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Hierarchical model to optimize performance in logistics policies: multi attribute analysis

Fabio De Felice[a] , Antonella Petrillo[b] , b[*]

[a,b], *University of Cassino, Cassino (FR), 03043, Italy*

Abstract

The purpose of this paper is to propose a new application methodology to evaluate the best inventory strategy through the use of an integrated approach based on Analytic Hierarchy Process (AHP) and Simulation. Our specific aim is to applying an integrated multicriteria decision making model based on AHP and simulation to improve inventory management and reverse logistics management in order to reduce total supply chain costs. The application methodology, which is loosely based on Simulation approach, incorporates the AHP approach to delineate and rank the relative importance weight of expressed judgments to analyze global supply chain decisions. Different inventory control policies to be used in a supply chain with products return are presented. Definitely AHP and simulation model is used in order to investigate and compare the behavior of the inventory control policies in terms of total supply chain costs.

Keywords: AHP, Modeling & Simulation, Reverse Logistics, Inventory Control Policies, Products Returns.

1. Introduction

Over the years, researchers and practitioners have developed and proposed numerous planning and control methods to integrate the return flow of used products into the producers' material management. In fact product recovery (repair, refurbishing, remanufacturing) is receiving increasing attention. In the past, engagement in recovery activities was often driven by legislation or by associated environmentally friendly image. But nowadays, the main reason for companies to become involved with product recovery is economical. Being active in product recovery reduces the need for virgin materials and thus leads to reduced costs (Teunter, 2004). In this context, it seems that the major difficulty is mainly due to the considerable uncertainty with respect to timing, quantity and quality of the return flow (that is often hard to influence by the producer) and to the integration of reverse logistics operations.

It is very important solve this problem because product recovery activities such as recycling, refurbishing and direct reuse are becoming integral to manufacturing supply chains. In today's manufacturing climate, producers are paying increased attention to the need for product recovery activities. Producers are looking for efficient ways to integrate reverse logistics into their supply chains, primarily to recover economic value from returned products, and to reduce disposal costs for non- recoverable waste (Realff, Ammons and Newton, 2000). From this point of view inventory

[*] Corresponding author. Tel. + 39-0776-299-4350 fax. +39-0776-299-4349
Email address: a.petrillo@unicas.it

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decisions are high risk and high impact for supply chain management. Without a proper inventory management, lost sales and customer dissatisfaction may occur. Likewise, inventory planning is critical to manufacturing. Material or component shortages can shut down a manufacturing line or force modification of production schedules, which creates additional cost and potential finished goods shortages. Just as out of stock occurrences can disrupt planned marketing and manufacturing operations, inventory overstocks also create operating problems and additional costs.

Management of inventory resources requires an understanding of the principles, cost, impact, and dynamics. When formulating inventory management policy, specific inventory relationships must be considered. The main key indicators of inventory performance are costs, service level and average on hand inventory. In this context a modern supply chain design needs to deal with the trade-offs between a variety of factors, including for example location and associated (fixed) operating costs of distribution centers (DCs), total transportation costs, and storage holding.

To improve supply chain inventory management we decided to propose a new application methodology based on the combined use of Analytic Hierarchy Process (AHP) and Modeling & Simulation. We, also describe the benefits of the use an integrated approach and the added advantages of using AHP in order to maximize shareholder value. The AHP model provides a way to detect interactions between various high-level decision factors, some of which are not easily quantifiable.

The paper is organized as follows: section 2 surveys the existing literature about AHP and Simulation applied to supply chain inventory systems and reverse logistics. Section 3 describes the proposed methodology together with an application example based on a real case study. Finally in the last section 4, conclusions and research guidelines for future work are summarized.

2. State of art overview

In this paragraph we briefly reviewed the researches which are most relevant for our work. In particular we analyzed publications regarding Analytic Hierarchy Process (AHP) apply to inventory management and reverse logistics problems and publications regarding inventory management and reverse logistics based on Modelling & Simulation approach.

AHP is a multiple criteria decision-making tool developed by prof. T.L. Saaty that has been used in almost all the applications related with decision-making (Vaidya and Kumar, 2006). The specialty of AHP is its flexibility to be integrated with different techniques like Linear Programming, Quality Function Deployment, Fuzzy Logic, etc (De Felice and Petrillo, 2010). We note that AHP is one of the most regarded techniques to inventory management and it was proposed independently by many authors. Inventory Management typically involve the selection of the most appropriate project delivery method as key project success factor that can be addressed using AHP (Korpela, Lehmusvaara and Nisonenc, 2007), (Al Khalil, 2002) or it involve vendor selection (Tam and Tummala, 2001). To identify an optimal order allocation strategy (Gajapal, Ganesh and Rajendran, 1994) or a proper classification system (Cakir and Canbolat, 2008). AHP method has been utilized by several authors.

In reverse logistics research AHP has been used by Staikos and Rahimifard (2007) to develop a decision model for product recovery of shoes. Kannan (2008) created a multicriteria decision making model using AHP and fuzzy analytical hierarchy process to evaluate collection centers for product recovery in the tire manufacturing industry in India. In another study, Fernández and Kekäle (2008) proposed a conceptual model using Delphi and AHP as an illustration of model-building under multiple conflicting priorities. Efendigil (2008) used fuzzy AHP to determine selection of third-party logistics providers in the presence of vagueness. Pochampally and Gupta (2008) also used fuzzy AHP in a reverse supply chain network study to select the most economical product to reprocess, identifying potential recovery facilities, and determining locations to minimize cost.

Many research works identify, as critical parameters in defining the optimal inventory control policies, the customers' demand pattern, the lead times and the information sharing. Most of the cases propose a comparative analysis of different operative scenarios or configurations (Modelling & Simulation is often used as what-if analysis or cognitive tool). The influence on supply chain performance of the most applied inventory policies (economic order quantity with stationary demand and dynamic economic lot size with non-stationary demand) is reported in Zipkin (2000). Bertsimas and Thiele (2006) propose an approach that takes into consideration demand uncertainty and provides as results insights about the optimal policy (considering an optimal tradeoff between performance and protection against uncertainty).

Other works related to inventory systems are reported in Zhao (2004) that presented a modified economic ordering quantity for a single supplier– retailer system in which production, inventory and transportation costs are all considered. Conjoint studies for the network planning are presented by Wasner and Zapfel (2004) although they are interested on solving the location problem together with the routing problem. Simulation provides an alternative method for detailed analysis of the complex real world systems such as the procurement. Given that a simulation model is well-suited for evaluating dynamic decision rules under 'what-if'' scenarios, a few attempts have been made to develop simulation models to improve procurement performances."

According to Chwif (2006) 'Simulation models are also a very popular approach for procurement process related problems. This simulation approach allows different combinations of decision strategies to be evaluated and thus provide adaptively necessary for efficient use in dynamic, on-line environments.

The state-of-the-art overview highlights that the AHP has never been used in combination with Simulation to investigate inventory management problems along the supply chain. Thus, in such a context, our research differs from previous work mainly because we consider an integrated approach based on multi criteria methodology and simulation approach.

3. Methodological Approach

In this paragraph an application methodology based on AHP and simulation is presented. The Analytic Hierarchy Process (AHP) was developed by Thomas Saaty (1980) in the early 1970s. The strength of the AHP approach lies in its ability to structure a complex, multi attribute, multi person and multi period problem hierarchically. In addition, it can also handle both qualitative (through representing qualitative attributes in terms of quantitative values) and quantitative attributes. Pairwise comparisons of the elements (usually, alternatives and attributes) can be established using a scale indicating the strength with which one element dominates another with respect to a higher level element. This scaling process can be translated into priority weights (scores) for comparison of alternatives.

The general approach followed in AHP is to decompose the problem and to make pairwise comparisons of all the elements (attributes, alternatives) at a given level with respect to the related elements in the level just above. AHP consists of three stages of problem solving decompositions, comparative judgments and synthesis of priorities. The degree of preference of the decision maker in the choice for each pairwise comparison is quantified on a scale of 1 to 9, and these quantities are placed in a matrix. A preference of 1 indicates equality between two items while a preference of 9 (absolute importance) indicates that one item is 9 times larger or more important than the one to which it is being compared. This scale was originally chosen, because in this way comparisons are being made within a limited range where perception is sensitive enough to make a distinction.

AHP usually involves three stages of problem solving: the principles of decomposition, comparative judgments, and synthesis of priority. The decomposition principle calls for constructing a hierarchy or network to represent a decision problem. The overall objective is located at the top of the hierarchy, and the criteria, sub criteria, and alternatives are placed at each descending level of the hierarchy. Once the matrix of pairwise comparisons has been developed, one can estimate the relative priority for each of the alternatives in terms of the specific criteria. Preferences derived from a criteria or sub criteria matrix are used to calculate a composite weight for each alternative. This part of AHP is referred to as synthesis. This enables AHP to obtain not only the rank order of the alternatives, but also their relative standings measured on a ratio scale.

The alternative with the highest overall rating is usually chosen as a final solution. Finally, AHP synthesizes these judgments to provide a quantitative measure of value. A judgment or comparison is the numerical representation of a relationship between two elements that share a common parent (Saaty, 2001). In mathematical terms, the verification of consistency is expressed through the calculation main eigenvalue λ_{max}: if the value is n then the matrix (of rank n) is consistent. More λ_{max} is equal to the number n more consistent is the result. The deviation of the coherence is shown in Equation 1 with the index of consistency (I.C.):

$$I.C. = (\lambda_{max} - n)/(n-1) < 0.10 \qquad (1)$$

where n is the number of components evaluated in the pairwise comparison matrix, and λ_{max} is the largest eigenvalue characterizing the previous matrix. Inconsistency may be considered a tolerable error in measurement only when it is of a lower order of magnitude (10 percent) than the actual measurement itself; otherwise the inconsistency would bias the result by a sizable error comparable to or exceeding the actual measurement itself (Saaty, 2005).

In Figure 1 the steps of the application methodology are illustrated.

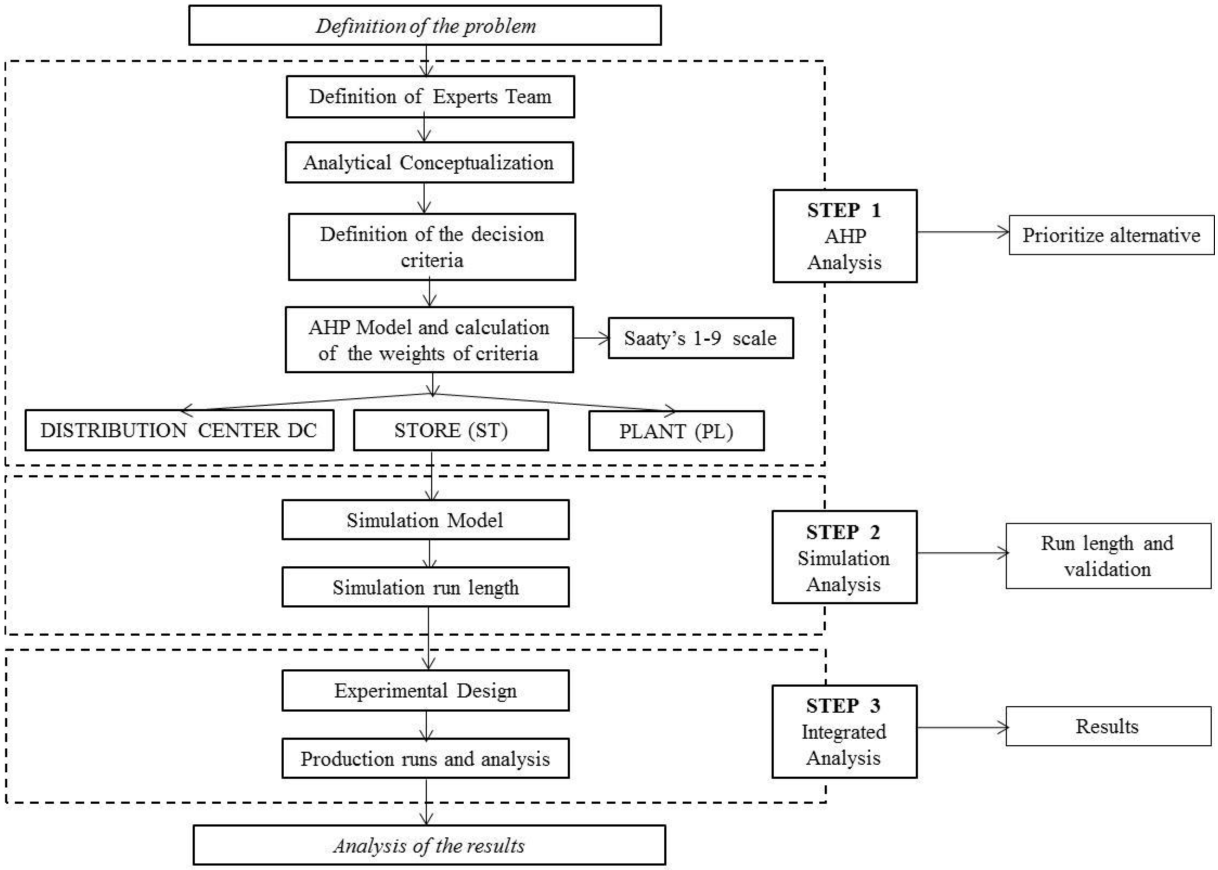

Fig. 1. Steps of proposed application methodology

3.1. Step 1: AHP Analysis

According to the principles of AHP, the first step in the analysis is to identify the criteria on which the analysis of the alternative is based. The criteria are then structured into a hierarchical form to represent the relationships between the identified factors. The main step in using the AHP is to derive priorities for each element in the hierarchy. The priorities are set by comparing each set of elements with respect to each of the elements in a higher level. In a typical AHP-hierarchy, the alternatives to be analysed would be added to the lowest level of the hierarchy. The alternatives would then be analysed in a pairwise manner with regard to each subcriterion in order to derive the overall priorities for the decision alternatives.

Definition of Experts Team. In order to work correctly to determine criteria and alternatives, an inter functional team was set up. It was composed of 2 delegates from the 5 main departments of the firm (commercial, technical, production, logistics and purchase departments). The solutions are designed in groups by using morphological analysis and the brainstorming technique. This team gave a description of the needs that a customer expects to satisfy. This procedure was repeated for the different groups. After sharing the list, the groups were set up again, and together defined a pooled ranking (De Felice, Petrillo, and Cooper, 2012).

Analytical Conceptualization. Figure 2 shows the supply chain conceptual model: let be N the number of supply chain echelons and N_k the number of node in the k-th supply chain echelon. In addition to the direct flow of items the supply chain includes also a reverse flow with two options: remanufacturing and disposal. Remanufactured items join the direct flow in any of the N supply chain echelon. Note that upstream and downstream supply chain boundaries respectively are outside suppliers and customers. Our model considers a three echelons supply chain with items return flows (including the remanufacturing and disposal options) and compares the behavior of the inventory control policies in terms of total cost.

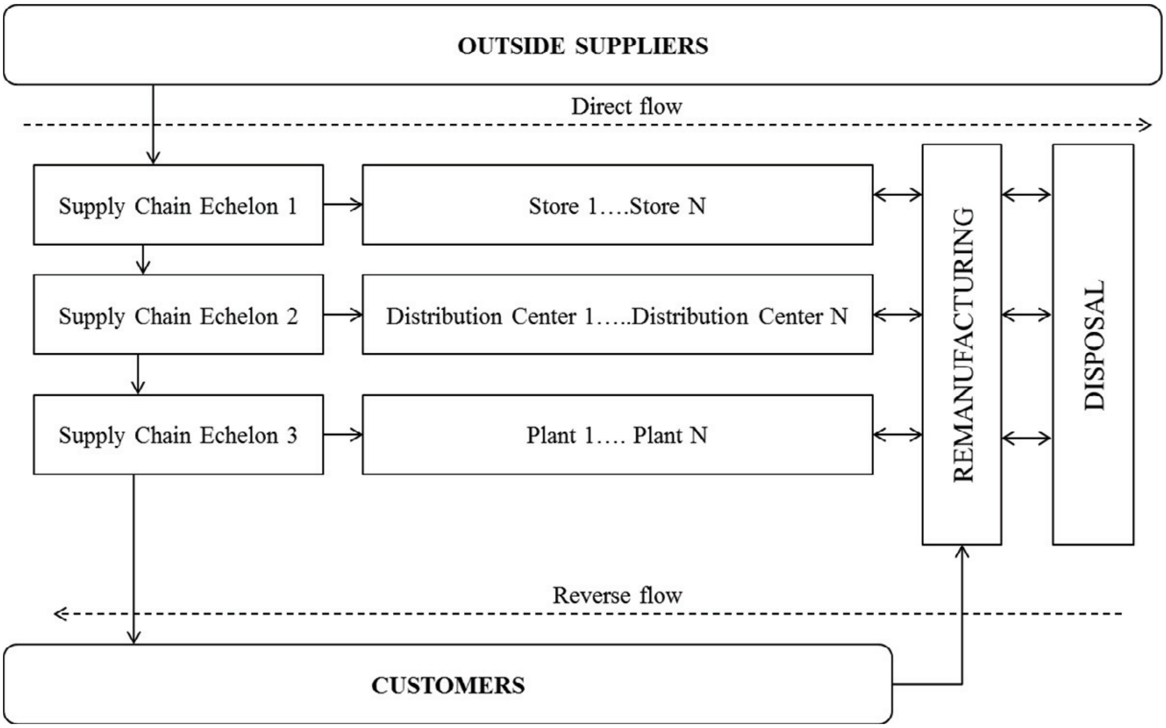

Fig. 2. Supply Chain conceptual model considered in the application example

The arrival process of customers demand at stores is Poisson; similarly the items return process to the remanufacturing area is Poisson. Inventory management within supply chain nodes is based on inventory control policies that consider both new items (shipped by upstream nodes) and remanufactured items. Stockouts occurrences at each supply chain node can be completely backordered, partially backordered or registered as lost sales based on managers' decision. The inventory management at each supply chain node has to answer to five different questions: (i) how often to review the stock status; (ii) when to order new items; (iii) quantity of new items; (iv) quantity of remanufactured items; (v) quantity of items to dispose. Note that, where not directly specified, the subscripts i, j and k respectively refer to the supply chain echelon i, echelon node j and item k. Our goal is to compare the behavior of the inventory control policies presented above in terms of total supply chain costs. This approach requires to specify inventory costs (including ordering costs, holding costs for new and remanufactured items, shortage costs, backordering costs), remanufacturing costs and disposal costs. Equation 2 evaluates the total expected annual cost (TC) for a generic item k at the echelon node j, supply chain echelon i:

$$\begin{aligned} TC_{ijk} &= OC_{ijk} m_{ijk} + v_{ijk} r_{ijk} \Delta T_{ijk} + (1 - P1_{ijk}) B1_{ijk} v_{ijk} n_{ijk} \\ &+ P1_{ijk} B2_{ijk} v_{ijk} n_{ijk} + rv_{ijk} rr_{ijk} \Delta T^{(r)}_{ijk} + (1 - P2_{ik}) rc_{ik} rn_{ik} \\ &+ P2_{ik} dc_{ik} rn_{ik} \end{aligned} \qquad (2)$$

where:
ΔT_{ijk}, total time an item is held on the warehouse shelves (serviceable inventory);
m_{ijk}, number of orders over 1 year for the item;
n_{ijk}, number of unit short over 1 year;
$\Delta T^{(r)}_{ijk}$,, total time an item is held on the warehouse shelves (recoverable inventory);
rn_{ik}, number of recoverable unit over 1 year, eventually intended for remanufacturing process;
OC_{ijk}, fixed cost per order;
$B1_{ijk}$, fractional charge per unit short (used to evaluate shortage cost);
$B2_{ijk}$, fractional charge per unit short (used to evaluate backorder costs);

$P1_{ijk}$, fractional part of stockouts backordered;
$P2_{ik}$, fractional part of disposed units;
v_{ijk}, unit value cost, expressed in €/unit;
r_{ijk}, inventory holding cost expressed in €/(€*year);
rr_k, inventory holding cost for the recoverable item;
rv_k, unit value cost (expressed in €/unit);
rc_{ik}, unit remanufacturing cost;
dc_{ik}, disposal cost.

Then four different inventory control policies to be used in a supply chain with products return are presented:

- Order-Point, Order-Quantity (s, Q) inventory control policy. This inventory control policy is based on continuous review; a fixed quantity Q_{ijk} is ordered when the inventory position, $IP_{ijk}(t)$ drops the order point $s_{ijk}(t)$. In this case $s_{ijk}(t)$ and Q_{ijk} are determined according to equations for simultaneous determination of s and Q for faster moving items.
- Order-Point, Order-Up-to-Level (s, S) inventory control policy. As in the previous case the inventory is reviewed continuously and an order is placed whenever the inventory position, $IP_{ijk}(t)$, drops the order point $s_{ijk}(t)$. A variable quantity is ordered to raise $IP_{ijk}(t)$ to the order-up-to-level $S_{ijk}(t)$.
- Periodic Review Order-Up-to-Level (R, S) inventory control policy. This inventory control policy is based on periodic review; every R units of time the inventory is checked and an order is placed that raises the inventory position, $IP_{ijk}(t)$, to the order-up-to-level $S_{ijk}(t)$.
- Periodic Review, Order-Point, Order-Up-to-Level (R, s, S) inventory control policy. As for the (R, S) inventory control policy, this policy is based on checking periodically the inventory. Every R units of time the inventory position $IP_{ijk}(t)$ is checked. If $IP_{ijk}(t)$ is below the order point $s_{ijk}(t)$ a variable quantity is ordered to raise the inventory position to the order-up-to-level $S_{ijk}(t)$.

Note that our treatment do not consider most of the common assumptions hold in most of the approaches proposed in literature. Specifically we are dealing with a multi-echelon system with items returns (with the double options: remanufacturing and disposal), supposing that the remanufactured items can enter the normal flow of items at any stage of the supply chain; remanufactured items are good as new items and economically more convenient but the Lead Time of the remanufactured items is different from zero and different from the Lead Time of the new items; items disposal is allowed at any stage of the supply chain.

According to the supply chain conceptual model a single network node is considered as store (ST), distribution center (DC) or plant (PL). A supply chain begins with one or more PLs and ends with one or more STs. STs usually satisfy market demand or demand from other STs, DCs satisfy STs demand or demand from others DCs and PLs satisfy DCs demand and demand from other PLs. As concerns the inventory management, all the inventory control policies are implemented within each supply chain node (ST, DC, PL). Obviously the inventory models take into account both the traditional forward-oriented product flow as well as the reverse product flow.

Definition of the decision criteria. As we said the firm management has highlighted three main value added policies: store (ST), distribution center (DC) and plant (PL). These general strategies have been decomposed in criteria cluster and following a description list of the most important variables and information, is proposed (see Table 1).

Table 1. Criteria and Sub Criteria description

CLUSTER	NODES
CC – Cluster Criteria	C1. Plants
	C2. Distribution Center
	C3. Plant
CT - Cluster Time	S1. Total time an item is held on the warehouse shelves (serviceable inventory)
	S2. Total time an item is held on the warehouse shelves (recoverable inventory)
CV - Cluster Value	S3. Fixed cost per order
	S4. Unit value cost, expressed in €/unit
	S5. Inventory holding cost expressed in €/(€*year)
	S6. Unit value cost (expressed in €/unit)
	S7. Unit remanufacturing cost
	S8. Disposal cost
	S9. Inventory holding cost for the recoverable item

CP - Cluster Products	S10. N° of orders over 1 year for the item
	S11. N° of unit short over 1 year
	S12. N° of recoverable unit over 1 year
	S13. Fractional charge per unit short (used to evaluate shortage cost)
	S14. Fractional charge per unit short (used to evaluate backorder costs)
	S15. Fractional part of stockouts backordered
	S16. Fractional part of disposed units
CI - Cluster Input Parameters	S17. Inventory policies
	S18. Demand forecast
	S19. Demand intensity
	S20. Demand variability
	S21. Lead times
	S22. Inter-arrival times
	S23. N° of items
	S24. N° of stores
	S25. N° of distribution centers
	S26. N° of plants
CA - Cluster Alternatives	A1. Inventory Costs
	A2. Remanufacturing Costs
	A3. Disposal Costs

AHP Model and calculation of the weights of criteria. Here below in Figure 3 is the AHP Model proposed.

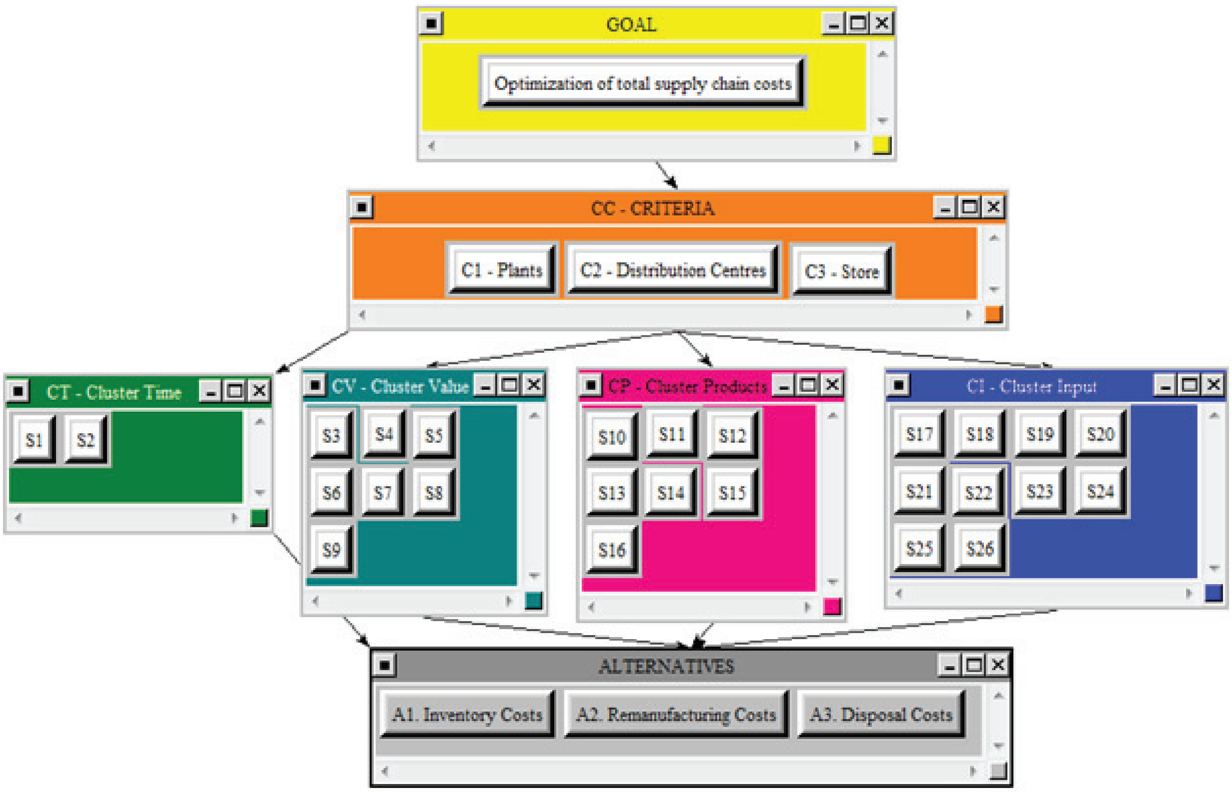

Fig. 3. The AHP Model

After the construction of the model the process is started from the pair-wise comparison matrix as shown in Table 1. The following Tables (from 2 to 6) AHP results are shown for global priorities regarding alternatives and different clusters.

Table 2. Results for global priorities regarding Alternatives

Alternatives	**Values**
A1. Inventory Costs	0.834469
A2. Remanufacturing Costs	0.788202
A3. Disposal Costs	1.000000

Table 3. Results for global priorities regarding CT - Cluster Time

CT - Cluster Time	**Values**
S1	0.45000
S2	0.55000

Table 4. Results for global priorities regarding CV - Cluster Value

CV - Cluster Value	**Values**
S3	0.09156
S4	0.09719
S5	0.10398
S6	0.11401
S7	0.15113
S8	0.21588
S9	0.22624

Table 5. Results for global priorities regarding CP - Cluster Products

CP - Cluster Products	**Values**
S10	0,21765
S11	0,09266
S12	0,14254
S13	0,12234
S14	0,11298
S15	0,10286
S16	0,19127

Table 6. Results for global priorities regarding CI - Cluster Input Parameters

CI - Cluster Input Parameters	**Values**
S17	0.06521
S18	0.11355
S19	0.13841
S20	0.16110
S21	0.09598
S22	0.09691
S23	0.09245
S24	0.07880
S25	0.07880
S26	0.07880

3.2 Step 2: Simulation Analysis

The management of inventory along the whole supply chain is usually affected by a wide range of factors. Simulation has been widely recognized as the best and most suitable methodology for investigation and problem-solving in real world complex systems in order to choose correctly, understand why, explore possibilities, diagnose problems, find optimal solutions, train personnel and managers, and transfer R&D results to real systems (Banks, 1998). The simulator recreates the logical connections, the flow of items and information among the various nodes of the supply chain. The accuracy and the quality throughout a simulation study are assessed by conducting verification and validation processes. The simulator verification has been made using a dynamic technique (debugging). All the simple++ code written within the simulation model has been debugged, correcting errors and carrying out, as consequence, the simulation model verification. The simulation run length (in order to obtain significant simulation results) has been evaluated by using the mean square pure error analysis (MSPE) for each supply chain node. According to the MSPE theory when multiple performance measures are used then the simulation run length is the longest value evaluated by the mean square pure error analysis (450 days). Finally the validation of the simulation model has been carried out by using the Face Validation technique (De Felice, Petrillo, Longo, and Carlomusto, 2011).

3.3 Step 3: Integrated Analysis

In addition to the actual supply chain configuration, the simulation model adds new features in terms of inventory control policies, market demand pattern, and lead time.

Experimental Design. The development of the simulator starts with a detailed analysis of the supply chain conceptual model implemented within the simulator. According to the supply chain conceptual model a single network node is considered as store (ST), distribution center (DC) or plant (PL). A supply chain begins with one or more PLs and ends with one or more STs. As concerns the inventory management, all the inventory control policies presented in section 3 are implemented within each supply chain node (ST, DC, PL).

Production runs and analysis. Graphic user interface gives to the user/manager the possibility to carry out a number of different what-if analysis by changing supply chain configuration and input parameters (i.e. inventory policies, demand forecast methods, demand intensity and variability, lead times, inter-arrival times, number of items, number of stores, distribution centers and plants, etc.). The application example proposed below aims at comparing the behavior (in terms of total supply chain costs) of the inventory control policies presented in a three-echelons supply chain that includes 6 Plants, 1 Distribution Center, 10 Stores and 20 different items. Three different scenarios are considered:

- all the supply chain nodes use the (s, Q) policy;
- all the supply chain nodes use the (s, S) policy;
- all the supply chain nodes use the (R, S) policy.

The figure 4 shows the total supply chain costs (in K€) in the three scenarios. Note that the best policy in terms of total cost is the (s, S) policy, the worst policy is the (R, S). When all the supply chain nodes use the (s, S) policy the total savings, compared to the use of (s, Q) and (R, S) policies, are respectively 1,415 K€ (about 8%) and 828 K€ (about 5%). It should be noted that the (s, S) policy as defined by authors performs quite well than the (s, Q) policy.

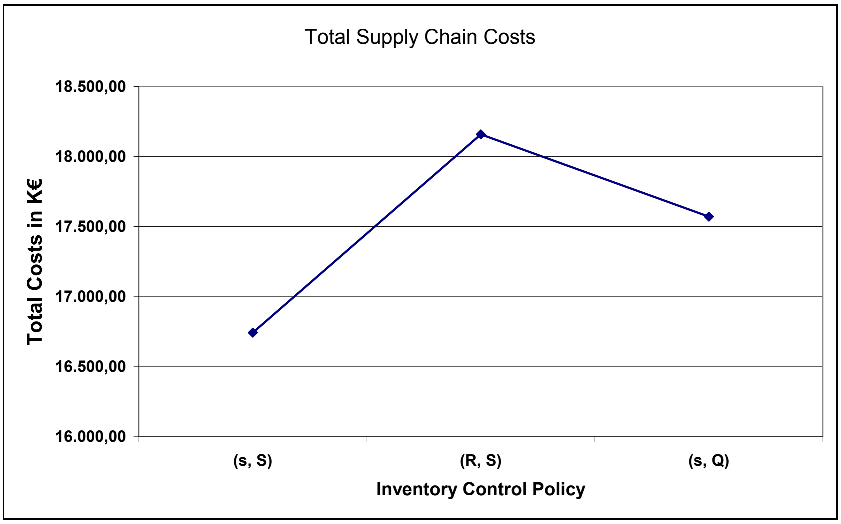

Fig. 4. Total Supply Chain Costs comparison

4. Conclusions and Results

Traditionally decisions made based on simulation models have been the outcomes of complicated statistical analyses and having confidence in them is a subjective matter. In this work we conducted a comprehensive investigation of the inventory systems along the supply chain applying an integrated approach based on Analytic Hierarchy Process a well know multi criteria technique and Simulation. Integrated approaches usually offer improved methodologies to better model real-world complex systems and increase confidence in results analysis outcomes. In particular new methodological approach has the potentials to reduce the impact of statistics in building models in addition to other significant benefits. When incorporate multiple criteria we have a major reasonably simple set of inventory policies. The utilization of AHP provides a way to combine several multiple criteria. AHP generates a consistent measure that can be used for reclassification of inventory items in a simple simulation structure. By using AHP, we involved both qualitative and quantitative attributes. A limitation of the approach is that more managerial time is needed to develop more information for each inventory item. However, the use of multiple criteria analysis can improve the quality and completeness of the inventory analysis. To make the results more manageable the use of AHP can be a powerful ally in supporting the policy development process. Finally we note that in today's manufacturing company, producers are paying increased attention to the need for product recovery activities. It is our aim to propose a further development of the present work applying an integrated multicriteria decision making model based on AHP and simulation including Benefits, Opportunities, Costs and Risks Analysis.

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