm. Of course, between the time we evaluate this capacity and the time the delay may occur, the capacity could have changed. When the planner does not have a close relationship with the firm, it will be difficult to evaluate this capacity correctly and therefore it should be set to a low value.

We are now in a position to calculate the number of firms needed to absorb a delay, and the resulting end delay, two inputs used to compute risk. For the example shown in Figure 6, we have to assign a mean delay and an absorption capacity for the 10 firms involved in the chain. If firm F1 causes a delay, we suppose this delay to be 1 day (see Figure 4). Since the absorption capacity of firm F2 is two days, we can say that F1 needs only one firm to absorb its one day delay, without any residual delay. Now if firm F9 causes a delay, this delay is assumed to be 2 days, and the overtaking capacity of firm F10 is only one day. So, in this case there will be a one-day end delay. In the system, if a delay can not be absorbed totally, the number of firm used to overtake this delay is the number of firms (in the fuzzy rules). Figure 7 expresses these calculations for all firms.

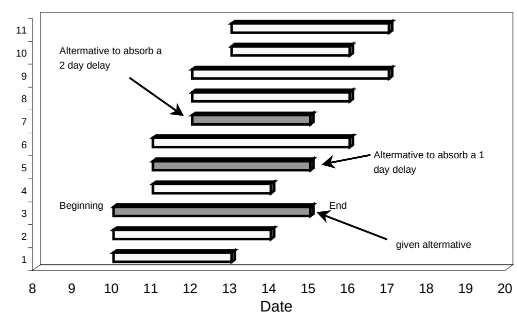


Figure 5: Evaluating the absorption capacity.

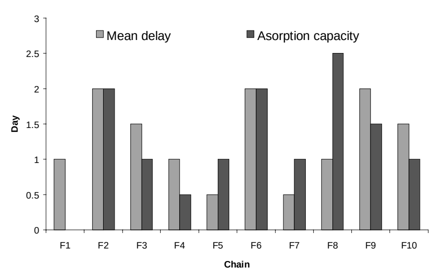


Figure 6: An example of mean delay and absorption capacity distributions over a given chain

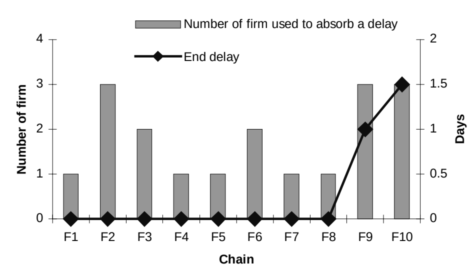


Figure 7: Example of the number of firm used to absorb a delay and the end delay.

The bars in Figure 7 present the importance of the re-scheduling task the planner may have to implement in case of delay in one firm. The architecture of the fuzzy logic system is shown in Figure 8.

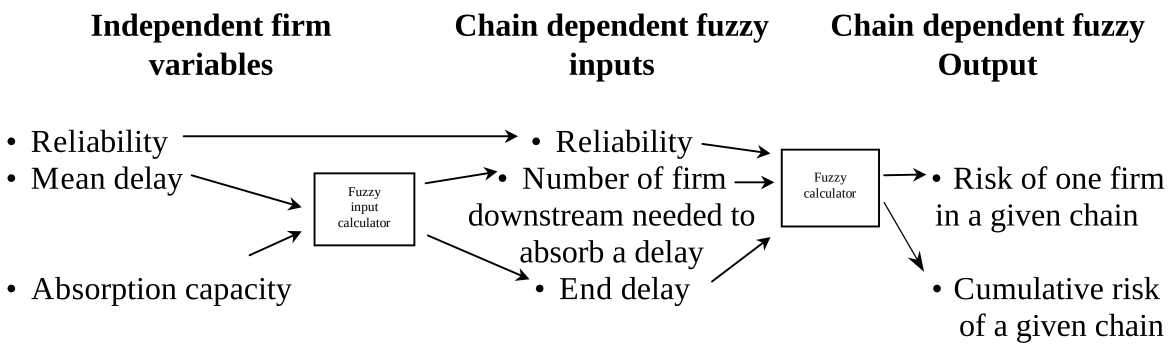


Figure 8: Architecture of the fuzzy logic system

2.4 FUZZY INFERENCE TO COMPUTE THE RISK

In this approach, we evaluate risk on a scale from 0 (minimum risk) to 10 (maximum risk); 8 fuzzy sets are used to describe this scale going from --- to ++++. In order to implement the rules involved in the risk and using the three mentioned input variables, we write the contents of Table 1. This table describes in a linguistic form the relation between each variable and risk, according to the value of the two other variables. Further, each rule involves one of the input fuzzy sets for each input variable. In our case, one rule involves three fuzzy sets.

	Number of firms needed to absorb delay					
	good			**bad**		
Reliability →	**Good**	**middle**	**Bad**	**good**	**Middle**	**Bad**
Good	---	-	+	--	+/-	++
Middle	--	+/-	++	-	+	+++
Bad	-	+	+++	+/-	++	++++
↑ ***End delay***						

Table 1: Fuzzy rules

These rules give more importance to the reliability variable, because in our vision this input accounts for most of the risk. The inference method used to compute the resulting risk level is based on Mamdani's approach. For a given set of inputs, the system computes independently the force of each rule, as the minimum of the membership value of the three input fuzzy sets involved.

With the force of these rules, the system can compute the risk level. For each output fuzzy set, the system modifies its membership function by maximising it with the maximum force of all the rules involving this output fuzzy set.

We obtain for each output fuzzy set, a new membership function, which allows defuzzification of the output risk, using the center of area method. Figure 9 presents a deffuzyfication method.

This method has been implemented as a computer program to allow the evaluation of risk with a human like fuzzy approach.

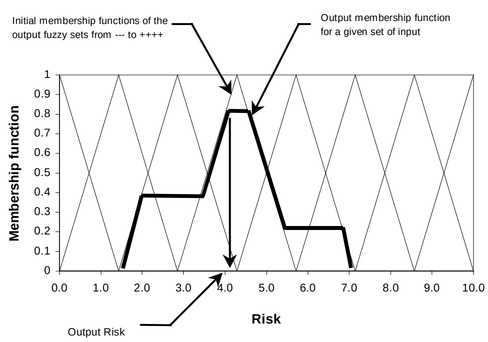


Figure 9: Defuzzification method

3 AN INTERACTIVE DECISION SUPPORT SYSTEM TO PLAN A VIRTUAL MANUFACTURING NETWORK

This part of the paper deals with a method to help a decision maker to plan a supply-chain network. For a given set of possible firms, this method presents a tool to express, according to the planner's point of view, a good compromise between the costs in the network and risks. Our method to compute risk is fuzzy, but the defuzzified risk measure is used as part of the decision support system. This is a little less complex than Thangavadivelu and Colvin (Thangavadivelu and Colvin, 1997), who use the multi-objective decision making procedure suggested by Bellman and Zadeh (Bellman and Zadeh, 1970), in a fuzzy logic implementation to schedule tillage operations in the agricultural domain. In this procedure, the best alternative is chosen to best satisfy a set of fuzzy objectives.

Let us consider the following example problem P:

P is a process which has four sub-processes $P = \{P_1; P_2; P_3; P_4\}$. We have three possible firms for each sub-process: A_1, B_1, and C_1 for the first sub-process P_1, A_2, B_2 and C_2 for the second sub-process P_2, and so on. Let F be the universe of all the firms.

These firms are all well known by the planner, who can express their reliabilities as well as all other information used to compute risk. The planner also knows the lead-time for each of the four sub-processes. Then, according to ranges of time he gives to the different firms, each of those firms come back to him with some bids in order for him to be able to find the most suitable chain.

Let B_{A1} be the set of all bided alternatives of the firm A_1, B_{A2} be the set of all bided alternatives of the firm A2 etc.

$B_{A1} = \{b_{A1,1}; b_{A1,2}; b_{A1,3}; b_{A1,4}; ..\}$
$B_{A2} = \{b_{A2,1}; b_{A2,2}; b_{A2,3}; b_{A2,4}; ..\}$
$B_{A3} = \{b_{A3,1}; b_{A3,2}; b_{A3,3}; b_{A3,4}; ..\}$
etc.

Each alternative can be expressed like in the following manner (this is consistent with Figure 2):

$b_{Xi,j} = (S_{xi,j}; F_{xi,j}; C_{xi,j})$ where
$S_{xi,j}$ is the starting date of the alternative j of the firm X_i
$F_{xi,j}$ is the finishing date of the alternative j of the firm X_i
$C_{xi,j}$ is the cost per unit of the alternative j of the firm X_i

Step 1: According to all these bids, the planner optimises within these alternatives, the least cost sequence of bids that can accomplish the process. This is done using a shortest path algorithm as described in section 2 of this paper. Let us call the solution sequence S_{S1}. The solution S_{S1} may be expressed as a sequence of specific bids within the chain S_1 of firms:

$S_{S1} = \{b_{A1,2}; b_{B2,2}; b_{A3,1}; b_{C4,3}\}$ where
$b_{A1,2}$, $b_{B2,2}$, $b_{A3,1}$ and $b_{C4,3}$ are the chosen bids (in a monolithic solution)
S_1 is the chain $\{A_1; B_2; A_3; C_4\}$.of firms used for this solution.

This solution involves a total cost of C_{S1}:

$C_{S1} = F_p \text{ x } (C_{A1,2} + C_{B2,2} + C_{A3,1} + C_{C4,3})$ where
C_{S1} is the smallest total cost if we use the solution S_1
F_p is the total quantity of product
$C_{A1,2}$; $C_{B2,2}$; $C_{A3,1}$ and $C_{C4,3}$ are the cost of the different alternatives.

S_{S1} must respect start and finish dates. The chain S_1 is simply represented with the firms involved in the sequence of bids in S_{S1}. Thus S_1 is an element of FxFxFxF. In this paper, each time we talk of a chain of firms S_i as a solution, we refer to the least cost sequence of bids in this sequence of firms. According to the chain of firms just computed, we can compute the risk for each firm.

Let R be a function from (F;FxFxFxF) to [0,10]. $R(A_1;\, A_1,\, B_2,\, A_3,\, C_4) = r_{A1,S1}$ is the risk involved by the firm A_1 of the chain S_1. $r_{A1,S1}\bullet[0,10]$ means that we consider the risk in the range 0 to 10. The total risk involved in the chain S_1 is the sum of all the single risks involved independently by all the firms of the chain. Thus,

$R_{T,S1} = \bullet r_{Xi,S1}$ where
$X_i = A_1, B_2, A_3$ and C_4
S_1 is the chain for which we want to compute the risk.

Step 2**:** As soon we have a first chain (an initial feasible solution), we can compute the impact of interchanging one single firm by another one.

For example in chain S_1, we can switch firms A_1 and B_1, because either can accomplish the first sub-process. We have now a new chain S_2 composed of firms B_1, B_2, A_3 and C_4. Within this chain, we can re-run the initial shortest path program in the form of a linear program, adding additional constraints imposing the use of firms involved in the chain. We would then find a new sequence of bids.

$S_{S2} = \{b_{B1,4};\, b_{B2,3};\, b_{A3,1};\, b_{C4,2}\}$ for a total cost C_{S2}

This new solution S_{S2} is the least expensive using the new chain, and the impact on the cost of switching A_1 and B_1 is $\bullet C$.

$$\bullet C = C_{S2} - C_{S1}$$

In a similar manner, we can compute the impact $\bullet R_T$ on total risk. The total risk involved in the solution S_2 is $R_{T,S2}$.

$R_{T,S2} = \bullet r_{Xi,S2}$ where
$X_i = B_1, B_2, A_3$ and C_4
S_2 is the chain for which we want to compute risk.

$$\bullet R_T = R_{T,S2} - R_{T,S1}$$

We can run this procedure for each of the firms not belonging to chain S_1. Then, the planner chooses a switch in chain S_1 to reduce risks, keeping an eye on costs, a process that can be repeated many times. This method is effectively a pair-wise interchange procedure to find an effective risk/cost combination. Figure 10 summaries our methodology

4 AN EXAMPLE

The illustrative case addresses the optimization of a supply-chain for a make-to-order situation. To realize the requested order, four tasks need to be completed. For each of these tasks, three potential firms have been identified. We define for each firm, specific bids and reliability information (the mean delay and the absorption capacity of the firm).

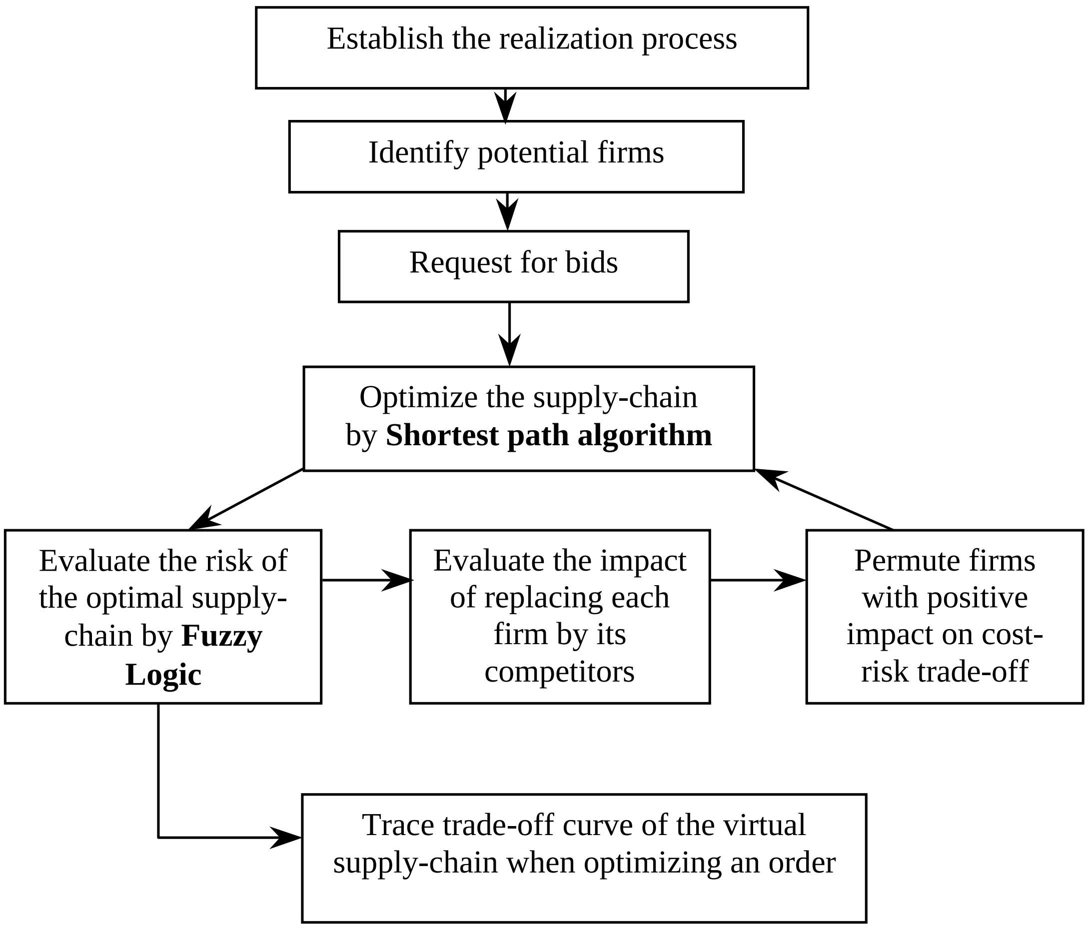


Figure 10 : Decision support methodology

We present the successive chains chosen by the planner, and the impact of each pair-wise interchange on costs and risks, in Tables 2 through 5. In this example we stop the procedure at chain S_5, but we could have continued to investigate other possibilities.

All of these choices are made subjectively, which means that the search proceeds through a sequence of solutions to find a good risk/cost combination. To support the decision making process one could establish a set of decision rules and follow them throughout the process.

Here is an example of such rules that we used in this example, which lead to the interchanges indicated in Tables 2 through 5:

To decide on the interchange alternatives we applied the following decision rules:

1. Identify replacement firms with greater risks reduction (accept – 0,5 deviation from the best reduction)

2. Select firm with minimum cost increase

Within chain S_1, in Table 1, we decide to interchange firms B_4 and C_4 because it decreases the total risk by 1.5 while increasing total cost by only \$50. At this step, we could have interchanged B_1 and C_1 to decrease the total risk by 1.9, but the cost would have increased by 140\$. Here, some alternatives are to be automatically rejected because they increase both the total risk and cost.

Within chain S_2, as seen in Table 2, we interchange B_3 and A_3 for the same reason. At this level, one alternative decreases cost while increasing risk. This alternative has the opposite sense to what we chose in chain S_1.

In chain S_3, as seen in Table 3, we interchange C_2 and A_2 because it decreases both the risk and cost. At this level, we could have interchanged A_1 and C_1 because it decreases both risk and the cost, but the first alternative was thought to be more interesting.

No advantage to interchange

	Replacing firms	
First chain S_1	**First choice**	**Second choice**
C_1 Single Risk = 4,5	**A_1** $\Delta C = +90\$$ $\Delta R_T = +0,5$	**B_1** $\Delta C = +140\$$ $\Delta R_T = -1,9$
A_2 Single Risk = 4,8	**B_2** $\Delta C = +70\$$ $\Delta R_T = -1,2$	**C_2** $\Delta C = +70\$$ $\Delta R_T = -0,1$
A_3 Single Risk = 4,0	**B_3** $\Delta C = +50\$$ $\Delta R_T = -1,0$	**C_3** $\Delta C = +140\$$ $\Delta R_T = -1,0$
C_4 Single Risk = 3,9	**A_4** $\Delta C = +90\$$ $\Delta R_T = +4,3$	**B_4** **$\Delta C = +50\$$ $\Delta R_T = -1,5$**
Total Cost C= 4490 \$ **Total Risk R_T = 17,3**		

If we interchange C_4 and A_4, the impact on the cost is +90\$ and on the risk +4,3

Chosen firm to be interchanged

Table 1: First chain

	Replacing firms	
Second chain S_2	**First choice**	**Second choice**
C_1 Single Risk = 4,5	**A_1** $\Delta C = +50\$ \quad \Delta R_T = +0,4$	**B_1** $\Delta C = +140\$ \quad \Delta R_T = -1,9$
A_2 Single Risk = 4,1	**B_2** $\Delta C = +70\$ \quad \Delta R_T = -1,0$	**C_2** $\Delta C = +30\$ \quad \Delta R_T = -0,4$
A_3 Single Risk = 3,6	**B_3** $\Delta C = +50\$ \quad \Delta R_T = -1,6$	**C_3** $\Delta C = +140\$ \quad \Delta R_T = -1,0$
B_4 Single Risk = 3,6	**A_4** $\Delta C = +40\$ \quad \Delta R_T = +5,8$	**C_4** $\Delta C = -50\$ \quad \Delta R_T = +1,5$
Total Cost C= 4540 $ **Total Risk R_T = 15,8**		

Table 2: Second chain

	Replacing firms	
Third chain S_3	**First choice**	**Second choice**
C_1 Single Risk = 4,5	**A_1** $\Delta C = -20\$ \quad \Delta R_T = -0,4$	**B_1** $\Delta C = +80\$ \quad \Delta R_T = -1,8$
A_2 Single Risk = 3,8	**B_2** $\Delta C = +90\$ \quad \Delta R_T = -0,7$	**C_2** $\Delta C = -40\$ \quad \Delta R_T = -0,4$
B_3 Single Risk = 2,3	**A_3** $\Delta C = -50\$ \quad \Delta R_T = +1,6$	**C_3** $\Delta C = +90\$ \quad \Delta R_T = +0,2$
B_4 Single Risk = 3,6	**A_4** $\Delta C = +40\$ \quad \Delta R_T = +6,0$	**C_4** $\Delta C = -50\$ \quad \Delta R_T = +2,1$
Total Cost C= 4590 $ **Total Risk R_T = 14,2**		

Table 3: Third chain

	Replacing firms	
Fourth chain S_4	**First choice**	**Second choice**
C_1 Single Risk = 4,5	**A_1** $\Delta C = +150\$ \quad \Delta R_T = -0,4$	**B_1** $\Delta C = +140\$ \quad \Delta R_T = -1,8$
C_2 Single Risk = 3,4	**A_2** $\Delta C = +40\$ \quad \Delta R_T = +0,4$	**B_2** $\Delta C = +130\$ \quad \Delta R_T = -0,3$
B_3 Single Risk = 2,3	**A_3** $\Delta C = +20\$ \quad \Delta R_T = +1,6$	**C_3** $\Delta C = +170\$ \quad \Delta R_T = +0,3$
B_4 Single Risk = 3,6	**A_4** $\Delta C = +40\$ \quad \Delta R_T = +3,5$	**C_4** $\Delta C = -50\$ \quad \Delta R_T = +2,0$
Total Cost C= 4550 $ **Total Risk R_T = 13,8**		

Table 4: Fourth chain

	Replacing firms	
Fith chain S_5	**First choice**	**Second choice**
B_1 Single Risk = 2,7	**A_1** ΔC = +10$ ΔR_T = +1,4	**C_1** ΔC = -140$ ΔR_T = +1,8
C_2 Single Risk = 3,4	**A_2** ΔC = -20$ ΔR_T = +0,4	**B_2** ΔC = +70$ ΔR_T = -0,3
B_3 Single Risk = 2,3	**A_3** ΔC = +20$ ΔR_T = +1,6	**C_3** ΔC = +170$ ΔR_T = +0,2
B_4 Single Risk = 3,6	**A_4** ΔC = +40$ ΔR_T = +3,5	**C_4** ΔC = -50$ ΔR_T = +2,0
Total Cost C= 4690 $ **Total Risk R_T = 12,0**		

Table 5: Fifth chain

In the chain S_4, as seen in Table 4, we decide to interchange B_1 and C_1, to decrease risk, even though cost increases by 140$.

Figure 11 presents in a graphical way, the evolution of total risk and cost during the five first steps of this series of changes.

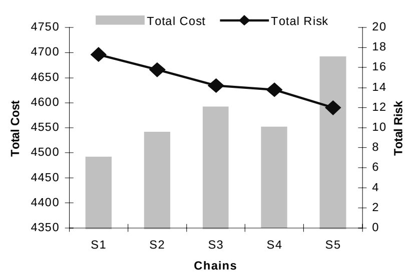


Figure 11: Total risk and cost evolution during the pair-wise interchange procedure

In this problem we have 3^4=81 possible solutions, which can all be enumerated. For the time being, we have developed a Visual Basic tool that helps the user input the problem, define and edit the fuzzy rules for risk measurement, solve the shortest path algorithm for an optimal cost-time configuration, and implement interactively the pair-wise interchange procedure to trade-off risk and costs.

5 CONCLUSIONS AND FURTHER STUDY

We see in this paper that risk is an important factor in the configuration of supply-chains for both traditional and virtual manufacturing enterprises. The most economical decision may on the hand, involve high risks. Therefore, each time a supply-chain is chosen in production or distribution systems, an assessment of the implicit risk involved may be made.

For risk assessment, we have identified certain variables, which we think can make a fuzzy estimation of the risks involved in virtual network planning. We chose a procedure based on fuzzy logic to measure risk in individual firms and in supply chains. We can naturally improve this procedure by taking other inputs into account. Examples of such inputs are, safety stock policies employed by firms, the number of processes required to complete a job, capacity utilization of firms, etc.

We are currently involved in developing a decision support system that will automatically present interesting alternatives to a planner. This will enhance our current capability where the planner has to make his own navigational decisions. What would also be interesting, is to try and evaluate the expected costs arising from a measured risk. This would then lead to an overall cost model to resolve the risk-cost trade-off.

On a different note, as soon as a supply-chain is determined for an order, or for a series of orders, we can analyze the risks at each node in the chain with a view to reduce the risk of having an eventual delay in the chain, or even to minimize disruptions in already planned production schedules, which could both be expensive outcomes. This type of risk measurement can point out the weakest links in the supply-chain. Strategies to reinforce weak points could be safety stock addition, planning in advance a task with a secondary firm in the eventuality that the primary firm cannot respect the initial order, imposing penalties on firms causing delays, etc.

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