Candidate Selection for Network Design of Distributed Manufacturing Systems

Mariagrazia Dotoli  
Dipartimento di Elettrotecnica ed Elettronica  
Politecnico di Bari  
Bari, Italy  
dotoli@deemail.poliba.it

Maria Pia Fanti  
Dipartimento di Elettrotecnica ed Elettronica  
Politecnico di Bari  
Bari, Italy  
fanti@deemail.poliba.it

Carlo Meloni  
Dipartimento di Elettrotecnica ed Elettronica  
Politecnico di Bari  
Bari, Italy  
meloni@deemail.poliba.it

Abstract - Supply chains are distributed manufacturing systems composed of various resources belonging to different companies. Efficient design of the supply chain network is essential for business to pursue a competitive advantage. In this paper a hierarchical methodology previously outlined by the authors is considered for supply chain network design. In the first level, the performance of the entities candidate to join the network is evaluated and efficient elements are singled out. The second level is aimed at developing a model to configure the network. Finally, the third level is devoted to validating the solution proposed in the first two levels. The paper focuses on the first level and proposes a four-step procedure to select the candidates in the supply chain stages. Some optimization multi-criteria techniques are considered and the proposed decision level is illustrated by way of a case study describing a network for desktop computer production.

Keywords: Distributed manufacturing, supply chain management, network design, decision making, candidate selection.

1 Introduction

A Supply Chain (SC) network is defined as a collection of independent companies, possessing complementary skills and integrated with streamlined material, information and financial flow [10]. The Integrated E-Supply Chain (IESC) is an emerging business strategy that integrates the supply chain design and the power of e-commerce in order to obtain more flexible and agile manufacturing processes. In the formation of an effective IESC network, the selection of partners in each tier of the SC for fulfillment of each and every order is extremely important [10]. In each stage of the SC one or more partners (producers, manufacturers, consumers etc.) have to be selected, making use of the information available on capacities, inventory, costs, distances, pollution. Notable contributions may be found as regards partner selection [3, 10, 11, 12]. However, there is a lack of literature dealing with component selection in the framework of a general purpose and well structured IESC network design methodology.

This paper focuses on SC candidate selection in the framework of a broader network design methodology for distributed manufacturing systems. We employ a configuration strategy for IESC network design, outlined by the authors in [4]. In the adopted configuration methodology the IESC design procedure is divided into a hierarchy organized in three decision levels: the candidate selection level, the network design level and the solution evaluation/validation level. In particular, the first level evaluates the performance of the entities candidate to join the network. Furthermore, the second level receives the stages of the IESC by the first level and describes the structure of the IESC. The aim of the second level is solving a multi-criteria optimization problem to configure the IESC network. Finally, the third level is devoted to evaluating and validating the solution proposed in the first two levels taking into account operational issues. This paper focuses on the first level (candidate selection) and proposes some solution techniques to select partners of an agile IESC. In particular, we consider two well-known procedures for estimating the relative efficiency of a group of actors (such as the candidate members of the supply chain): Electre [2] and the Analytic Hierarchy Process (AHP) [7]. On the basis of efficiency criteria derived from aggregate data and stated by the decision team, the output of this module contributes to create a set of entities considered as candidates connected by links representing transportation and communication. A case study is analyzed and the different solutions obtained for the first decision module are presented and compared.

2 The integrated e-supply chain description

An Integrated E-Supply Chain (IESC) network can be defined as a hyper-network of material flows overlaid with an e-business information network. In the structure of the IESC project, partners contain autonomous or semi-
autonomous business entities collectively responsible for the full lifecycle of a product. More precisely, the considered IESC contains different stages, that may include raw material supply, intermediate supply, manufacturing, distribution, retail, customers, and de-manufacturing or re-cycling. For example, inbound stages may have partners that are raw material suppliers or plant stages. Moreover, the distribution stages may have partners such as manufacturers, product distributions and warehouses. Finally, outbound stages can be composed of retailers, customers, recyclers and de-manufacturers. After the de-manufacturing stage, recovered material, components or energy feedback to suitable supply chain stages may be considered.

With reference to the generic IESC project depicted in Figure 1, we denote the IESC stages by the set \( ST = \{ P_1, \ldots, P_k, \ldots, P_N \} \), where \( N \) is the number of stages. In particular, each stage \( P_k \) is described as a set of partners representing different actors of the SC. Moreover, the partners of different IESC stages can be connected by transportation and information links. More precisely, an \( m \)-link represents the physical transportation link between two partners. Multiple \( m \)-links are allowed between two partners to model different transportation modes or split delivery routes. In addition, an \( e \)-link can be completed by an \( e \)-link, i.e., an e-business relationship between business entities for streamlining the material flow efficiently and effectively. An \( e \)-link can speed up the communication process and thus reduce the response time affecting performance measures such as cost, productivity and energy use of partners and \( m \)-links in the material flow network. Obviously, an \( e \)-link may connect two partners of the SC also without the presence of an \( m \)-link. Hence, the proposed structure is able to extend the traditional SC into a more sustainable and integrated production system. We remark that for the sake of simplicity in the IESC project depicted in Figure 1 the links attributes (i.e., transportation and/or communication features) are omitted.

![Figure 1. The structure of a generic IESC project](image)

3 Hierarchical design of an integrated e-supply chain

3.1 The hierarchical structure of decisions

Consider the project of a distributed manufacturing process such as the one depicted in Figure 1. The SC network to be designed requires a number of component suppliers, subassembly manufacturers, logistics service providers and users located in different geographical sites. We also assume that there are a number of buyers with orders for a set of finished products. The distributed manufacturing system is arranged as an IESC composed of a sequence of stages dynamically connected by material transporters and by information exchange. Obviously, the efficiency of the IESC network closely depends on the partners selected to rise to the formation of each stage [10]. Hence, the task of designing the distributed manufacturing system is crucial for business to pursue a competitive advantage.

In this section we employ a three-level approach, outlined by the authors in [4], to solve the IESC configuration (or reconfiguration) decision problem. The design of the IESC is decomposed in three hierarchical levels that suggest different solutions analyzing sets of data and considering different scenarios. Figure 2 shows the hierarchical structure of the IESC configuration decision problem and depicts the three levels of the design procedure. A specific module is devoted to each decision stage and the interactions between modules allow us to obtain and refine proposal configurations for the SC. The levels of the hierarchical structure of decisions are briefly reviewed in the following [4], and a suited module to synthesize the first level of the decision making structure is subsequently proposed.

3.2 First level: candidate selection module

This module applies some multi-criteria data analysis techniques to the company’s database in order to create a pool of ranked candidates to join the IESC...
At this level the criteria to select partners are based on aggregate performance indices that are used to analyze the efficiency of the potential members. Hence, we consider different procedures for estimating the relative efficiency of a group of SC partners. The output of this module produces a ranking of the entities considered as candidates.

The optimization procedure performed by this module can be described by way of the following four steps that are iterated for each stage of the IESC.

- The first step of the procedure has to single out the candidate set of the generic stage, denoted by \( P_k^C = \{ n_{i}^c \} \). The set \( P_k^C \) collects all the candidates \( n_{i}^c \) that may compose the stage \( P_k \) of the SC in the final project.

- The second step defines the most relevant criteria that measure the impact of each alternative. To this aim the following criteria can be used \([1, 2]\):
  - financial (F), including cost and financial return;
  - risk management (RM), including risk of plant failure and damage following natural disasters;
  - environmental (E), including effect on relationship with resource partners and on access to resources;
  - flexibility (FL), representing the capacity of the candidate to adjust market requests;
  - operation times (T), representing the ability to respect the decided dead-lines;
  - quality (Q), evaluating the goods of the products and of the provided service.

- The third step determines a normalized score for each candidate with reference to each criterion. The scores for each criterion are based on a 0 to 100 scale. These data, where each alternative is assessed using each criterion, produce a table of impacts, referred to as performance indices.

- The fourth and last step of the procedure is the optimization process, able to provide an ordered final ranking of the partners in \( P_k^C \) based on the criteria and scores obtained by the previous steps. At this point, the designer is ready to select the candidates in a subset \( P_k^C \subset P_k^C \) denoting the actors of the k-th stage of the final IESC project (level 2 of the hierarchical decision structure, see Figure 2).
To implement this decision level, several well-known Multi-Attribute Decision Making (MADM) methodologies can be adopted: e.g., the Electre method [2, 13], the Analytic Hierarchy Process (AHP) [7, 13] and many others, such as the Data Envelopment Analysis [8] and fuzzy logic based strategies [5]. In particular, to show an example of the candidate selection module, we propose a case study in which the candidate ranking and classification are performed using the Electre and AHP methods. The rationale for our selection is the popularity of the two methodologies.

4.1 Case study

We consider an IESC case study inspired to an example proposed in [6]. The target product is a typical desktop computer system consisting of the computer, hard disk driver, monitor, keyboard and mouse. The supply chain is composed of N = 6 stages. For the sake of simplicity, suppose that all partners in stages P_k with k ≠ 2 have already been selected in the project. More precisely, suppose that the IESC project consists of: stage P_1, including four suppliers, stage P_2, including a number of manufacturers, stage P_3, including two distributors, stage P_4, including two retailers, stage P_5, including one consumer, and stage P_6, including four recyclers. Thus, we focus on the task of partner selection for the second stage: the manufacturers. Obviously, the methodology proposed for manufacturer selection can be applied to each stage of the IESC. The first step of the procedure determines the candidate set of the second stage, e.g. \( P_2 = \{ n_1, n_2, \ldots, n_{15} \} \), where we assume that 15 candidates are competing to join the second stage of the SC. Having defined the most relevant criteria in the second step (F, RM, E, FL, T, Q), the step third assigns the scores to each candidate: Table 1 reports the performance matrix assigned to each alternative manufacturer. Finally, the fourth step is implemented in the sequel adopting in turn the well-known MADM Electre and AHP methodologies.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>PERFORMANCE MATRIX OF MANUFACTURERS WITH SCORES FOR EACH CRITERION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n_1</td>
</tr>
<tr>
<td>F</td>
<td>10</td>
</tr>
<tr>
<td>RM</td>
<td>30</td>
</tr>
<tr>
<td>E</td>
<td>80</td>
</tr>
<tr>
<td>FL</td>
<td>40</td>
</tr>
<tr>
<td>T</td>
<td>65</td>
</tr>
<tr>
<td>Q</td>
<td>85</td>
</tr>
</tbody>
</table>

4.2 Electre method solution

The Electre method [2, 13] is a multiple criteria sorting method originally developed to incorporate imprecision and uncertainty in decision making by using thresholds of indifference, preference and veto. A further feature distinguishes Electre from many MADM solution methods: it is fundamentally non-compensatory. In other words, low scores with reference to some criteria cannot be compensated by high scores on other criteria. To apply the Electre method the decision makers are required to define a table collecting the indifference, preference and veto thresholds as well as a set of weight-importance coefficients. In particular, while thresholds model the non-compensatory nature of the method, the weights deal with preference information, reflecting the relative importance of each criterion according to the decision making team [2]. The thresholds and weights are subjective: once the performances are agreed upon by all decision makers, then the subjective inputs of thresholds and weights can be processed. The thresholds and weights defined for the case study are shown in Table 2.

Using the thresholds of Table 2, the Electre method seeks for an outranking relation. Table 3 shows the final ranking of the candidates, resulting from the intersection of the results of an ascending and a descending distillation process. In particular, the outranking relation is obtained with a Matlab implementation of the method, that employs the intrinsic characteristic of the Matlab programming environment to operate with matrices [9]. According to the results in Table 3, level 2 of the decision making procedure (see Figure 2) selects P_2 = \{ n_2 \} if one manufacturer only is to be included in the SC network. On the contrary, if several manufacturers have to be incorporated in the SC, a corresponding number of candidates are selected from Table 3 starting from the one with the highest position: if for instance two manufacturers are to be included in the SC, the decision makers select P_2 = \{ n_2, n_3 \}.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>THRESHOLDS AND WEIGHTS FOR ELECTRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>RM</td>
</tr>
<tr>
<td>Indifference threshold 20</td>
<td>25</td>
</tr>
<tr>
<td>Preference threshold 30</td>
<td>45</td>
</tr>
<tr>
<td>Veto threshold 60</td>
<td>85</td>
</tr>
<tr>
<td>Weights 0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>MANUFACTURERS RANKING ACCORDING TO THE ELECTRE METHOD FOR THE CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1 2 3 5 6 7 8 9 10 12 13</td>
<td></td>
</tr>
<tr>
<td>Manufacturer n_2 n_3 n_4 n_5 n_6 n_7 n_8 n_9 n_10 n_11 n_12</td>
<td></td>
</tr>
</tbody>
</table>

4.3 AHP method solution

AHP is a widely used technique for multi-attribute decision making [7, 13]. It is based upon pair-wise subjective judgment of elements which are used to complete a table. More precisely, a pair-wise comparison is performed between each couple of candidates in the SC considering a criterion at a time. In one of the most common versions of AHP, for each difference of candidates performance indices in relation to each criterion the method assesses a score, i.e., it assigns a low value for small differences and a high value for large
differences. Obviously, such a scores scale is subjective and several variants of the method have been singled out in the related literature according to different scales [13]. For the sake of simplicity, in the following we make use of Saaty’s original AHP scale [7, 13]. The first row of Table 4 shows the possible range of differences obtained in the comparison and the second row reports the assigned scales. After the pair-wise comparisons are completed, AHP then produces a ranking of the candidates according to the contribution of each alternative to the total effort of all the candidates. Referring to the input values shown in Table I, Table 5 shows the final ranking of the candidates. As for the Electre method implementation, the AHP outranking relation is obtained in the Matlab framework, making use of the distinctive feature of such a programming environment to operate with matrices [9].

<table>
<thead>
<tr>
<th>TABLE 4</th>
<th>AHP POINT RATIO SCALES FOR THE CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pairwise differences</td>
<td>0-5</td>
</tr>
<tr>
<td>AHP scale</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 5</th>
<th>MANUFACTURERS RANKING ACCORDING TO THE AHP METHOD FOR CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>n5c</td>
</tr>
</tbody>
</table>

4.4 Comparing Electre and AHP methods

Choosing some parameters in the candidates selection methods considered in the previous sections presents considerable cognitive difficulties in the determination of the thresholds and weights. Indeed, most often the decision maker team makes such crucial decisions by reducing the complexity of the objective and using heuristic techniques. As a result, while such simplifications facilitate the actual decision process, they inevitably lead to sub-optimal results.

In addition, evaluating the behavior of the two previously adopted methods, some differences may be singled out:

- the Electre method is based on common sense techniques, that are typical in a decision process. However, the main flaw of the methodology is in the fact that the resulting candidates ranking depends on the choice of the threshold values, as well as on the number of available alternatives. In fact, when the latter are numerous, taking into account the various performance criteria in the choice of thresholds and weights becomes impractical;

- the advantage of the AHP method is the possibility for the decision maker to use qualitative decisions based on pair-wise comparisons of the alternatives. A disadvantage is the necessity to repeat all the pair-wise comparisons if a new alternative has to be added.

A comparison of the results of the Electre and AHP methods shows that, even though the candidates classification is different in the two solutions (see Tables 3 and 5), several manufacturers are assigned a similar ranking position in both procedures: as an example, alternative n5c evaluated as the best partner both in Electre and AHP; in addition, candidates n4c, n9c and n14c are assigned low weights both by Electre and AHP.

4.5 Case study (continued): the IESC network

Consider the supply chain composed of N=6 stages previously described. Suppose that one manufacturer only has to be included in the SC network by the decision making procedure. As a result, the IESC structure includes (see Figure 3): four suppliers, one manufacturer, two distributors, two retailers, one consumer and four recyclers, for a total of N=14 partners. Note that the second stage is P2={n5}. Clearly, with reference to the Electre (or AHP) results obtained in subsections 4.2 and 4.3, actor n5 in the supply chain represents the manufacturer previously indicated by n5c. Note that Figure 3 exhibits the m- and e-links of the IESC network.

![Figure 3. The stages of the IECS network of the case study](image-url)
5 Conclusions

This paper adopts a three-level hierarchical approach to design and configure an Integrated Supply Chain (IESC). In particular, we propose a suited module to synthesize the first level of the decision making structure for IESC design, that performs candidate selection for the IESC project. More specifically, the proposed candidate selection module is organized in a four step procedure that uses aggregate performance indices and optimization techniques to obtain a ranking of potential candidates for each stage of the IESC. To perform the solutions, some well-known optimization multi-criteria models are proposed and analyzed showing a case study modeling a network producing desktop computers. The second and third module of the hierarchical procedure are not described in detail and will be the subject of future research and study. The envisaged end result is to obtain a general purpose strategy that may be applied over different design horizons in the formation of an IESC.

References