

# Analysing Logistics Flows in Industrial Clusters Using an Enterprise Input-Output Model

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## ABSTRACT

Industrial clusters provide an interesting example of local systems of production that are facing global competition. The firms' processes acquire raw materials, convert them into final products, and deliver final products to retailers. Short and long range transfers of materials and energy are becoming crucial for clusters' competitiveness. Logistics activities have a particular importance for geographic clusters where production activities and residences are remarkably diffused and this results in high mobility and environmental problems. The coordination of transport demand implies a new integration and organization of logistics not only to reduce costs and enhance management control, but also to reduce their impact on the environment.

In the paper, we propose the use of an enterprise input-output model to analyse logistics flows in order to support coordination policy at the level of the whole industrial cluster.

First, logistics flows between firms' processes are modelled aggregating similar processes to create a complete account for logistics flows in the industrial cluster. Successively, considering the disaggregated representation of processes, different coordination policies for logistics flows ranging from hierarchy to market are examined and modelled. The effects of such policies on input-output coefficients of the industrial cluster model and on logistics performance are evaluated. A case study related to an Italian cluster producing leather upholstery is considered and different coordination policies are compared also in terms of impact on productivity and environment.

## 1. INTRODUCTION

### 1.1. Industrial clusters

Industrial clusters provide an interesting example of local systems of production trying to face global competition (Piore and Sabel 1984; Porter 1989; Krugman 1991; Markusen 1996). Clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions in a particular field that compete but also cooperate (Porter 1998). Clusters may present different configurations: their location and organization vary from relatively confined areas, to clusters that transcend local

planning authorities areas and even regional boundaries. Referring to the term *industrial district* Markusen (1996) distinguishes four types of clusters: i) Marshallian industrial districts, regions where the business structure is comprised of small, locally owned firms that make investment and production decisions locally, and the Italianate variant of the Marshallian industrial district model, mainly characterised by the fact that firms consciously network with each other to solve problems; (ii) hub-and-spoke industrial districts present in regions where a number of key firms and/or facilities act as anchors or hubs to the regional economy, with suppliers and related activities spread out around them like spokes of a wheel; (iii) satellite platform, a congregation of branch facilities of externally based multi-plant firms; (iv) state-anchored industrial district, where a public or non-profit entity, be it a military base, a university, or a concentration of government offices, is a key anchor tenant in the district.

Anyway, even in the globalization era, a cluster is somehow a concentration of firms, which is embedded within a local community and which benefits from collaboration, and from cognitive and material relationships. The firms' processes operate exchanging materials and energy in the local area and with the outside market, as the openness degree of the cluster increases. So, short and long range transfers of materials are becoming crucial for clusters competitiveness and logistics is assuming a relevant role both at company and cluster level. Increasing efforts need to be spent in coordinating logistics flows and markets to increase efficiency and mitigate environmental impacts.

## 1.2. Logistics for clusters

With globalization, few products for sale in any country are entirely produced by domestic firms making use of domestic inputs only. It has become the rule rather than the exception that the product, components of the product, or resources used in the production of the product are of foreign origin. Enterprises are forced to reorganize their business processes, to be able to react quickly and cost effectively on fast changing market demands.

The movement of freight has significant environmental effects, which are accentuated by the growing market share of the most energy intensive modes of transportation (truck and air<sup>1</sup>) and the relative decline of other modes (ship and rail<sup>2</sup>) (EEA 2004). The EU White Paper on Transport Policy (CEC 2001) recognises that transport energy consumption is increasing and that 28% of CO<sub>2</sub> emissions are now transport-related. Carbon dioxide emissions continue to rise, as transport demand outstrips improvements in energy-related emissions. The sector with the largest projected increase in EU-15 emissions is transport.

Many analysts have also overlooked the environmental efficiency associated with larger scale production (Gosso 2005). Moreover, the indirect or second-order effects often dwarf the direct environmental effects of changes in transportation. These effects, which result from the changes in behaviour induced by changes to the transportation system, include changes in the number and organization of business as well as the proliferation of products facilitated by information technology (Cortright 2001).

One of the core concepts in transport and economic geography leans on the assumption that transportation is a derived demand. Without activities taking place at an origin and destination, transportation loses its purpose and thus cannot take place (Bamford 2001). Transportation is consequently an activity which is dependent on other activities; an auxiliary function much like a service. Fairly unnoticed from the economic geography and transport community, there has been a growing body of evidence that questions this core concept. It has been argued that contemporary developments in freight distribution underline a new dynamic environment, often

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<sup>1</sup> Air transport is growing by 6–9 % per year in both the old and new EU Member States.

<sup>2</sup> The market shares of modes such as rail are increasing only marginally, if at all.

global in scale, which challenges the conceptualization of transportation as a derived demand (Hesse and Rodrigue 2004). Logistics is thus more than a functional change in freight distribution, since the paradigm it provides changes the structure of distribution itself.

It must be readily acknowledged that the functions of production, consumption and distribution have become closely embedded making their respective differentiation problematic. The emergence of time-constrained distribution systems (i.e. just-in-time) is mainly the results of pressures from manufacturing and retailing activities seeking to improve efficiency and productivity. The reduction of transport costs helped this process, but paradoxically, as transport costs and inventory levels dropped, the value of time increased. The certainty of time becomes as important as the shortness of time in distribution (Cortright 2001). Integrated transport demand implies a new geography of logistics which has implications for freight planning and forecasting models.

Logistics and transportation activities have a particular importance also in small enterprise systems where productive activities and residences are remarkably diffused and this results in high mobility and environmental problems. But historically logistics has been considered an issue deserving modest priority and in fact SMEs are not able to manage their logistics needs. In studies on the development processes of industrial clusters, logistics deficiencies are often stressed as important causes of crisis and loss of competitiveness (Lattarulo 2001). The firms tend to focus on the core business. The lack of interest for logistics indicates a prevailing attention to competition on the product and substantial short-sightedness as far as potential innovative and competitive supply and distribution are concerned. But nowadays logistics starts to be seen as a value-adding process that directly supports the primary goal of an enterprise, which has to be competitive in terms of a higher level of customer service, competitive price and quality, and flexibility in response to market demands.

In the industrial clusters the geographic concentration of production processes and their outsourcing policies, set the need for a strong coordination and management of the logistics flows, both inside and outside the geographic boundary. Not only it is necessary the coordination of these flows to reduce costs and enhance management control, but also to reduce their impact on the environment. In fact, coordination implies a complex organisation of the deliveries, it affects costs and timely deliveries reducing the number of transfers. Coordination at the cluster level means that the stakeholders involved have to understand the benefit to share services despite the sometimes ruthless competition.

In this paper, logistics flows in an industrial cluster are analyzed adopting a particular enterprise input-output model based on production processes. Coordination policies for logistics flows among production processes are compared in terms of performance and of impact on the environment. A case study related to an Italian cluster producing leather upholstery is considered and different coordination policies are compared also in terms of impact on productivity and environment.

## **2. INPUT-OUTPUT MODEL BASED ON PROCESSES**

Input-output (I-O) models can use a level of disaggregation which involves dividing up the economy by sectors and/or regions. A familiar example of this is the input-output model that takes the form of a matrix, recording the pattern of materials and energy flow between industrial sectors, and between each sector and the final customer (Miller and Blair 1985).

But this level might not be enough if micro-scale and local economy are considered (like a single enterprise or a system of enterprises, such as an industrial cluster). Analyses at a level of aggregation that takes into account the widely different resources, materials, forms of energy, and production processes to which technological changes specifically apply should be carried

out. Therefore, the level of aggregation used in published I-O tables, even if regionalized, can be still much too broad for accurate analysis for industrial clusters.

At a commodity level of disaggregation, it is apparent that the same commodity can in many cases be produced by several alternative processes. A still higher level of disaggregation is therefore needed. The higher the level of disaggregation the better the conformity to actual materials/energy flows. Both a technological and an economical analysis are therefore pursued, this enabling to correlate process technologies with energy needs.

The drawback of working on a micro-scale analysis is the lack of constancy in the input coefficients, because it is sufficient the technological change in a process to modify the input coefficients. But on the other hand, because of the small scale, it is easy to know which technological changes are employed in one or more processes and the modifications to apply to the technical coefficients.

Enterprise input-output model is a general term for a set of models with applications to various cases in business. When applied to a single firm, the model considers the firm's departments a suitable level of disaggregation. For a group of firms, the appropriate level can be the firms themselves. In an industrial cluster or product chain, the different phases in the production process may be viewed as the significant level. Enterprise input-output models have received growing attention in the 1990s (i.e. Lin and Polenske 1998).

Enterprise input-output accounts are useful to complement the managerial and financial accounting systems currently used extensively by firms (Polenske 1997; Marangoni and Fezzi 2002; Marangoni et al. 2004; see Stone 1969, for an early contribution). In particular, Lin and Polenske (1998) built a specific input-output model for a steel plant, based on production processes rather than on products or branches. Using a similar approach, Albino et al. (2002, 2003) have formulated models that analyze the complex network of materials, energy and pollution flows that characterize the supply chain of a final product (see also Tang et al. 1994, or Grubbström and Tang 2000).

At the single firm's level the enterprise input-output model is useful to coordinate and manage internal and external logistics flows. At the level of the whole industrial cluster the enterprise input-output model can be effective to analyse logistics flows and to support coordination policies among firms and their production processes. Accordingly, in this paper the industrial cluster is considered as a network of production processes which transform inputs into outputs. Then, raw materials, semi-finished products, energy and waste flows among processes are modelled using input-output techniques. Flows between cluster processes and the environment are considered to take into account waste and energy.

Similar production processes are modelled as a simple aggregated process. Then, the network can be modelled at the aggregated or disaggregated level.

Similarly, the transportation of materials within the cluster is modelled in an aggregated and disaggregated way to create a complete account for logistics flows in the industrial cluster. Starting from the disaggregated representation of processes, different coordination policies ranging from hierarchy to market are examined and modelled. The effects of such policies on input-output coefficients of the industrial cluster model and on logistics flows are evaluated.

### **3. THE MODELS**

In this section two models are proposed for industrial clusters using input-output approach based on processes, namely the aggregated and disaggregated models.

### 3.1. The aggregated model

At the aggregated level, an industrial cluster is considered as a network of production processes where each production process is the aggregation of all similar processes occurring in the cluster. This network can be fully described if all the interrelated processes as well as input and output flows are identified.

The proposed enterprise input-output model is based on a previous input-output model that uses physical units (Albino et al. 2003). It has been modified to take account of the transports which allow input-output flows.

Transportation is modelled as a production process which provides other processes with inputs consisting of logistics service. Different transportation systems require to be modelled as different transportation processes.

Let  $Z_0$  be the matrix of *domestic* (i.e. to and from production processes within the cluster) intermediate deliveries,  $f_0$  is the vector of final demands (i.e. demands leaving the cluster), and  $x_0$  the vector of gross outputs. If  $n$  processes are distinguished, including transportation as production process, the matrix  $Z_0$  is of size  $n \times n$ , and the vectors  $f_0$ , and  $x_0$  are  $n \times 1$ . It is assumed that each process has a single main product as its output. Each of these processes may require intermediate inputs from the other processes, but not from itself so that the entries on the main diagonal of the matrix  $Z_0$  are zero. The main product of transportation is the distance covered within the cluster by the transportation mean to convey all main products to their destinations, i.e. the value of final demand for the transportation process is equal to zero. Of course, also other inputs are required for production. These are  $p$  primary inputs (i.e. products not produced by one of the  $n$  production processes) that include various types of energy. Next to the output of the main product, the processes also produce  $m$  by-products and waste.  $r_0$  and  $w_0$  are the primary input vector and the by-product and waste vector of size  $p \times 1$  and  $m \times 1$ , respectively.

Define the intermediate coefficient matrix  $A$  as follows:

$$A \equiv Z_0 \hat{x}_0^{-1}$$

where a “hat” is used to denote a diagonal matrix. We now have:

$$x_0 = Ax_0 + f_0 = (I - A)^{-1} f_0$$

It is possible to estimate  $R$ , the  $p \times n$  matrix of primary input coefficients with element  $r_{pj}$  denoting the use of primary input  $p$  per unit of output of product  $j$ , and  $W$ , the  $m \times n$  matrix of its output coefficients with element  $w_{mj}$  denoting the output of by-product or waste type  $m$  per unit of output of product  $j$ . It results:

$$r_0 = R x_0$$

$$w_0 = W x_0$$

Note that the coefficient matrices  $A$ ,  $R$  and  $W$  are numerically obtained from observed data. A change in the final demand vector induces a change in the gross outputs and subsequently changes in the input of primary products, and changes in the output of by-products and waste.

Suppose that the final demand changes into  $\bar{f}$ , and that the intermediate coefficients matrix  $A$ , the primary input coefficients matrix  $R$ , and the output coefficients matrix  $W$ , are constant (which seems a reasonable assumption in the short-run), then the output changes into:

$$\bar{x} = (I - A)^{-1} \bar{f}$$

Given this new output vector, the requirements of primary inputs and the outputs of by-products and waste are:

$$\begin{aligned} \bar{r} &= R\bar{x} \\ \bar{w} &= W\bar{x} \end{aligned}$$

where  $\bar{r}$  gives the new  $p \times 1$  vector of primary inputs, and  $\bar{w}$  the new  $m \times 1$  vector of by-products and waste types.

However, this aggregated model is not able to take account of all primary inputs transportation. To overcome this limit, we add *virtual* processes, so to take account of the transportation service of the primary inputs. Each virtual process, corresponding to a specific primary input, has an output that can be transported to all the production processes requiring that input. For each virtual process no inputs are allowed from the production processes. Moreover, the primary input of a virtual process is equal to the sum of the corresponding primary input of all production processes.

Then, if we assume to have one transportation process only serving the cluster, each of the  $n-1$  processes requires inputs from the  $n$ -th process, i.e. the transportation process  $T$ . In particular, being the final demand of process  $T$  equal to zero, its output is required by the  $n-1$  actual processes of the cluster, and by the  $p$  virtual processes. As a consequence, the concept of intermediate coefficient associated with the transportation process can be extended.

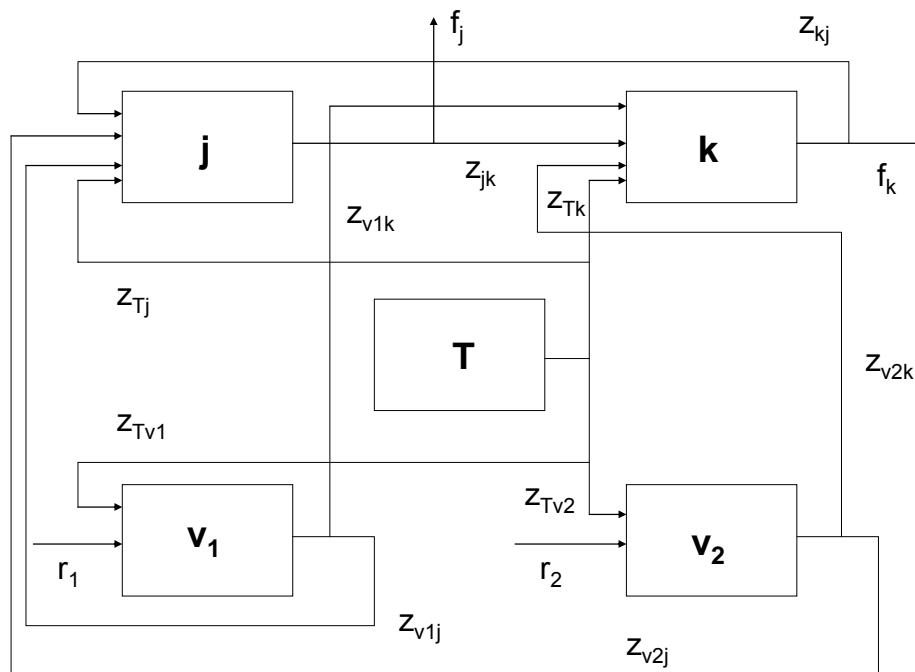


Figure 1. Transport modelling for two processes (j and k) and for two virtual processes (v1 and v2).

As shown in Figure 1, let us consider two production processes, j and k, two virtual processes, v<sub>1</sub> and v<sub>2</sub>, corresponding to two primary inputs from outside cluster, r<sub>1</sub> and r<sub>2</sub>, respectively, and the process T having, for the sake of simplicity, no intermediate deliveries from process j and k, and no primary inputs. No waste and by-product outputs are considered.

Then, the domestic intermediate deliveries of process T, v<sub>1</sub>, and v<sub>2</sub> to the process j and k are equal to:

$$z_{Tj} = a_{Tj}x_j = a_{Tj}(z_{jk} + f_j)$$

$$z_{Tk} = a_{Tk}x_k = a_{Tk}(z_{kj} + f_k)$$

$$z_{v_1j} = a_{v_1j}x_j$$

$$z_{v_1k} = a_{v_1k}x_k$$

$$z_{v_2j} = a_{v_2j}x_j$$

$$z_{v_2k} = a_{v_2k}x_k$$

where  $a_{Tj}$ ,  $a_{Tk}$ ,  $a_{v_1j}$ ,  $a_{v_1k}$ ,  $a_{v_2j}$ , and  $a_{v_2k}$  are the intermediate coefficients related to process T, v<sub>1</sub>, and v<sub>2</sub>, respectively. Let us consider that  $a_{v_1j}$ ,  $a_{v_1k}$ ,  $a_{v_2j}$ , and  $a_{v_2k}$  correspond to  $r_{1j}$ ,  $r_{1k}$ ,  $r_{2j}$ , and  $r_{2k}$  which are the primary input coefficients of the model without virtual processes v<sub>1</sub> and v<sub>2</sub>.

$z_{Tj}$  and  $z_{Tk}$  represent the distance covered by the transportation mean to convey the total output of process j and k, respectively, to their geographical destination (to production processes and outside the cluster).

In order to account for the distance covered inside the cluster by primary inputs, we consider the virtual processes v<sub>1</sub> and v<sub>2</sub> located on the cluster border. So, the related intermediate coefficients can be estimated as:

$$a_{Tv_1} = \frac{z_{Tv_1}}{x_{v_1}} = \frac{z_{Tv_1}}{z_{v_1j} + z_{v_1k}} = \frac{z_{Tv_1}}{r_1} = \frac{z_{Tv_1}^j + z_{Tv_1}^k}{r_1}$$

$$a_{Tv_2} = \frac{z_{Tv_2}}{x_{v_2}} = \frac{z_{Tv_2}}{z_{v_2j} + z_{v_2k}} = \frac{z_{Tv_2}}{r_2} = \frac{z_{Tv_2}^j + z_{Tv_2}^k}{r_2}$$

where  $z_{Tv_1}^j$  and  $z_{Tv_1}^k$  represent the distance covered to transport the primary input r<sub>1</sub> from the cluster border (virtual process v<sub>1</sub>) to the process j and k, respectively. Similarly for  $z_{Tv_2}^j$  and  $z_{Tv_2}^k$ .

In Table 1 the balance table shows the materials/energy account of the example of Figure 1.

	j	k	T	v <sub>1</sub>	v <sub>2</sub>
j	-	$z_{jk}$	-	-	-
k	$z_{kj}$	-	-	-	-
T	$z_{Tj}$	$z_{Tk}$	-	$z_{Tv_1} = z_{Tv_1}^j + z_{Tv_1}^k$	$z_{Tv_2} = z_{Tv_2}^j + z_{Tv_2}^k$
v <sub>1</sub>	$z_{v_1j} = a_{v_1j}x_j$	$z_{v_1k} = a_{v_1k}x_k$	-	-	-
v <sub>2</sub>	$z_{v_2j} = a_{v_2j}x_j$	$z_{v_2k} = a_{v_2k}x_k$	-	-	-
Primary input 1	-	-	-	r <sub>1</sub>	-
Primary input 2	-	-	-	-	r <sub>2</sub>

Table 1. Balance table for the example of Figure 1.

So, to account for all the distance covered in order to produce an unit of the main product of process j, we define an extended intermediate coefficient  $a_{Tj}^*$  as:

$$a_{Tj}^* = \frac{z_{Tj} + z_{Tv_1}^j + z_{Tv_2}^j}{z_{jk} + f_j}$$

In a similar way, we have:

$$a_{Tk}^* = \frac{z_{Tk} + z_{Tv_1}^k + z_{Tv_2}^k}{z_{kj} + f_k}$$

### 3.2. The disaggregated model

In the previous section we propose the use of an enterprise input-output model to analyse logistics flows between aggregated processes in an industrial cluster. Processes and flows can be modelled in a disaggregated way to take into account actual logistics flows between micro-processes (production units) in the industrial cluster. The disaggregated model is then suitable to estimate the intermediate coefficients related to the actual transport process as well as to evaluate the impact of specific coordination policies on the above coefficients.

Now, let us consider two processes, j and k, where process j supplies process k. The disaggregated flow between the generic supplier (s) and customer (d) micro-processes belonging to process j and k, respectively, can be represented as in Figure 2 where arrows correspond to customer-supplier relationships.

Actual flows result from the matching of the actual supply and demand of main products operated by each micro-process and from the specific coordination policies adopted by customers, suppliers and logistics service providers.

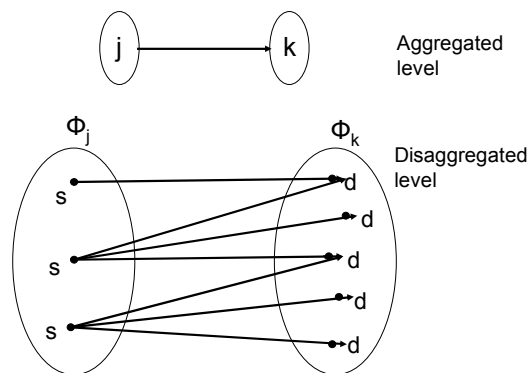


Figure 2. Logistics flows from micro-processes s to micro-processes d belonging to process j and k, respectively.

As shown in the previous section, during the time interval assumed for the analysis, the flow of the main product of process j to process k is equal to  $z_{jk}$ .

If process j results from the aggregation of  $N_s$  micro-processes, let us define  $\phi_j$  the set of all micro-processes forming process j. Similarly, if process k results from the aggregation of  $N_d$

micro-processes, let us define  $\phi_k$  the set of all micro-processes forming process k. Let us define  $N_{sd}$  be the total number of customer-supplier relationships between s and d micro-processes.

Now, let us assume that the time interval considered for the analysis of process inputs and outputs (the one used in the aggregated model) can be divided into  $N_t$  time periods being t the generic time period for the analysis of flows between micro-processes.

So, during each time period t the flow  $X_{sd}^{(t)}$  of main product may occur from the micro-process s to the micro-process d.

Then, it results:

$$z_{jk} = \sum_{t=1}^{N_t} \sum_{s \in \Phi_j} \sum_{d \in \Phi_k} X_{sd}^{(t)}$$

Similarly, main products can flow from micro-processes s to outside cluster.

In Figure 3 the logistics flows from micro-processes s of process j to outside cluster are shown.

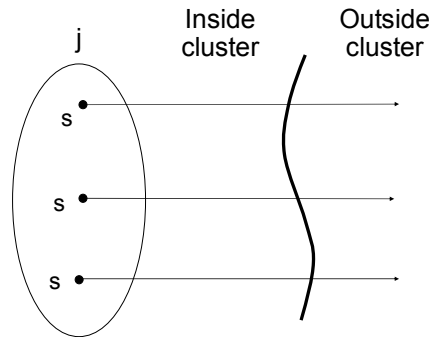


Figure 3. Logistics flows from micro-processes s of process j to outside cluster.

Let us define  $X_{so}^{(t)}$  be the flow of the main product of micro-process s to outside cluster during the time period t. Then, it results:

$$f_j = \sum_{t=1}^{N_t} \sum_{s \in \Phi_j} X_{so}^{(t)}$$

Let us define  $L_{ss}$ ,  $L_{sd}$ ,  $L_{dd}$ , and  $L_{so}$  be the distance between origin s and another origin s, between origin s and destination d, between destination d and another destination d and from origin s to outside cluster, respectively. The last one is assumed to be measured as the average distance between origin s and the boundary of the cluster. So, the total output of the transportation process provided to process j,  $z_{Tj}$ , to transport main products to process k and to outside cluster can be evaluated taking into consideration the number of trips required.

Let us consider  $Y_{ss}^{(t)}$ ,  $Y_{sd}^{(t)}$ ,  $Y_{dd}^{(t)}$ , and  $Y_{so}^{(t)}$  be the number of trips required in the time period t for the product transportation between origin s and another origin s, between origin s and destination d, between destination d and another destination d, and from origin s to outside cluster, respectively. For the sake of brevity, no backward trips are considered in the following. Then, it results:

$$z_{Tj} = \sum_{t=1}^{N_t} \left[ \sum_{s \in \Phi_j} \left( \sum_{s \in \Phi_j} L_{ss} Y_{ss}^{(t)} + \sum_{d \in \Phi_k} L_{sd} Y_{sd}^{(t)} + L_{so} Y_{so}^{(t)} \right) + \sum_{d \in \Phi_k} \sum_{d \in \Phi_k} L_{dd} Y_{dd}^{(t)} \right]$$

This result can be easily extended to the case where j supplies more processes, obtaining:

$$z_{Tj} = \sum_{t=1}^{N_t} \sum_{s \in \Phi_j} L_{so} Y_{so}^{(t)} + \sum_k \sum_{t=1}^{N_t} \left[ \sum_{s \in \Phi_j} \left( \sum_{s \in \Phi_j} L_{ss} Y_{ss}^{(t)} + \sum_{d \in \Phi_k} L_{sd} Y_{sd}^{(t)} \right) + \sum_{d \in \Phi_k} \sum_{d \in \Phi_k} L_{dd} Y_{dd}^{(t)} \right]$$

where the sum over k takes account of all processes served by process j.

Using data related to actual logistics flows, the disaggregated model allows then to estimate the intermediate coefficient  $a_{Tj}$  as:

$$a_{Tj} = \frac{\sum_{t=1}^{N_t} \sum_{s \in \Phi_j} L_{so} Y_{so}^{(t)} + \sum_k \sum_{t=1}^{N_t} \left[ \sum_{s \in \Phi_j} \left( \sum_{s \in \Phi_j} L_{ss} Y_{ss}^{(t)} + \sum_{d \in \Phi_k} L_{sd} Y_{sd}^{(t)} \right) + \sum_{d \in \Phi_k} \sum_{d \in \Phi_k} L_{dd} Y_{dd}^{(t)} \right]}{\sum_{t=1}^{N_t} \sum_{s \in \Phi_j} X_{so}^{(t)} + \sum_k \sum_{t=1}^{N_t} \sum_{s \in \Phi_j} \sum_{d \in \Phi_k} X_{sd}^{(t)}}$$

The extended intermediate coefficient  $a_{Tj}^*$  can be easily estimated if virtual micro-processes are considered for all primary inputs.

#### 4. LOGISTICS FLOWS AND COORDINATION POLICIES

The disaggregated model permits the analysis of the impact of different coordination policies for logistics flows on the intermediate coefficients associated with the transport process. These coefficients are estimated using data related to actual logistics flows which reflect the actual coordination policy.

However, logistics flows can occur during the time period t following different rules depending on the level of coordination characterizing the transactions among the different players/owners of each micro-process. In fact, micro-processes are production units generally owned by different companies as well as the provider of the logistics service may be a different company.

Then, different coordination policies can be tested to evaluate how such policies can affect logistics performances in the industrial cluster model such as  $a_{Tj}$  coefficients. If coordination is assumed to be related only to the aggregation of logistics flows in order to reduce the number of the transportation trips required, specific policies are recognized. In particular, they range from pure hierarchy to pure market.

Pure market policy assumes that each logistics flow is operated independently from all other flows and no coordination is possible. Logistic service is dedicated to each demand to be satisfied by each corresponding supply.

Pure hierarchy policy maximizes the filling of transportation units allowing the aggregation of all logistic flows. This occurs in the case the hierarchical control of all logistics flows is allowed.

Then, to evaluate how  $a_{Tj}$  can be affected by the coordination policy, four cases are considered as the combination of two coordination policies and two levels of uncertainty for logistics flows. For the sake of simplicity, the four cases are defined for a couple of process where process j is assumed to supply only process k and outside cluster.

For both the coordination policies, in any time period the logistics flow between each micro-process  $s$  to any micro-process  $d$ , and to outside cluster is assumed to be:  $X_{sd} = \frac{1}{N_t} \sum_{t=1}^{N_t} X_{sd}^{(t)}$  and

$X_{so} = \frac{1}{N_t} \sum_{t=1}^{N_t} X_{so}^{(t)}$ , respectively. So, based on the actual data, each logistics flow is assumed to be equal to the average value of logistics flows over all time periods  $N_t$ , and, as a result, period-independent.

In the first coordination policy, in any time period, each flow is managed as a separate market transaction. This is a pure market and period-independent policy.

In the second coordination policy, in any time period, flows are coordinated in a way to assure the minimization of the number of transportation trips for that time period; this corresponds to a pure hierarchy and period-independent coordination policy.

Then, two levels of uncertainty are considered assuming flows to be represented by deterministic or stochastic variables. If  $X_{sd}$  and  $X_{so}$  are random variables, then it holds:  $E(X_{sd}) = \frac{1}{N_t} \sum_{t=1}^{N_t} X_{sd}^{(t)}$

and  $E(X_{so}) = \frac{1}{N_t} \sum_{t=1}^{N_t} X_{so}^{(t)}$ , respectively. In particular, in order to get the maximum degree of uncertainty for a discrete and positive random variable,  $X_{sd}$  and  $X_{so}$  should be assumed to be Poisson random variables. In this section, however, they are considered general random variables.

So, the following four cases result:

- Pure market and period-independent policy, and deterministic flows;
- Pure market and period-independent policy, and stochastic flows;
- Pure hierarchy and period-independent policy, and deterministic flows;
- Pure hierarchy and period-independent policy, and stochastic flows.

Based on the different assumptions of each case, we set:

- $X_{sd}$  and  $X_{so}$  be the deterministic/random variables corresponding to the quantity of products to be transported from origin  $s$  to destination  $d$ , and to outside cluster, respectively, in each period  $t$ ;
- $C$  be the maximum quantity of product transported by each trip;
- $Y_{sd}$  and  $Y_{so}$  be the deterministic/random variables corresponding to the number of trips required for the product transportation from origin  $s$  to destination  $d$ , and to outside cluster, respectively, in each period  $t$ ;
- $N_{jk}$  and  $N_{jo}$  be the deterministic/random variables corresponding to the number of trips required for the product transportation from process  $j$  to process  $k$ , and to outside cluster, respectively, in all periods;
- $z_{jk}$  and  $f_k$  be the deterministic/random variables corresponding to the number of products to be transported from process  $j$  to process  $k$ , and to outside cluster, respectively, in all periods;
- $A_{sd}$  and  $A_{so}$  be the deterministic/random variables corresponding to the utilization rate of all trips from origin  $s$  to destination  $d$ , and to outside cluster in any period; the utilization rates,  $A_{jk}$  and  $A_{jo}$ , of all trips from process  $j$  to process  $k$ , and to outside cluster, respectively, are defined as the average values of all  $A_{sd}$ , and  $A_{so}$ , respectively.

Now, knowing actual values for all variables  $X_{sd}$  and  $X_{so}$ , for each case we can compute  $a_{Tj}$  as well as other logistics performance measures.

*Pure market and period-independent policy, and deterministic flows*

It results:

$$Y_{sd} = \text{int}_{\text{sup}} \left( \frac{X_{sd}}{C} \right); Y_{so} = \text{int}_{\text{sup}} \left( \frac{X_{so}}{C} \right)$$

$$N_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} Y_{sd}; N_{jo} = N_t \sum_{s=1}^{N_s} Y_{so}$$

$$z_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}; f_j = N_t \sum_{s=1}^{N_s} X_{so}$$

The utilization rate,  $A_{jk}$ , can be computed as follows:

$$A_{jk} = \frac{1}{N_{sd}} \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} A_{sd} = \frac{1}{N_{sd}} \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} \frac{X_{sd}}{Y_{sd}}$$

$A_{jo}$  can be similarly computed. Now,  $a_{Tj}$  can be evaluated as:

$$a_{Tj} = \frac{z_{Tj}}{z_{jk} + f_j} = \frac{N_t \sum_{s=1}^{N_s} \left( \sum_{d=1}^{N_d} L_{sd} Y_{sd} + L_{so} Y_{so} \right)}{z_{jk} + f_j}$$

*Pure market and period-independent policy, and stochastic flows*

If the discrete probability distribution is known for each  $X_{sd}$  and  $X_{so}$ , it results for each couple (s,d):

$$\text{Pr ob}\{Y_{sd} = 0\} = \text{Pr ob}\{X_{sd} = 0\} \text{ and } \text{Pr ob}\{Y_{sd} = k\} = \text{Pr ob}\{(k-1)C < X_{sd} \leq kC\} \text{ for } k = 1, 2, 3, \dots$$

and for each couple (s,o):

$$\text{Pr ob}\{Y_{so} = 0\} = \text{Pr ob}\{X_{so} = 0\} \text{ and } \text{Pr ob}\{Y_{so} = k\} = \text{Pr ob}\{(k-1)C < X_{so} \leq kC\} \text{ for } k = 1, 2, 3, \dots$$

Then, we have:

$$N_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} Y_{sd}; N_{jo} = N_t \sum_{s=1}^{N_s} Y_{so}$$

$$z_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}; f_j = N_t \sum_{s=1}^{N_s} X_{so}$$

with expected values:

$$E(N_{jk}) = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} E(Y_{sd}); \quad E(N_{jo}) = N_t \sum_{s=1}^{N_s} E(Y_{so})$$

$$E(z_{jk}) = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} E(X_{sd}); \quad E(f_j) = N_t \sum_{s=1}^{N_s} E(X_{so})$$

The utilization rate,  $A_{jk}$ , can be computed being:

$$\Pr ob \left\{ A_{sd} = \frac{\frac{r}{C}}{\text{int}_{\text{sup}} \left( \frac{r}{C} \right)} \right\} = \Pr ob \{ X_{sd} = r \} \quad \text{for } r = 1, 2, 3, \dots$$

and having no trip for  $r = 0$ . Then, we define:

$$A_{jk} = \frac{1}{N_{sd}} \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} E(A_{sd}) = \frac{1}{N_{sd}} \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} \sum_{r=1}^{\infty} \frac{\frac{r}{C}}{\text{int}_{\text{sup}} \left( \frac{r}{C} \right)} \Pr ob \{ X_{sd} = r \}$$

$A_{jo}$  can be similarly computed. Now,  $a_{Tj}$  can be evaluated as:

$$a_{Tj} = \frac{E(z_{Tj})}{E(z_{jk} + f_j)} = \frac{N_t \sum_{s=1}^{N_s} \left( \sum_{d=1}^{N_d} L_{sd} E(Y_{sd}) + L_{so} E(Y_{so}) \right)}{E(z_{jk}) + E(f_j)}$$

*Pure hierarchy and period-independent coordination policy, and deterministic flows*

For the sake of simplicity, let us neglect the logistics flows between origins and between destinations aimed at maximizing the utilization rate of all trips.

It results:

$$N_{jk} = N_t \text{int}_{\text{sup}} \left( \frac{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}}{C} \right); \quad N_{jo} = N_t \text{int}_{\text{sup}} \left( \frac{\sum_{s=1}^{N_s} X_{so}}{C} \right)$$

$$z_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}; \quad f_j = N_t \sum_{s=1}^{N_s} X_{so}$$

The utilization rate,  $A_{jk}$ , can be computed as follows:

$$A_{jk} = \frac{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}}{C} \bigg/ \text{int}_{\text{sup}} \left( \frac{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}}{C} \right)$$

$A_{jo}$  can be similarly computed. Now,  $a_{Tj}$  can be evaluated as:

$$a_{Tj} = \frac{z_{Tj}}{z_{jk} + f_j} = \frac{L_{jk} N_{jk} + L_{jo} N_{jo}}{z_{jk} + f_j}$$

where  $L_{jk}$  and  $L_{jo}$  are the following weighted average distances from all micro-processes  $s$  to all micro-processes  $d$  and cluster outside, respectively:

$$L_{jk} = \frac{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd} L_{sd}}{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}}; \quad L_{jo} = \frac{\sum_{s=1}^{N_s} X_{so} L_{so}}{\sum_{s=1}^{N_s} X_{so}}$$

#### *Pure hierarchy and period-independent coordination policy, and stochastic flows*

For the sake of simplicity, let us neglect the logistics flows between origins and between destinations aimed at maximizing the utilization rate of all trips.

If the discrete probability distribution is known for each  $X_{sd}$  and  $X_{so}$ , it results for flows between process  $j$  and process  $k$ :

$$\text{Pr ob} \left\{ \frac{N_{jk}}{N_t} = 0 \right\} = \text{Pr ob} \left\{ \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd} = 0 \right\}$$

and

$$\text{Pr ob} \left\{ \frac{N_{jk}}{N_t} = k \right\} = \text{Pr ob} \left\{ (k-1)C < \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd} \leq kC \right\} \quad \text{for } k = 1, 2, 3, \dots$$

and for flows between process  $j$  and outside cluster:

$$\text{Pr ob} \left\{ \frac{N_{jo}}{N_t} = 0 \right\} = \text{Pr ob} \left\{ \sum_{s=1}^{N_s} X_{so} = 0 \right\}$$

and

$$\text{Pr ob} \left\{ \frac{N_{jo}}{N_t} = k \right\} = \text{Pr ob} \left\{ (k-1)C < \sum_{s=1}^{N_s} X_{so} \leq kC \right\} \quad \text{for } k = 1, 2, 3, \dots$$

Then, we have:

$$N_{jk} = N_t \text{int}_{\text{sup}} \left( \frac{\sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}}{C} \right); N_{jo} = N_t \text{int}_{\text{sup}} \left( \frac{\sum_{s=1}^{N_s} X_{so}}{C} \right)$$

$$z_{jk} = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd}; f_j = N_t \sum_{s=1}^{N_s} X_{so}$$

with expected values:

$$E(N_{jk}) = N_t \sum_{r=1}^{\infty} r \times \text{Pr ob} \left\{ \frac{N_{jk}}{N_t} = r \right\}; E(N_{jo}) = N_t \sum_{r=1}^{\infty} r \times \text{Pr ob} \left\{ \frac{N_{jo}}{N_t} = r \right\}$$

$$E(z_{jk}) = N_t \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} E(X_{sd}); E(f_j) = N_t \sum_{s=1}^{N_s} E(X_{so})$$

The utilization rate,  $A_{jk}$ , can be computed being:

$$\text{Pr ob} \left\{ A_{jk} = \frac{\frac{r}{C}}{\text{int}_{\text{sup}} \left( \frac{r}{C} \right)} \right\} = \text{Pr ob} \left\{ \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd} = r \right\} \quad \text{for } r = 1, 2, 3, \dots$$

and having no trip for  $r = 0$ . Then, we define:

$$E(A_{jk}) = \sum_{r=1}^{\infty} \frac{\frac{r}{C}}{\text{int}_{\text{sup}} \left( \frac{r}{C} \right)} \text{Pr ob} \left\{ \sum_{s=1}^{N_s} \sum_{d=1}^{N_d} X_{sd} = r \right\}$$

$A_{jo}$  can be similarly computed. Now,  $a_{Tj}$  can be evaluated as:

$$a_{Tj} = \frac{E(z_{Tj})}{E(z_{jk} + f_j)} = \frac{N_t \left[ L_{jk} E \left( \frac{N_{jk}}{N_t} \right) + L_{jo} E \left( \frac{N_{jo}}{N_t} \right) \right]}{E(z_{jk}) + E(f_j)} = \frac{L_{jk} E(N_{jk}) + L_{jo} E(N_{jo})}{E(z_{jk}) + E(f_j)}$$

## 5. A CASE STUDY

An Italian industrial cluster has been considered as a case study. It is geographically located in the Murgia area that belongs to two Italian regions in Southern Italy, Puglia and Basilicata, and, in particular, to the municipalities of Altamura, Matera, and Santeramo in Colle. The cluster is specialized in upholstery production. Some activities, such as wood frame assembling, leather cutting, polyurethane preparation, sofa assembling, are performed within the cluster by different

firms. Most of the leather sofas (i.e. the final product) are exported and the most important firm of the cluster is the world market leader. The cluster is characterized by supplier-customer relationships among the different firms co-located in the same area.

In the cluster area, the production process network distinguishes the eight production processes listed in Table 2 with their main products. These eight production processes are the key processes in the district in terms of their logistical, economical and technological importance. In terms of outputs, each production process is characterized by only one main product (a specific intermediate or final product), and by waste, pollution and by-products. Figure 4 indicates all the inputs and outputs required for each production process.

The output of process 8 consists of leather sofas that leave the factory after final inspection (i.e. the controlling process). Because there are one-, two- and three-seat sofas, the output of the district is measured in seats (i.e., number of assembled and controlled seats). Note that, for example, the output of a two-seat and a three-seat sofa would thus be accounted for five seats.

Production processes	Main products
1: Frame realization (FR)	Basic frames (BF)
2: Strapping (S)	Strapped frames (SF)
3: Frame preparation (FP)	Final frames (FF)
4: Polyurethane cutting (PC)	Cut polyurethane (CP)
5: Leather cutting (LC)	Cut leather (CL)
6: Leather stitching (LS)	Leather covers (LC)
7: Assembling (A)	Assembled seats (AS)
8: Controlling (C)	Controlled seats (CS)

Table 2. Production processes and main products with their abbreviations.

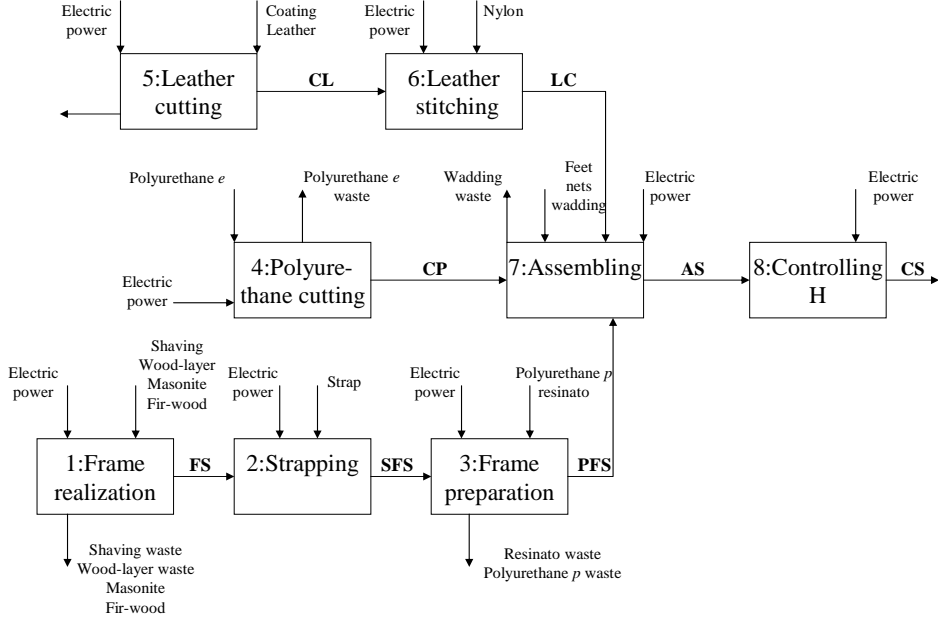


Figure 4. All the inputs and outputs required for each production process.

In Albino et al. (2003) an enterprise input-output model has been applied to the eight production processes of the cluster. In this section we apply the aggregated and disaggregated models considering the transport (T) process and two production processes, namely “polyurethane cutting” (PC) and “assembling” (A), with a sample of corresponding micro-processes. The sample consists of three PC micro-processes supplying six A micro-processes. Data have been gathered for a period of six days. In Table 3 the distance between PC micro-processes and A micro-processes are reported.

PC/A	d=1	d=2	d=3	d=4	d=5	d=6
s=1	0	12	6	14	10	2
s=2	4	6	16	8	12	18
s=3	8	5	2	0	4	12

Table 3. Distances [km] between PC and A micro-processes.

The average quantities of cut polyurethane flowing each day from PC micro-processes to A micro-processes have been estimated and are shown in Table 4.

PC/A	d=1	d=2	d=3	d=4	d=5	d=6	Total
s=1	0	27	25	0	22	0	74
s=2	34	28	0	0	0	0	62
s=3	0	0	22	39	31	57	149
Total	34	55	47	39	53	57	285

Table 4. Average quantities [ $m^3$ ] of product flowing each day from PC micro-processes to A micro-processes.

It should be noted that in the actual case only leather seats (i.e. the output of process 8) are used to satisfy final demand. That is, they are sold to wholesale and retail traders outside the industrial cluster or directly to consumers. However, having considered the A process as the final process, we only consider the final demand of this process. Assembled seats are inspected in the same place where they are assembled; so, no transportation will be required for assembled seats. Moreover, at the present, PC and A processes do not import any intermediate products.

Two primary inputs have been considered: the polyurethane for PC process and wadding for A process. All of them come from processes located outside cluster. Then, two virtual processes have been modelled,  $v_1$  and  $v_2$ , to take account of transportation of primary inputs.

The aggregated model is used first to consider the logistics flows between the process “polyurethane cutting” (process j) and “assembling” (process k) and then to estimate the pollutant emissions in the cluster area because of transportation.

The balance table referred to one week is reported in Table 5.

Processes	j	k	T	v <sub>1</sub>	v <sub>2</sub>	Final demand	Gross output
j [m <sup>3</sup> /week]	0	1710	0	0	0	0	1710
k [assembled seats/week]	0	0	0	0	0	810	810
T [km/week]	516	0	0	600	240	0	1356
v <sub>1</sub> [m <sup>3</sup> /week]	1878	0	0	0	0	0	1878
v <sub>2</sub> [m <sup>3</sup> /week]	0	834	0	0	0	0	834
						Total	
Primary input 1 [m <sup>3</sup> /week]	0	0	0	1878	0	1878	
Primary input 2 [m <sup>3</sup> /week]	0	0	0	0	834	834	

Table 5. Balance table.

Then, the intermediate coefficients can be computed (Table 6).

Processes	j	k	T	v <sub>1</sub>	v <sub>2</sub>
j	0	2.111	0	0	0
k	0	0	0	0	0
T	0.302	0	0	0.319	0.288
v <sub>1</sub>	1.098	0	0	0	0
v <sub>2</sub>	0	1.03	0	0	0

Table 6. Intermediate coefficients.

In Table 7 the values of some logistics performance measures related to the actual case (with C=24 m<sup>3</sup> for all trips) are reported.

	Values
N <sub>jk</sub> [trips/week]	81
A <sub>jk</sub>	0.88
z <sub>Tj</sub> [km/week]	516
a <sub>Tj</sub> [km/m <sup>3</sup> ]	0.30

Table 7. Logistics performance measures for the actual case.

If the extended intermediate coefficient  $a_{Tj}^*$  is evaluated, all the transportation inputs required to produce and deliver a cubic meter of cut polyurethane are accounted. A significant difference is observed being:

$$a_{Tj}^* = \frac{z_{Tj} + z_{Tv_1}^j}{z_{jk}} = 0.653 \text{ [km/m}^3\text{]}$$

In fact, in this case, the transportation input to convey primary inputs to process j is greater than the one needed to deliver the output of process j.

Pollutant emissions caused by truck transportation can be evaluated considering that emissions depend on the maximum truck load. In Table 8 data from the literature (APAT 2003) are reported.

Pollutant	Emissions [g/km]	
	Maximum truck load < 3.5 t	Maximum truck load > 3.5 t
NO <sub>x</sub>	1.1	7.2
CO	0.06	3.00
CO <sub>2</sub>	250	700
PM <sub>10</sub>	0.25	0.45

Table 8. Pollutant emissions caused by truck transportation (source: APAT 2003).

In the actual case ( $C= 24 \text{ m}^3$ ), corresponding to truck load greater than 3.5 t, the output coefficients are computed and shown in Table 9.

Pollutants/Processes	j	k	T	v <sub>1</sub>	v <sub>2</sub>
NO <sub>x</sub>	0	0	7.2	0	0
CO	0	0	3.00	0	0
CO <sub>2</sub>	0	0	700	0	0
PM <sub>10</sub>	0	0	0.45	0	0

Table 9. Output coefficients.

Pollutant emissions caused by the transportation of the output and of the primary inputs of process j and k are shown in Table 10.

Pollutant	Emissions [g/week]			
	Primary Inputs (Process j)	Output (Process j)	Primary Inputs (Process k)	Output (Process k)
NO <sub>x</sub>	4320	3715	1728	0
CO	1800	1548	720	0
CO <sub>2</sub>	420000	361200	168000	0
PM10	270	232	108	0

Table 10. Pollutant emissions caused by truck transportation of the output and of the primary inputs of process j and k in the actual case.

These results can be used to estimate how much pollutant is emitted to produce each seat of sofa based on the processes considered in the model. For instance, for each seat 1172 g of CO<sub>2</sub> are emitted only for the logistics flows taken in consideration.

The aggregated model can be useful for planning purposes. For instance, change in the final demand of assembled seats generates a change in transportation inputs and pollutant emissions. Different logistics service can change intermediate coefficients as well as improvement in the technology of the transportation system can modify output coefficients and reduce pollutant emissions. As an example, the increase of 10% of the final demand of assembled seats in a year

can result in the growth of CO<sub>2</sub> emission caused by transportation comparable with the CO<sub>2</sub> emission required to produce 9.5 MWh.

The disaggregated model is now considered to compare logistics flows in the actual versus four cases based on different coordination policies of logistics flows. They are:

- Case MD: Pure market and period-independent policy, and deterministic flows;
- Case MS: Pure market and period-independent policy, and stochastic flows;
- Case HD: Pure hierarchy and period-independent, and deterministic flows;
- Case HS: Pure hierarchy and period-independent, and stochastic flows.

If all  $X_{sd}$ , referred to the time period of one day, are deterministic (cases MD and HD) or Poisson random (cases MS and HS) variables having deterministic and average values, respectively, reported in Table 4, the impact of coordination policies on performance measures related to logistics flows is shown in Table 11. Results are compared also for different values of C, namely 12 m<sup>3</sup>, 18 m<sup>3</sup>, 24 m<sup>3</sup>, 30 m<sup>3</sup>, and 36 m<sup>3</sup>.

		C = 12 m <sup>3</sup>	C = 18 m <sup>3</sup>	C = 24 m <sup>3</sup>	C = 30 m <sup>3</sup>	C = 36 m <sup>3</sup>
Case MD	N <sub>jk</sub> [trips/week]	168.0	126.0	102.0	78.0	66.0
	A <sub>jk</sub>	0.85	0.75	0.72	0.76	0.73
	z <sub>Tj</sub> [km/week]	1080	816	672	456	408
	a <sub>Tj</sub> [km/m <sup>3</sup> ]	0.63	0.48	0.39	0.27	0.24
Case MS	E(N <sub>jk</sub> ) [trips/week]	165.6	121.2	97.2	73.8	67.2
	E(A <sub>jk</sub> )	0.85	0.78	0.74	0.74	0.71
	E(z <sub>Tj</sub> ) [km/week]	1068	774	624	492	420
	a <sub>Tj</sub> [km/m <sup>3</sup> ]	0.62	0.45	0.37	0.29	0.25
Case HD	N <sub>jk</sub> [trips/week]	144.0	96.0	72.0	60.0	48.0
	A <sub>jk</sub>	0.99	0.99	0.99	0.95	0.99
	z <sub>Tj</sub> [km/week]	936	624	468	390	312
	a <sub>Tj</sub> [km/m <sup>3</sup> ]	0.55	0.37	0.27	0.23	0.18
Case HS	E(N <sub>jk</sub> ) [trips/week]	145.2	97.8	74.4	59.4	50.4
	E(A <sub>jk</sub> )	0.98	0.97	0.96	0.95	0.94
	E(z <sub>Tj</sub> ) [km/week]	942	636	480	390	330
	a <sub>Tj</sub> [km/m <sup>3</sup> ]	0.55	0.37	0.28	0.23	0.19

Table 11. Logistics performance measures for the four cases of coordination policies and different values of C.

As a general result, pure hierarchy cases show better performance than pure market cases. However, we are not considering other operations performance measures that can benefit from market conditions (i.e. responsiveness).

Comparing the actual case (Table 7) with the MD, MS, HD, and HS corresponding cases (i.e. C=24 m<sup>3</sup>), we observe that the actual case shows performance values closer to HD and HS than to MD and MS. Then, the actual case is far from pure market operation conditions. This result is coherent with the fact that in the actual case suppliers of cut polyurethane take care of transportation. As a consequence, a kind of optimization has to be expected from the supply side. In Figure 5 logistics performance measures are depicted to point out how the actual case is far from the best and worst theoretical cases for each performance.

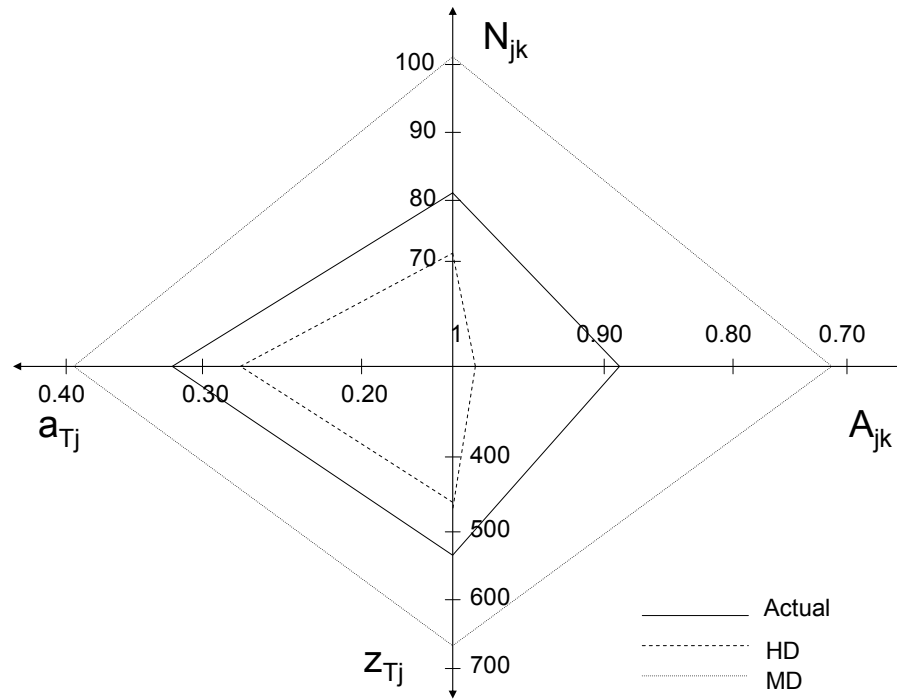


Figure 5. Logistics performance measures for  $C=24 \text{ m}^3$ : actual vs. theoretical cases.

Uncertainty affects logistics performance. The most interesting result is that in the pure market cases it reduces  $a_{Tj}$  only for low values of  $C$  whereas  $a_{Tj}$  increase for high values of  $C$ . It doesn't show any effect in the pure hierarchy case. The ratio between the average quantity daily transported and  $C$  seems to affect performance as it is possible to observe comparing deterministic versus stochastic corresponding cases for different values of  $C$ . Moreover, as  $C$  increases some benefits can be obtained in terms of performance. However, as  $C$  increases, being the asymptotic value of  $N_{jk}$  equal to  $N_{sd}$  for MD and MS cases and one for HD and HS cases, greater benefits are expected in the latter rather than in the former cases.

More in-depth considerations are required to take account of the trade-off between internal operations and external logistics flows management for each process involved.

Pollutant emissions can be evaluated for different coordination policies and values of  $C$ . Results are shown in Table 12.

For  $C=24 \text{ m}^3$ , HD is the best case for pollutant emissions. It is worthwhile to consider that emission reductions of approximately 30% result when a pure hierarchy coordination policy substitutes a pure market policy. For the same coordination policy, while some benefits in logistics performance can be obtained increasing  $C$ , from the pollution point of view significant benefits arise if smaller load trucks are adopted (see  $C=12 \text{ m}^3$ ).

So, a well-known trade-off problem can be considered balancing logistics and pollution performance.

In this case study, only transportation pollutant emissions have been considered being this paper focused on transportation modelling only.

		C = 12 m <sup>3</sup> (<3.5 t)	C = 18 m <sup>3</sup> (>3.5 t)	C = 24 m <sup>3</sup> (>3.5 t)	C = 30 m <sup>3</sup> (>3.5 t)	C = 36 m <sup>3</sup> (>3.5 t)
Case MD	NO <sub>x</sub>	1188	5874	4836	3282	2934
	CO	64.8	2448	2016	1368	1224
	CO <sub>2</sub>	270000	571200	470400	319200	280200
	PM <sub>10</sub>	270.0	367.2	302.4	205.2	183.6
Case MS	NO <sub>x</sub>	1356	6480	4494	3630	3024
	CO	73.8	2700	1872	1512	3542.4
	CO <sub>2</sub>	307800	630000	436800	352800	344400
	PM <sub>10</sub>	307.8	405.0	280.8	226.8	221.4
Case HD	NO <sub>x</sub>	1032	4494	3372	2808	2244
	CO	56.4	1872	1404	1170	936
	CO <sub>2</sub>	234000	436800	327600	273000	218400
	PM <sub>10</sub>	234.0	280.8	210.6	175.8	140.4
Case HS	NO <sub>x</sub>	1038	4578	3456	2808	2376
	CO	56.4	1908	1440	1170	990
	CO <sub>2</sub>	235800	445200	336000	273000	231000
	PM <sub>10</sub>	235.8	286.2	216.0	175.8	148.8

Table 12. Pollutant emissions [g/week] for the different cases of coordination policies and for the different values of C.

## 6. CONCLUSIONS

The relevance of logistics for industrial cluster is increasing as the phenomenon of globalization progresses. The need to analyze logistics flows is stressed by the impact of logistics performance on the competitiveness of companies located in the cluster area and of the cluster as a whole.

In this paper the logistics flows of the cluster are modelled using enterprise input-output approach. An aggregated model has been developed to account for transportation in a cluster. All transportation inputs required by a specific production process to acquire primary inputs and to deliver output are evaluated as well as their impact in terms of wastes (air pollution).

A disaggregated model is then proposed to compare the coordination policy of transportation flows in the actual case versus the different coordination policies ranging from pure hierarchy to pure market.

Models have been applied to the case study related to an Italian cluster producing leather upholstery.

In the case study, hierarchy coordination policies show better results than market ones. However, the trade-off between internal operations and external logistics flows management has not been considered. In fact, logistics performance measures evaluated do not include measures related to internal operations management of each micro-process. However, such performance measures can be considered if time and stocks are modelled.

The impact of uncertainty on logistics performance seems to depend on the ratio between C and the average quantity flowing between micro-processes. In the case study, in some range of values of C stochastic flows allow better results than deterministic ones.

Finally, as C increases, greater benefits are expected in the pure hierarchy rather than in pure market coordination policies.

Pollution caused by transportation is also evaluated. The impact of coordination policies on pollution's emissions is measured. The most interesting result is that less pollution is obtained increasing C values but a significant reduction can arise when trucks with a smaller maximum load are adopted. In this case, the benefit results because of significant lower emissions (output coefficients) of the transportation mean.

As a consequence, a well-known trade-off problem can be analysed balancing logistics and pollution performance using the proposed models. More general trade-offs can be investigated by the developed models being this paper focused on transportation modelling only.

The proposed approach can be easily extended to context different from industrial clusters where a network of processes requires transportation. However, in this case coefficients need to be monitored in order to update them any time a change in technology occurs.

## REFERENCES

- Albino, V., Izzo, C., Kühtz, S. (2002) Input-Output Models for the Analysis of a Local/Global Supply Chain, *International Journal of Production Economics*, 78, pp. 119-131.
- Albino, V., Dietzenbacher, E., Kühtz, S. (2003) Analyzing Material and Energy Flows in an Industrial District using an Enterprise Input-Output Model, *Economic Systems Research*, 15, pp. 457-480.
- APAT (2003) Le emissioni atmosferiche da trasporto stradale in Italia, [<http://www.sinanet.apat.it>].
- Bamford, C.G. (2001) *Transport Economics*, 2nd edition (Oxford: Heinemann).
- Commission of the European Communities (2001) *European Transport Policy for 2020: Time to Decide* (Luxembourg: Office for Official Publications of the European Communities) [[http://www.europa.eu.int/comm/energy\\_transport/en/lb\\_en.html](http://www.europa.eu.int/comm/energy_transport/en/lb_en.html)].
- Cortright, J. (2001) How will changes in information technology change the demand for freight transportation and industrial location? *Roundtable on E-Freight: Metropolitan Implications*, March 9, Portland, OR.
- European Energy Agency (2004) *EEA signals 2004, A European Environment Agency update on selected issues* (Copenhagen: European Energy Agency).
- Gosso, M. (2005) Trasporto merci e sviluppo sostenibile: concreta opportunità o moderna utopia?, *Economia e Management*, 5, pp. 95-111.
- Grubbström, R.W., Tang, O. (2000) An Overview of Input-Output Analysis Applied to Production-Inventory Systems, *Economic Systems Research*, 12, pp. 3-25.
- Hesse, M., Rodrigue, J.-P. (2004) The Transport Geography of Logistics and Freight Distribution, *Journal of Transport Geography*, 12, pp. 171-184.
- Krugman, P. (1991) *Geography and trade* (Cambridge, MA: MIT Press).
- Lattarulo, P. (Ed) (2001) *Logistica e trasporti nel distretto industriale di Prato. Anello debole o fattore strategico di crescita?* (Milano: Angeli).
- Lin, X., Polenske, K.R. (1998) Input-Output Modelling of Production Processes for Business Management, *Structural Change and Economic Dynamics*, 9, pp. 205-226.
- Marangoni, G., Colombo, G., Fezzi, G. (2004) Modelling Intra-Group Relationships, *Economic Systems Research*, 16, pp. 85-106.
- Marangoni, G., Fezzi, G. (2002) I-O for Management Control: The Case of GlaxoSmithKline, *Economic Systems Research*, 14, pp. 245-256.
- Markusen, A. (1996) Sticky places in slippery space: A typology of industrial districts, *Economic Geography*, 72, pp. 293-313.

- Miller, R.E., Blair, P.D. (1985) *Input Output Analysis: Foundations and Extensions* (Englewood Cliffs, NJ: Prentice Hall).
- Piore, M., Sabel, C. (1984) *The Second Industrial Divide: Possibilities for Prosperity* (New York, NY: Basic Books).
- Polenske, K.R. (1997) Linked System of Enterprise, Regional, National Input-Output Accounts for Policy Analysis, in: M. Chatterji (Ed) *Regional Science: perspectives for the future*, (London: Macmillan).
- Porter, M.E. (1989) *The competitive advantage of nations* (New York, NY: Free Press).
- Porter, M.E. (1998) Clusters and the new economics of competition, *Harvard Business Review*, 76(6), pp. 77-90.
- Stone, D. (1969) Input-Output Analysis and the Multi-Product Firm, *Financial Analysis Journal*, 25, pp. 96-102.
- Tang, X., Elbrond, J., Li, X. (1994) Some Applications of Input-Output Analysis in a Gold Mine, *Economic Systems Research*, 6, pp. 435-447.