A METHOD FOR MODELLING AND EVALUATING SUPPLY CHAIN PERFORMANCE USING FUZZY SETS

I. ELMAHI*, C. THIRION**, A. HAMZAOUI***, J. L. SCULFORT**
* LABORATOIRE SYSTÈME ET TRANSPORT (S. E. T), UNIVERSITÉ DE TECHNOLOGIE DE BELFORT-MONBÉLIARD
UTBM- SITE DE BELFORT, 90010 BELFORT CEDEX FRANCE
PHONE: (+33) 3 84 58 33 47 FAX: (+33) 3 84 58 33 42
** LABORATOIRE DE GÉNIE LOGISTIQUE, *** LABORATOIRE D'AUTOMATISME ET MICROELECTRONIQUE. IUT DE TROYES, 9 RUE DE QUEBEC, 10026 TROYES, CEDEX FRANCE
ilham.elmahi@utbm.fr - {c.thirion, a.hamzaoui, jl.sclufort}@univ-reims.iut-troyes.fr

KEYWORDS

Logistics Optimisation, Supply Chain management, Fuzzy logic, E-business.

ABSTRACT

During the last decade, the supply chain management literature was well enriched. Many works dealt with the optimisation problem using dynamic programming or heuristics. In this paper, we propose a new approach based on fuzzy systems for modelling and evaluating performance of supply chain. Particularly, we consider here a framework of e-business industry. The concept of satisfying the request of the customers is studied and the underlying problems for managing this chain are discussed. After describing the elements of the model, theirs input and output parameters, we analyse results of simulation and optimise them in the aim of giving help to deal with the indistinct data met by the decision-makers.

INTRODUCTION

The key in today's logistics is managing the overall demand and supply chain. Concepts such as ECR (Efficient Consumer Response) are examples of supply chain management. In order to manage the total chain, many companies are developing advanced planning and scheduling software that act as the linking-pin between execution systems of different parts in a chain.
Business through Internet has already changed the economical world and developments have not yet stopped. In B2B (Business to Business) and B2C (Business to Customer) a lot of people use the web for their commercial operations. In many industries, e-business is performed (Electronic Market Places) [Carvalho 2001]. Now, the question is what impact on logistics?

Logistics and management networks constitute a strategic subject which adds value and allows progress in term of delivery time, cost and quality. This success necessitates a good optimisation of the total chain. Many companies are re-engineering their distribution processes. Introduction of Internet and development of the e-commerce have a great impact on the global distribution. Many service providers try to establish a global network of logistics services.
This study analyses an e-bookshop. The suppliers are the publishers or the editors situated all around the world; the consumers are located at different places and the e-bookshop plays the part of the service providers. The process begins when the customer orders one or several products (book, CD-ROM..); then, a sequence of operations is activated mostly according to an order not clearly defined [Bocker *et.al* 2001]. Figure1 represents the typical supply chain environments of the e-bookshop:

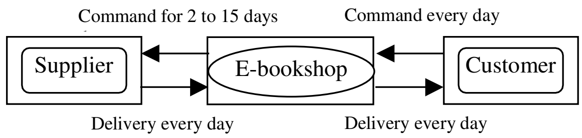

Figure 1: Logistic environment of the e-bookshop

The globalisation, the strong competition due to the opening of borders and the international dimension of exchanges leads to new challenges as multi-modality and small transported quantity due to various transports planning techniques [Mea *et.al* 1998]. Consequently, deliveries must be made while taking into account three essential functions. First, minimising the delays of deliveries. Second, moving products from the supplier until the final customer with the least global cost (choice of the transports). Third, guarantee for a good quality of service for the customer like minimising its waiting time and respecting the promised dates.

PROBLEM STATEMENT

The company working in e-business has a trade site in which products and net price can be seen. Supplementary costs such as airports or customs taxes can not be directly included due to the bad knowledge of the products final destination. However, a date of availability and as a consequence a date of the delivery can be imprecisely given.
The objectives of any company are obtaining a satisfactory margin to develop the faithfulness of her customers [Allab *et.al* 2001]. Whereas, the most researchers working on supply chain optimisation problem suppose several simplifying hypotheses. For instance, they assume that:

- the processing of each command starts as soon as it is received;
- the transportation tools are always available;
- there is no unpredictable incident which delays sequences of supply chain;
- all the ordered products are really available in the e-business company stock at the suitable dates.

Generally, if we consider a single customer, we can imagine that one can choose between several transportation routes. That leads to multiple possibilities in order to satisfy this request.

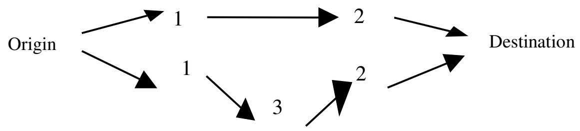

Figure 2: Choice between two possible routes

In figure2, the first route is direct but the second one take into account the point called 3. Even if this second path is longer than the first one, it can be less expensive. Two events are often noticed:

- Financial and temporal costs of a path are often affected in an indistinct way by the cost of the others [Chen *et.al.* 2001], on account of the mutual effects between segments of the same voyage;
- Even if information about traffic is available, the driver can not perceive the exact cost (rather time cost) of every parts of the travel and his choice is then subjective [Yu and Li 2000].

The modelling of the e-bookshop logistics environment was realised by using fuzzy logic. Indeed, this concept provides a very fine description of some complex systems without requiring the use of sophisticated mathematical models. Its flexibility with regard to the classic logic in term of consideration of indistinct notions shows that fuzzy logic is an adequate tool for modelling the language and the human reasoning which allows the manager to make successful decisions.

AN OVERVIEW OF FUZZY LOGIC THEORY

Fuzzy logic is based on the fuzzy sets theory in which the fundamental characterisation is the absence of abrupt frontiers [Klir *et.al.* 1996]. Introduced by Lotfi. A. Zadeh in 1965; fuzzy logic has for purpose the representation of the indistinct knowledge and the approached reasoning. For each system including numerical inputs and outputs, the fuzzy processing associates to these inputs some fuzzy characterisations to which correspond the membership functions. The degrees of these memberships belonging to the interval [0, 1] are illustrated in the figure 3. This step is called fuzzification.

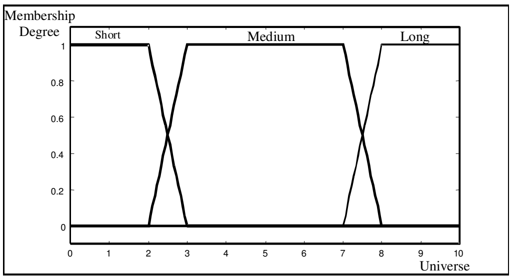

Figure 3: Trapezoïdal membership functions of time

In the second step, one computes the fuzzy outputs from the previous fuzzy inputs and from a set of rules. This operation is called fuzzy inference. The last stage is the defuzzification; it leads to transform fuzzy outputs in exact values to be able to control a dynamical process [Borne *et.al* 1998], or to make decisions. The principle described above is illustrated in the figure 4.

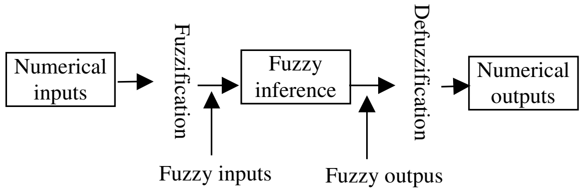

Fig.4: Diagram of the fuzzy processing.

NOTATIONS

In order to surround various problems met in the supply chain management of an e-bookshop, we look for various parameters acting on this chain. In the aim to give, simultaneously, global and clear sight of the supply chain to be managed, we classified them according to the kinds of their contributing activity. Thus, we establish our model from eight entities which represent eight fuzzy subsystems. Each one has its own inputs, its own outputs and its own rules of appropriate inferences. Model inputs are variables that often influence and control the functioning of a logistic process; for the e-bookshop, we select the following ones:

- Completion Rate (CR): ratio of the number of products really received from the supplier and the number of commanded products.
- Lead-Time (LT): spent time between the time when the company asks the supplier for a product using EDI (Electronic Data Interchange) and the time when it arrives really in the stock of the e-bookshop.
- Traffic (TR): level of congestion of road, highway, railways, and air network..
- Tool of transport (TT): express (aerial way), standard (road, railway) or slow (seaway).
- Distance (DI): estimates implicitly the real notion of distance between the customer who asked for products and the e-bookshop company.
- Cost of the Conditioning (CC): cost of packaging of products and grouping them in batches.
- Other Payment (OP): customs charges, port taxes..
- Waiting Time (WT): difference time between the moment when the company receives the command from the customer and the moment when it delivers him the wished products.
- Proportion of Customers (PC): proportion of the customers that the company was able to serve really at the promised dates.

The fuzzy inference is represented with rules of types "if-and-then"; the technique of inference used here is "min-max" and the defuzzification used the "centre of gravity".

For example: "*If lead-time is short and the rate of completion is great then the supplier is efficient*". The terms, "*short*", "*great*" and "*efficient*" are the fuzzy characterisations respectively of the lead-time, rate of completion and the supplier.

Output parameters are chosen according to our optimisation and the requirements of the development:
- Time of Delivery (DT): date when the e-bookshop company promises to deliver the customer.
- Global Cost (GC): all estimated costs for the delivery.
- Quality of Service (QS): satisfaction of the customers and consequently the capacity of the company to develop faithfulness of her customers.

MODEL AND SIMULATION

Our purpose is to determine from the precedent inputs, the values of the three outputs satisfying the customer and the company requirements in term of delay, global cost and quality of the service. We classify them according three fuzzy subsets.

Table 1: Decomposition of outputs into 3 fuzzy subsets.

Fuzzy Subsets / Outputs	1st subset	2nd subset	3rd Subset
Delivery time	Short [0 2]	Medium [3 4]	Long [6 7]
Global cost	Low [0 2]	Medium [3 6]	High [7 10]
Service quality	Bad [0 4]	Medium [5 7]	Good [8 10]

Owing to uncertainties in the data and the daily variations of the work conditions, we classify, in a similar way, the inputs according to three fuzzy subsets corresponding to real data. The following table shows these classifications.

Table 2: Decomposition of inputs into 3 fuzzy subsets.

Fuzzy subsets / Inputs	1st subset	2nd subset	3rd subset
LT	Short [0 2]	Medium [3 6]	Long [7 10]
CR	Small [0 3]	Medium [4 6]	Great [7 10]
TR	Low [0 2]	Medium [3 4]	High [5 7]
TT	Express [0 1]	Standard [2 3]	Lent [4 7]
DI	Short [0 2]	Medium [3 6]	Long [7 10]
CC	Low [0 2]	Medium [3 6]	High [7 10]
OP	Little [0 2]	Medium [3 5]	Much [6 10]
WT	Short [0 2]	Medium [3 4]	Lent [5 7]
PC	Bad [0 2]	Medium [3 5]	Good [6 7]

The eight fuzzy subsystems previously evoked are:

- Fuzzy subsystem "supplier", its inputs are completion rate and lead-time. It is called supplier because it allows making decision about the speed and the effectiveness of the supplier.
- Fuzzy subsystem "availability", its inputs are supplier and tool of transport. This subset provides a time interval when the ordered product will be available in the stock of the e-bookshop.
- Fuzzy subsystem "region", its inputs are traffic and tool of transport used. It describes the congestion degree of the geographic region where the customer is situated.
- Fuzzy subsystem "customer", its inputs are region and distance. This output estimates the degree of difficulty to deliver a customer.
- Fuzzy subsystem "delivery time", its inputs are customer and availability.
- Fuzzy subsystem "transport cost", its inputs are tool of transport and distance. It gives an idea of the transport cost.
- Fuzzy subsystem "global cost", it represents the estimation of total cost by the company. Its inputs are transport cost, conditioning cost and some other payments.
- Fuzzy subsystem "quality of service", it is an essential benchmarking indicator for the e-bookshop companies; its inputs are availability, waiting time and proportion of customers served really at just time.

The intermediate outputs of the model are also classified according to three fuzzy subsets. The functioning of the model depends on the geographic position of the customer and on the type of command. Each input (table 2) can have unpredictable values for each couple (customer, command). Consequently, the output values belong, also, either to the first, or the second or the third fuzzy subset. Then, for each combination of the nine input values, the model computes, at first, computes the intermediate output values according to fuzzy rules established on the second step of the fuzzy processing. This classification are brought in the table 3:

Table 3 Decomposition of intermediate outputs

Fuzzy subsets / Intermediate Outputs	1st subset	2nd subset	3rd subset
Supplier	Effective [0 2]	Medium [3 6]	Lent [7 10]
Region	Easy [0 3]	Medium [4 7]	Difficult [8 10]
Customer	Close [0 2]	Medium [3 6]	Far [7 10]
Availability	Short [0 1]	Medium [2 3]	Long [4 7]
Transport cost	Low [0 2]	Medium [3 5]	High [6 10]

The fuzzy logic toolbox of Matlab (5.3) and Simulink3 were used to establish the model and to make simulations.

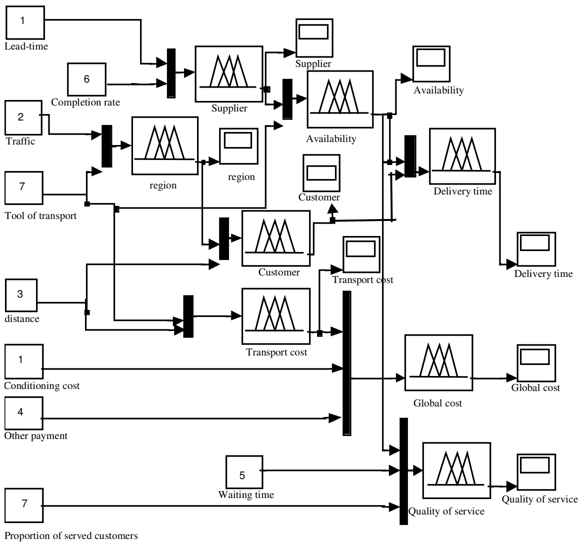

Figure 5: Fuzzy logic model.

The Established model allowed us to make several simulations. For each couple (customer, command), we find several possible solutions as the form of (delivery time, global cost, quality of service). Some of these simulation results are represented in the table 4:

Table 4: Simulation results of the fuzzy model

LT	CR	TR	TT	DI	CC	OP	WT	PC	**DT**	**GC**	**QS**
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*7*	***1.24***	***1.24***	***8.7***
3	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*6*	***1.25***	***1.24***	***8.6***
3	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*7*	***1.24***	***1.25***	***8.7***
1	*1*	*3*	*1*	*1*	*1*	*1*	*1*	*6*	***1.24***	***1.24***	***8.6***
1	*1*	*1*	*3*	*1*	*1*	*1*	*1*	*7*	***1.24***	***1.24***	***8.35***
1	*1*	*1*	*7*	*1*	*1*	*1*	*1*	*5*	***4***	***1.24***	***8.75***
1	*1*	*1*	*1*	*4*	*1*	*1*	*1*	*7*	***1.25***	***1.24***	***8.69***
1	*1*	*1*	*1*	*8*	*1*	*1*	*1*	*7*	***6.2***	***1.24***	***8.69***
1	*1*	*1*	*1*	*1*	*4*	*1*	*1*	*7*	***1.25***	***1.3***	***8.69***
1	*1*	*1*	*1*	*1*	*7*	*1*	*1*	*4*	***1.25***	***4.5***	***6***
1	*1*	*1*	*1*	*1*	*1*	*4*	*1*	*7*	***1.24***	***1.27***	***2.35***
1	*1*	*1*	*1*	*1*	*1*	*1*	*4*	*7*	***1.24***	***1.25***	***6.35***
1	*8*	*7*	*7*	*10*	*1*	*1*	*7*	*1*	***6.2***	***1.25***	***2.3***
1	*8*	*7*	*7*	*1*	*1*	*1*	*7*	*1*	***4***	***1.24***	***4***
10	*8*	*7*	*7*	*10*	*10*	*10*	*7*	*1*	***6.2***	***8.25***	***4***
5	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*4*	***4***	***4.5***	***3.48***
10	*10*	*7*	*2*	*3*	*3*	*3*	*3*	*3*	***3.99***	***4.5***	***8.62***
4	*4*	*4*	*2*	*7*	*7*	*7*	*7*	*7*	***6.2***	***8.25***	***2.35***
4	*4*	*4*	*2*	*7*	*7*	*7*	*1*	*7*	***6.2***	***8.25***	***6***
10	*1*	*1*	*2*	*1*	*1*	*1*	*7*	*1*	***1.25***	***1.25***	***6***
1	*4*	*4*	*1*	*1*	*4*	*4*	*1*	*1*	***1.49***	***4.5***	***8.7***
1	*7*	*7*	*1*	*1*	*7*	*7*	*1*	*2*	***1.49***	***8.2***	***6.73***
7	*1*	*1*	*7*	*7*	*1*	*1*	*7*	*7*	***6.2***	***1.24***	***4.5***
6	*1*	*1*	*6*	*6*	*1*	*1*	*7*	*7*	***1.25***	***1.25***	***4.67***

RESULTS AND INTERPRETATIONS

The three columns on right-hand side show the model outputs. These outputs need to be optimised. The purpose here is to determine a solution of the form (DT, GC, QS) that has the smallest delivery time (DT), the lowest global cost (GC) and the highest quality of service (QS). Consequently, we proceed by the minimisation of the criterion J defined as follows:

$$\text{Min } J = (DT + GC + 1/QS)$$

The following constraints must be taken into account:

$$DT \in [0,2],\ GC \in [0, 2] \text{ and } QS \in [8, 10].$$

The best solutions verifying the precedent criterion are:

1- (DT, GC, QS) = [1.24; 1.24; 8.7] corresponding to the following input values (1; 1; 1; 1; 1; 1; 1; 1; 7).
2- (DT, GC, QS) = [1.24; 1.25; 8.7] corresponding to the following input values (3; 1; 1; 1; 1; 1; 1; 1; 7).

Clearly, when choosing the better solution, the decision-makers will keep the first one. This result means that the least global cost is obtained with a shorter lead-time (value "1" is smaller than "3"). In other words, the e-bookshop needs a supplier more efficient for this delivery.

During simulations, we noticed also another effect; when we refine the rules in the fuzzy inference, we can reach better values of QS. This drives us to propose an another way of decision: why do not add a new fuzzy system after the three outputs DT, GC and QS, which, according to new refined attributed rules and conditions, decides to keep or not a given solution?.

Effectively, when we add a ninth fuzzy subsystem, called "Final solution", the model becomes as presented on the figure 6.

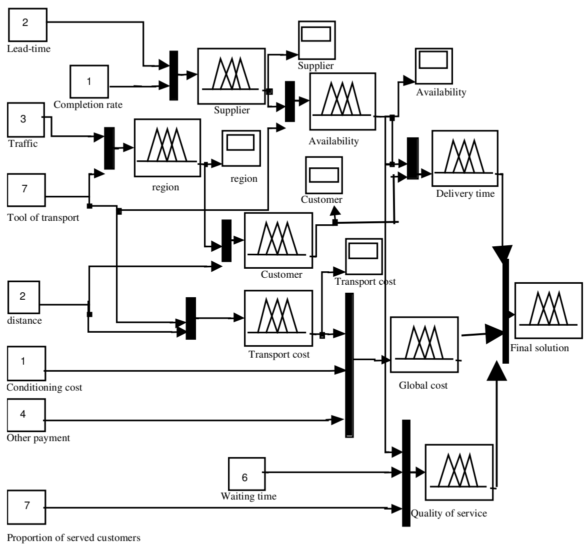

Figure 6: Final fuzzy model

For this last fuzzy system, we choose [0; 10] as the universe of discourse and five triangular memberships functions. We select such memberships functions in order to obtain a better classification of final solutions. The fuzzy characterisations are "very bad", "bad", "medium", "good" and "very good". The figure 7 explains more these triangular membership functions.

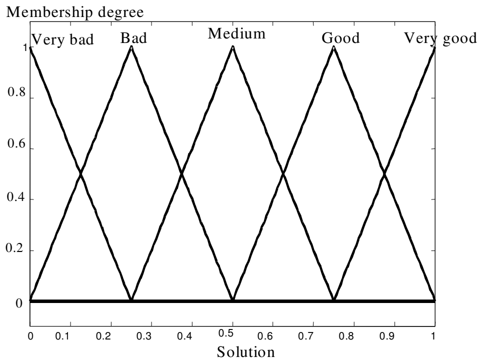

Fig 7: Membership functions of the final solution

We choose the number "7,5" of universe of discourse which corresponds to characterisation “good" as the limit to accept or to reject a solution. After simulation, The model keeps the following solutions:

[1.24; 1.24; 8.7] corresponds to (1; 1; 1; 1; 1; 1; 1; 1; 7).
[1.25; 1.24; 8.6] corresponds to (3; 1; 1; 1; 1; 1; 1; 1; 7).
[1.24; 1.25; 8.7] corresponds to (1; 3; 1; 1; 1; 1; 1; 1; 7).
[1.24; 1.24; 8.6] corresponds to (1; 1; 3; 1; 1; 1; 1; 1; 7).
[1.24; 1.24 8.35] corresponds to (1; 1; 1; 3; 1; 1; 1; 1; 7).
[4; 1.24; 8.75] corresponds to (1; 1; 1; 7; 1; 1; 1; 1; 7).
[1.25; 1.24; 8.69] corresponds to (1; 1; 4; 1; 1; 1; 1; 1; 7).
[1.25; 1.3 8.69] corresponds to (1; 1; 1; 1; 1; 4; 1; 1; 7).
[1.24; 1.27; 8.69] corresponds to (1; 1; 1; 1; 1; 1; 4; 1; 7).

The added fuzzy subsystem (Fig.6) ended in nine "accepted" solutions. We find among them, those that already founded when using minimisation of the previous criterion J. We notice here that the solution [4; 1.24; 8.75] belongs also to accepted solutions, it has a "DT = 4" which belongs to the subset of medium DT, but it has the highest QS = 8.75. If the QS value rather than DT value interest the decider, he can choose this last solution which contain a peak value of QS and a DT less good.
So, the extended model allows to better assisting the decision-makers to select the set of optimal solutions, which are convenient for their different requirements.

CONCLUSION

We have proposed in this paper a new approach to model supply chain network of an e-bookshop using fuzzy logic theory. The contribution of fuzzy subsets is considerable because it allows us to propose to the supply chain managers a new technique to better master and manage their supply chain. This can be easily visualised in the simulation results of the final fuzzy model. This last one have the advantage to be an evolutionary model. In other words, we always can widen the model by adding new fuzzy systems to take into account new parameters of the supply chain.
Further work will be concentrated on dealing more deeply with this approach by the way of more applying it to other types of industry, making comparison with other techniques and widening the model in order to contain more standard supply chain cells.

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AUTHOR BIOGRAPHY

ELMAHI Ilham was born in 1975. She received the maîtrise diploma on génie éléctrique from the Université de Sciences et Techniques of Marrakech, Morocco. In 2001, she received the optimisation and security of systems master degree from the Université de Reims Champagne Ardenne and the Université de Technologies de Troyes, France. Currently, she is Ph.D student at the Université de Technologie de Belfort-Monbéliard where she works on command and optimisation of the transport within the supply chain framework and teaches Petri nets.