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MULTIPLE CRITERIA SUPPLIER SELECTION NETWORK MODEL*

1. SUPPLIER SELECTION PROBLEM

Supplier selection processes have received considerable attention in business (see e.g. [9]). The analysis and design of supply chains has been an active area of research (see e.g. [11]). Sourcing has come up as a very strategic issue in the management of supply chain networks in the modern era of global competition. Most production systems are organized as networks of units. Sourcing decisions have the capability of impacting the effectiveness of supply chain networks. Determining suitable suppliers in supply chain networks has become a key strategic issue. The nature of these decisions is usually complex and unstructured. The supplier selection problem is a multiple criteria problem. Many influence factors such as price, quality, flexibility, and delivery performance must be considered to determine suitable suppliers. These influence factors can be divided into quantitative and qualitative factors.

Generally, supplier selection is a multicriteria decision problem. The methods suggested in the related literatures can be classified into two categories:

- weighting models,
- mathematical programming models.

The weighting model, which focuses on commonly used evaluation criteria, includes:

- the linear scoring model (e.g. [10]),
- the Analytic Hierarchy Process (AHP) model (e.g. [1]).

The linear scoring model assigns weights and scores arbitrarily, for example, 1 for “unsatisfactory” and 5 for “outstanding”. Hence, the model has an implicit and incorrect assumption: e.g., “outstanding” is five times better

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than “unsatisfactory”. The problem is avoided in the AHP model by converting the priorities into the ratings with regard to each criterion using pair-wise comparisons.

Mathematical programming models are:

– goal programming or multiobjective programming (e.g. [12]),
– the linear programming or mixed integer programming with the expression of multiple objectives as constraints (e.g. [5]).

Objective function coefficients should be determined prior to making mathematical programming models. The drawback of goal programming and multiobjective programming is that it requires arbitrary aspiration levels and cannot accommodate subjective criteria.

In recent years, research on supplier selection process has highlighted the relationships that exist between companies in supply chains. Supply strategies adopt the network approach to supplier selection and focus on the coordination and integration of different supply chains. Supplier-customer relationships are changing to a cooperative form. The impact of information sharing plays a crucial role. Supplier selection process becomes a multicriteria group cooperative decision making problem. It is necessary to take in the account the network and dynamic environment.

Decision making process for supplier selection has some specifications:

– Multiple selection criteria.
– Qualitative and quantitative criteria.
– Group decision making problem.
– Cooperative behavior.
– Incomplete information.
– Networks.
– Dynamic and uncertain environment.

The proposed model respects these specifications. The approach combines the Analytic Network Process (ANP) and the Aspiration Level Oriented Procedure (ALOP). The ANP is a network generalization of AHP. The ALOP is based on goal programming approach. The GROUP-ALOP approach respects the supplier selection problem as a group decision making problem. The proposed approach can be used for dynamic environment.

2. ANP WEIGHTING MODEL

The Analytic Hierarchy Process (AHP) is the method for setting priorities [6]. A priority scale based on reference is the AHP way to standardize non--unique scales in order to combine multiple performance measures. The AHP derives ratio scale priorities by making paired comparisons of elements on a common hierarchy level by using a 1 to 9 scale of absolute numbers. The absolute number from the scale is an approximation to the ratio w_j/w_k and then is possible to derive values of w_j and w_k. The AHP method uses the general model for synthesis of the performance measures in the hierarchical structure.

$$u_i = \sum_{j=1}^{n} v_j w_{jk}$$

The Analytic Network Process (ANP) is the method [7] that makes it possible to deal systematically with all kinds of dependence and feedback in the performance system. The well-known AHP theory is a special case of the Analytic Network Process that can be very useful for incorporating linkages in the performance system.

The structure of the ANP model is described by clusters of elements connected by their dependence on one another. A cluster groups elements (success factors, managerial measures, process drivers, business units) that share a set of attributes. At least one element in each of these clusters is connected to some element in another cluster. These connections indicate the flow of influence between the elements (see Figure 1).

The clusters in the supplier selection problem can be suppliers, producers, customers, and evaluating criteria also. The connections among members of supply chain networks are material, financial and information flows.

Paired comparisons are inputs for computing a global performance of network systems. A supermatrix is a matrix of all elements by all elements. The weights from the paired comparisons are placed in the appropriate column of the supermatrix. The sum of each column corresponds to the number of comparison sets. The weights in the column corresponding to the cluster are multiplied by the weight of the cluster. Each column of the weighted supermatrix sums to one and the matrix is column stochastic. Its powers can stabilize after some iterations to limited supermatrix. The columns of each block of the matrix are identical and we can read off the global priority of units.

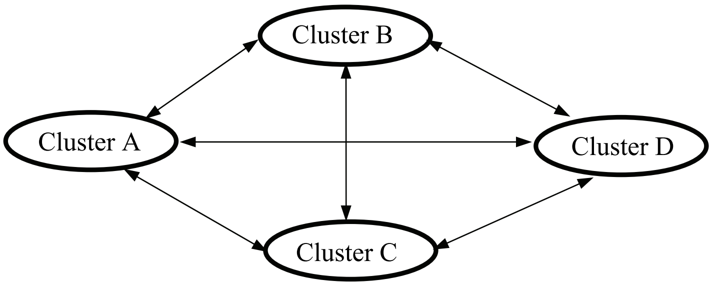
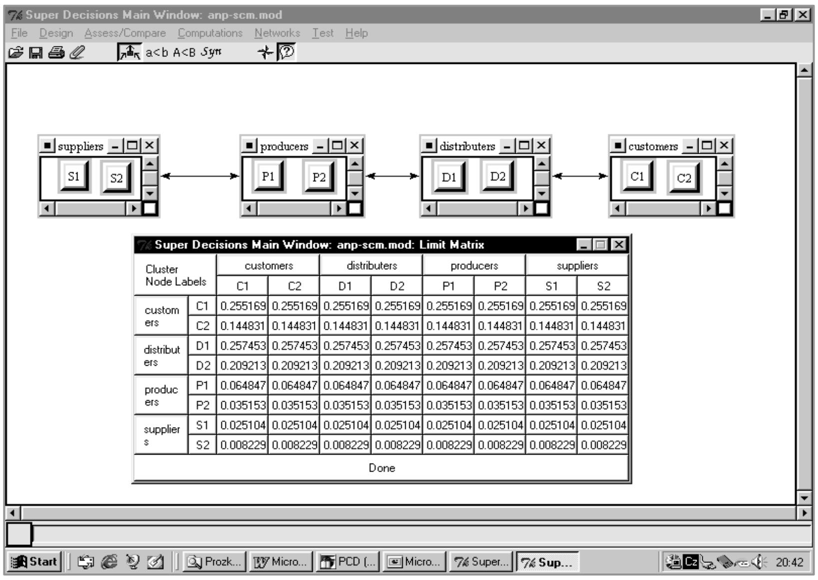


Fig. 1. Flows of influence between the elements

By ANP approach are determined weights of elements in the network model. In supplier selection problem the elements can be members of supply network, evaluating criteria, products, items etc. We made some experiments with evaluation of different supply chain structures. For computation the priorities of units we use software Super Decisions provided by Creative Decisions Foundation (see www.creativedecisions.net). We show a simple example of performance evaluation of units in supply chain structure composed from 2 suppliers, 2 producers, 2 distributors and 2 customers. The initial paired comparisons of units were implemented. On the Super Decisions Main Window (see Figure 2) are shown the structure of the system and global priorities of the units.



Cluster Node Labels		customers		distributers		producers		suppliers	
		C1	C2	D1	D2	P1	P2	S1	S2
customers	C1	0.255169	0.255169	0.255169	0.255169	0.255169	0.255169	0.255169	0.255169
	C2	0.144831	0.144831	0.144831	0.144831	0.144831	0.144831	0.144831	0.144831
distributers	D1	0.257453	0.257453	0.257453	0.257453	0.257453	0.257453	0.257453	0.257453
	D2	0.209213	0.209213	0.209213	0.209213	0.209213	0.209213	0.209213	0.209213
producers	P1	0.064847	0.064847	0.064847	0.064847	0.064847	0.064847	0.064847	0.064847
	P2	0.035153	0.035153	0.035153	0.035153	0.035153	0.035153	0.035153	0.035153
suppliers	S1	0.025104	0.025104	0.025104	0.025104	0.025104	0.025104	0.025104	0.025104
	S2	0.008229	0.008229	0.008229	0.008229	0.008229	0.008229	0.008229	0.008229

Fig. 2. Super Decisions

3. MULTI-OBJECTIVE PROGRAMMING GROUP DECISION-MAKING MODEL

Some basic ideas of formal approaches of the problem solving can be introduced to cooperative decision making. There are two aspects of the problem solving – representation and searching. The state space representation introduces the concepts of states and operators. An operator transforms one state into another state. A solution could be obtained by a search process, first applies operators to the initial state to produce new states and so on, until the goal state is produced.

Communication between suppliers and customers can be provided through information sharing (schematically see Figure 3).

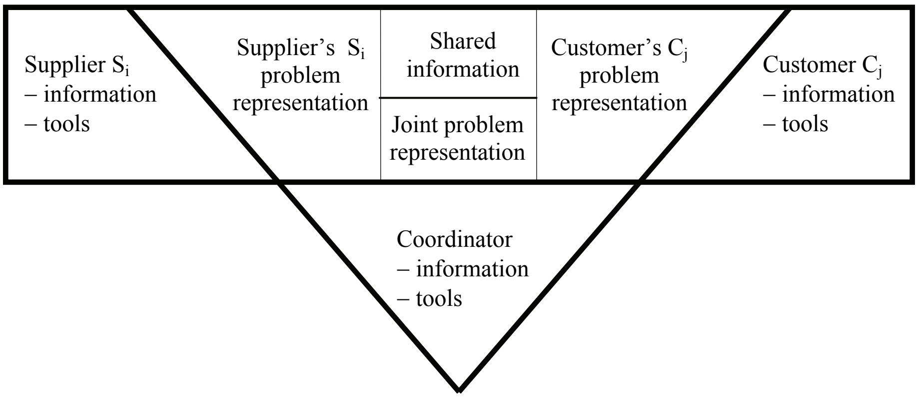


Fig. 3. Communication through information sharing

We propose a two phases' interactive approach for solving cooperative decision making problems (see [2]):

1. Finding the ideal solution for individual agents.
2. Finding a consensus for all the agents.

In the first phase every decision maker searches the ideal alternative by the assertivity principle. The general formulation of a multicriteria decision problem for an individual unit is expressed as follows:

$$\mathbf{z(x)} = (z_1(\mathbf{x}), z_2(\mathbf{x}), ..., z_k(\mathbf{x})) \to \text{"max"}, \qquad \mathbf{x} \in X$$

where X is a decision space, x is a decision alternative and $z_1, z_2, ..., z_k$ are the criteria. The decision space is defined by objective restrictions and by mutual goals of all the decision makers in the aspiration level formulation. The decision alternative $\mathbf{x}$ is transformed by the criteria to criteria values $\mathbf{z} \in Z$, where Z is a criteria space. Every decision making units has its own criteria. People appear to satisfy rather than attempting to optimize. That means substituting goals of reaching specified aspiration levels for goals of maximizing.

We denote $\mathbf{y}^{(s)}$ aspiration levels of the criteria and $\Delta\mathbf{y}^{(s)}$ changes of aspiration levels in the step s. We search alternatives for which it holds:

$$\mathbf{z(x)} \geq \mathbf{y}^{(s)}, \qquad \mathbf{x} \in X$$

According to heuristic information from results of the previous condition the decision making unit changes the aspiration levels of criteria for step s + 1:

$$\mathbf{y}(s+1) = \mathbf{y}(s) + \Delta\mathbf{y}(s)$$

We can formulate the multicriteria decision problem as a state space representation. The state space corresponds with the criteria space Z, where the states are the aspiration levels of the criteria $\mathbf{y}^{(s)}$ and the operators are changes of the aspiration levels $\Delta\mathbf{y}^{(s)}$. The start state is a vector of the initial aspiration levels and the goal state is a vector of the criteria levels for the best alternative. For finding the ideal alternative we use the depth-first search method with backtracking procedure. The heuristic information is distance between an arbitrary state and the goal state.

We propose an interactive procedure ALOP (Aspiration Levels Oriented Procedure) for multiobjective linear programming problems, where the decision space X is determined by linear constraints:

$$X = \{\mathbf{x} \in R^n;\ A\mathbf{x} \leq b\ ,\ \mathbf{x} \geq 0\}$$

and $z_i = \mathbf{c}_i\mathbf{x}$, $i = 1, 2, \ldots, k$, are linear objective functions. Then $\mathbf{z}(\mathbf{x}) = C\mathbf{x}$, where C is a coefficient matrix of objectives.

The decision alternative $\mathbf{x} = (x_1, x_2, \ldots, x_n)$ is a vector of n variables. The decision maker states aspiration levels $\mathbf{y}^{(s)}$for the criteria values. There are three possibilities for aspiration levels $\mathbf{y}^{(s)}$. The problem can be feasible, infeasible or the problem has a unique nondominated solution. We verify the three possibilities by solving the problem:

$$v = \sum_{i=1}^{k} w_i^+ \ d_i^+ \rightarrow \max$$

$$C\mathbf{x} - \mathbf{d}^+ = \mathbf{y}^{(s)}$$

$$\mathbf{x} \in X\ ,\ \mathbf{d}^+ \geq \mathbf{0}$$

If it holds:

- $v > 0$, then the problem is feasible and d_i^+ are proposed changes $\mathbf{y}^{(s)}$ of aspiration levels which achieve a nondominated solution in the next step,
- $v = 0$, then we obtained a nondominated solution,
- the problem is infeasible, then we search the nearest solution to the aspiration levels by solving the goal programming problem:

$$v = \sum_{i=1}^{k} \frac{1}{\overline{z}_i} (d_i^+ + d_i^-) \rightarrow \min$$

$$\mathrm{C}\mathbf{x} - \mathbf{d}^+ + \mathbf{d}^- = \mathbf{y}^{(s)}$$

$$\mathbf{x} \in \mathrm{X} \,,\ \mathbf{d}^+ \geq \mathbf{0} \,,\ \mathbf{d}^- \geq \mathbf{0}$$

The solution of the problem is feasible with changes of the aspiration levels $\Delta\,\mathbf{y}^{(s)} = \mathbf{d}^+ - \mathbf{d}^-$. For small changes of nondominated solutions the duality theory is applied. Dual variables to objective constraints in the problem are denoted u_i, $i = 1, 2, \ldots, k$.

If it holds:

$$\sum_{i=1}^{k} u_i \Delta y_i^{(s)} = 0$$

then for some changes $\Delta\,\mathbf{y}^{(s)}$ the value $v = 0$ is not changed and we obtained another nondominated solution. The decision maker can state $k - 1$ small changes of the aspiration levels $\Delta y_i^{(s)}$, $i = 1, 2, \ldots, k$, $i \neq r$, then the change of the aspiration level for criterion r is calculated from previous equation.

The decision maker chooses a forward direction or backtracking. Results of the procedure ALOP are the path of tentative aspiration levels and the ideal solution.

In the second phase a consensus could be obtained by the search process and the principle of cooperativeness is applied. The heuristic information for the decision-making unit is the distance between his proposal and the opponent's proposal. We assume that all the decision makers found their ideal alternatives. We propose an interactive procedure GROUP-ALOP for searching a consensus.

For simplicity we assume the model with one supplier and one customer:

$$z^1(\mathbf{x}) \rightarrow \text{"max"}$$

$$z^2(\mathbf{x}) \rightarrow \text{"max"}$$

$$\mathbf{x} \in \mathrm{X}$$

The decision-making units search a consensus on a common decision space X. The decision making units change aspiration levels of the criteria y^1, y^2. The sets of feasible alternatives for the aspiration levels y^1 and y^2 are X^1 and X^2.

$$z^1(\mathbf{x}) \geq \mathbf{y}^1, \qquad \mathbf{x} \in X$$

$$z^2(\mathbf{x}) \geq \mathbf{y}^2, \qquad \mathbf{x} \in X$$

The consensus set S of the negotiations is the intersection of sets X^1 and X^2:

$$S = X^1 \cap X^2$$

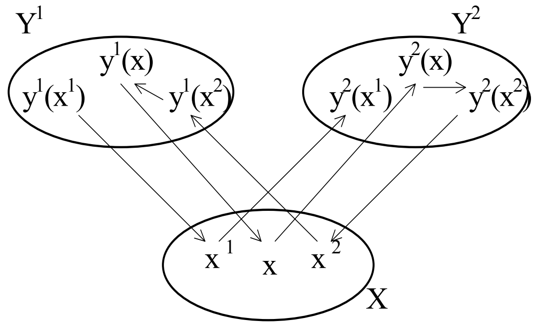


Fig. 4. Negotiation process

By changes of the aspiration levels the consensus set *S* is changed too. The decision makers search one element consensus set *S* by alternating of the consensus proposals. The image of partner's proposal can be taken as aspiration levels in one's own criteria space. In searching for a consensus the distance between the proposals is heuristic information. The paths of the tentative aspiration levels can be used for the backtracking procedure. The forward directions can be directed by proposed new aspiration levels in step s +1:

$$\mathbf{y}^1(s+1) = (1-\alpha)\mathbf{y}^1(s) + \alpha\, \mathbf{z}^1(\mathbf{x}^2)$$

$$\mathbf{y}^2(s+1) = (1-\beta)\mathbf{y}^2(s) + \beta\, \mathbf{z}^2(\mathbf{x}^1)$$

where $\alpha, \beta \in <0,1>$ are the coefficients of cooperativeness.

Each decision maker applies cooperative strategy as long as his partner does the same. If the partner exploits the decision maker on a particular step, the decision maker then applies the exploitative strategy on the next step and continues to do so until the partner switches back to the cooperative strategy. Under these conditions, the problem stabilizes with the decision makers pursuing the mutually cooperative strategy and receiving the consensus.

The current structure is dynamic representation of results of negotiation process among units. The proposed model is discrete dynamic model and the cooperation of units is based on contracts and formal agreements achieved in negotiation process. The contracts are evaluated by multiple criteria as time, quality and costs. There are different approaches to modeling multicriteria negotiation processes, as utility concept, concept of pressure, concept of coalitions. The set of modeling concepts can be a basis for developing negotiation support.

4. SUPPLIER SELECTION DYNAMIC NETWORK MODEL

The scope of strategic fit refers to the functions and stages within a network system that coordinate strategy and target a common goal. Agile intercompany scope refers to firm's ability to achieve strategic fit when partnering with network stages that change over time. A manufacturer may interface with a different set of suppliers depending on the product. The situation in reality is much more dynamic as product life cycles get shorter and companies try to satisfy the changing needs of individual customers. The level of agility becomes more important as the competitive environment becomes more dynamic.

The proposed model is a combination of advantages of traditional approaches with adding new approaches for new specifications of supplier selection problem. The approach combines the ANP and the GROUP-ALOP. The ANP provides weights $\mathbf{w}$ in the network model. The elements can be members of supply network, evaluating criteria, products, items etc. By ANP can be evaluated qualitative criteria also. The weights $\mathbf{w}$ are used in the GROUP-ALOP approach.

Today's world is dynamic. The proposed approach can be used for this dynamic environment. The AHP and ANP have been static but for today's world analyzing is very important time dependent decision making. The DHP/DNP (Dynamic Hierarchy Process/Dynamic Network Process) methods were introduced [8]. There are two ways to study dynamic decisions:

structural, by including scenarios, and functional by explicitly involving time in the judgment process. For the functional dynamics there are analytic or numerical solutions. The basic idea with the numerical approach is to obtain the time dependent principal eigenvector by simulation. The DNP provides weights for time periods t =1,2,…,T.

The connections are time dependent. The importance of the criteria, suppliers etc. and aspiration levels changes. There are many time dependent situations in network economy. For example the dynamics of new product adoption can be expressed by S-curve (see Figure 5).

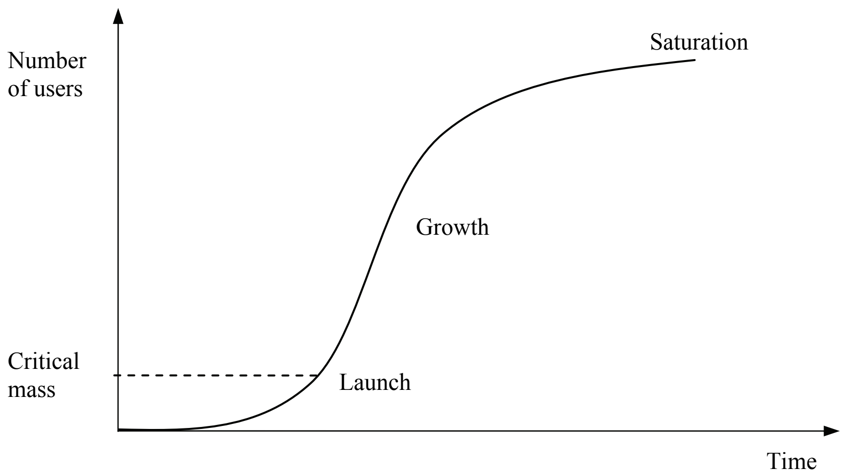


Fig. 5. Adaptation dynamics

The reality of today's networks includes features:

- large-scale nature and complexity,
- increasing congestion,
- complementarity,
- externalities,
- switching costs,
- alternative behaviors of users of the networks,
- interactions between the networks themselves.

Many of today's networks are characterized by both a large-scale nature and complexity of the network topology. Congestion is playing an increasing role in not only transportation networks but also in telecommunication networks. The crucial relationship in networks is the complementarity between the pieces of the network. Networks exhibit positive externalities. The value of a unit of the good increases with the expected number of units to be sold. Cost of switching to a different service or adopting a new technology are significant. There are various types of these costs as contracts, training and learning, data conversion, search costs etc. The decisions made by the users of the networks, in turn, affect not only the users themselves but others, as well, in terms of profits and costs, timeliness of deliveries, the quality of the environment etc. Network connections bring important effects. Networks established for the purpose of sharing or creating new information provide better, more complete information as more units join and use them. The attractiveness to users of networks increases as they increase in size.

In the supplier selection problem are important feedback and dependencies between items or suppliers:

- positive and negative feedback,
- substitution and complementarity.

The positive feedback (see Figure 6) can be expressed as: the strong will be stronger and the weak will be weaker.

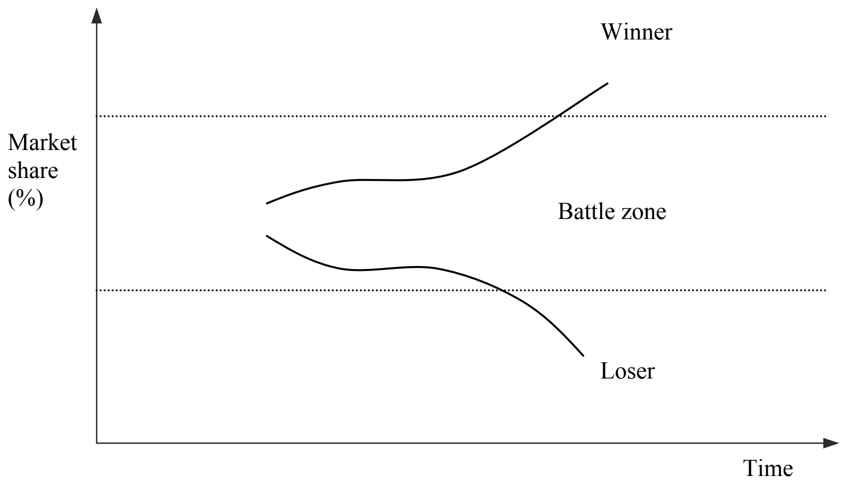


Fig. 6. Positive feedback

Example 1

We use the DNP method for an illustration of positive feedback. The time dependent comparison of two products is expressed by the S-curve:

$$a_{12}(t) = \frac{9}{1 + 7 \cdot 0{,}01^{t}}$$

The paired comparison matrix:

$$\begin{bmatrix} 1 & a_{12}(t) \\ 1/a_{12}(t) & 1 \end{bmatrix}$$

The numerical data are shown in Table 1 and plotted in Figure 7 and Figure 8.

Table 1

Dynamic comparisons

t	$a_{12}(t)$	$w_1(t)$	$w_2(t)$
0	1,13	0,53	0,47
0,1	1,66	0,62	0,38
0,2	2,38	0,7	0,3
0,3	3,26	0,77	0,23
0,4	4,27	0,81	0,19
0,5	5,29	0,84	0,16
0,6	6,24	0,86	0,14
0,7	7,04	0,87	0,13
0,8	7,65	0,88	0,12
0,9	8,10	0,89	0,11
1	8,41	0,9	0,1

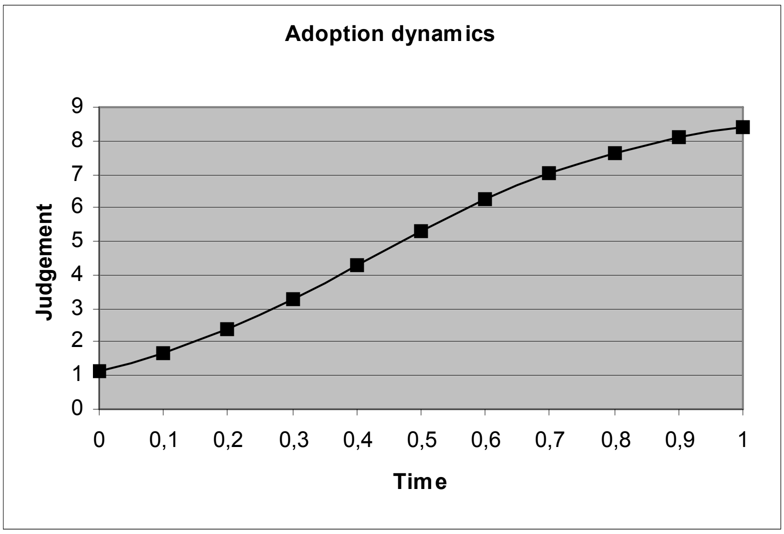


Fig. 7. Adaptation dynamics – example

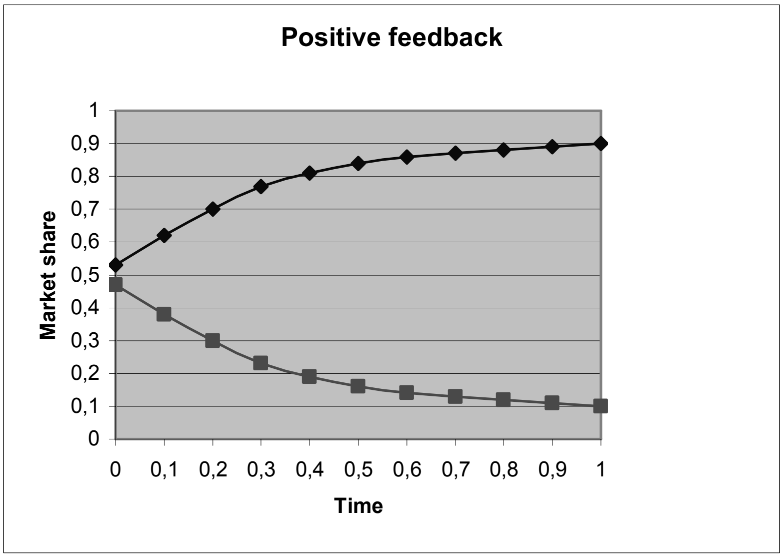


Fig. 8. Positive feedback – example

Supplier selection processes have received considerable attention in business. Sourcing has become a very strategic issue in the management of supply chain networks in the modern era of global competition. Sourcing decisions have the capability of impacting the effectiveness of supply chain networks. Determining suitable suppliers in supply chain networks has become a key strategic issue. The nature of these decisions is usually complex and unstructured. Supplier-customer relationships are changing to a cooperative form. The impact of information sharing plays a crucial role. The supplier selection problem is a multiple criteria group decision making problem. Many influence factors such as price, quality, flexibility, and delivery performance must be considered to determine suitable suppliers. These influence factors can be divided into quantitative and qualitative factors.

Two items A and B are complementary, if it holds for weights:

$$w(\{A, B\}) > w(\{A\}) + w(\{B\})$$

Two items A and B are substitute, if it holds for weights:

$$w(\{A, B\}) < w(\{A\}) + w(\{B\})$$

The combination of Dynamic Network Process and dynamic version of GROUP-ALOP seems to be the appropriate method for the specific features of the supplier selection problem in network economy. The approach combines time dependent weights **w**(t) from DNP and time dependent aspiration levels **y**(t), t =1,2,…,T, from GROUP-ALOP.

The approach can be structured in the following phases:

1. The DNP is used for comparison of importance of the suppliers, supplies, criteria etc. There are dependencies among units. Inputs are objective and subjective information of units. Outputs are weights for time periods t =1,2,…,T.
2. The GROUP-ALOP approach is applied for negotiation process between suppliers and the customer. For every time period in negotiation steps s the aspiration levels of criteria are changed to get a consensus. Inputs are the common decision space, criteria, and weights from the previous phase. Outputs are proposals for a consensus for time periods t =1,2,…,T.
3. Participants evaluate the proposals by own characteristics and make next proposals or determine the final values. Outputs are supplies from selected suppliers for time periods t =1,2,…,T.

The approach is illustrated in Example 2. The approach is very flexible and a simple example can clarify basic insights only.

Example 2

Assume a manufacturer produces three products (P_i, i = 1,2,3) from two key parts (A, B). The product P_1 contains one piece of the part A, the product P_2 contains one piece of the part B, and the new product P_3 contains one piece of the part A and one piece of the part B. The manufacturer looks at three suppliers, (S_j, j = 1,2,3) providing the two parts (A, B) and compares bids according two criteria, prices and reliability levels (p, r). The supplier S_1 produces parts A, the supplier S_2 produces parts B, and the supplier S_3 produces parts A and B. The supplier selection process is dynamic, in time periods (t = 1,2,3).

The relative importance of criteria (p, r) for parts (A, B) changes dramatically in time periods. The criteria are dependent each other and the parts are dependent each other for the product P_3 also. The DNP method was used for weights calculation. For simplicity we assume that weights are the same for the parts.

Table 2

Weights of criteria

t	$w_p(t)$	$w_r(t)$
1	0.8	0.2
2	0.5	0.5
3	0.3	0.7

In every time period will be in progress negotiation process with suppliers. The firm negotiates quantity, price and reliability levels of parts A, B. The weights **w** are used in the GROUP-ALOP approach. In every negotiation step s aspiration levels are changed. Results of the negotiation process are price and reliability levels for time periods.

Table 3

Negotiated final price and reliability levels

t	$p_{1A}(t)$	$p_{2B}(t)$	$p_{3A}(t)$	$p_{3B}(t)$	$r_{1A}(t)$	$r_{2B}(t)$	$r_{3A}(t)$	$r_{3B}(t)$
1	2	3	3	4	0.7	0.7	0.7	0.7
2	2.5	3.5	2	3	0.75	0.75	0.8	0.8
3	3	4	1.5	2.5	0.8	0.8	0.9	0.9

The decision set for the firm is restricted by forecasted demands $D_i(t)$, $i = 1,2,3$, $t = 1,2,3$, and capacities. Unit profits $c_i(t)$, $i = 1,2,3$, $t = 1,2,3$, are dependent on price and reliability levels of parts A, B, among others.

Table 4

Forecasted demands and unit profits

t	$D_1(t)$	$D_2(t)$	$D_3(t)$	$c_1(t)$	$c_2(t)$	$c_3(t)$
1	50	80	10	5	6	4
2	30	60	30	4	5	7
3	10	30	100	3	4	10

The production quantities $x_i(t)$, $i = 1,2,3$, $t = 1,2,3$ are bounded by forecasted demands:

$$x_i(t) \leq D_i(t) \quad i = 1,2,3, \; t = 1,2,3$$

The firm capacity makes possible to produce 100 final products in every time period:

$$x_1(t) + x_2(t) + x_3(t) \leq 100, \quad t = 1,2,3$$

For simplicity, assume the firm evaluates the negotiation position by expected profit $z(t)$, t = 1,2,3,

$$z(t) = c_1(t)x_1(t) + c_2(t)x_2(t) + c_3(t)x_3(t) \rightarrow \max$$

The solution of the decision problem:

Table 5

Production quantities and profits

t	$x_1(t)$	$x_2(t)$	$x_3(t)$	$z(t)$
1	20	80	0	580
2	10	60	30	550
3	0	0	100	1000

The required supplies $q_{jA}(t)$, $q_{jB}(t)$, i = 1,2,3, t = 1,2,3, are calculated:

Table 6

Required supplies

t	$q_{1A}(t)$	$q_{2B}(t)$	$q_{3A}(t)$	$q_{3B}(t)$
1	20	80	0	0
2	10	60	30	30
3	0	0	100	100

CONCLUSIONS

Supplier selection process is a very important strategic issue. The process is very complex. There are new trends in supply process. The new very important features in supplier selection problem are network structure of suppliers and items, dynamic connections and cooperative decision making. The proposed model captures important trends in supply process. The approach combines advantages of the traditional approaches for supplier selection problems, weighting models and mathematical programming models and adds approaches for new specifications of supplier selection problem. There is a combination of Dynamic Network Process and the dynamic version of GROUP-Aspiration Levels Oriented Procedure. The approach is very flexible. The aim is not only a supplier selection but managing supplier--customer relations also. Research work continues and testing on real applications is needed.

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