MULTICRITERIA METHODOLOGY FOR COLD SUPPLY CHAIN MANAGEMENT: AN APPROACH

Pablo Zubía Aloy , ITENE – Packaging, Transport & Logistics Research Centre. Parque Tecnológico, C/ Albert Einstein, 1 - 46980 Paterna (Valencia) – SPAIN. Phone: +34 96 390 54 00 - Fax. 96 390 54 01 - www.itene.com

Vicente Cloquell Ballester, Universidad Politécnica de Valencia – Departamento de Proyectos de Ingeniería. Camino de Vera, s/n - 46022 Valencia – SPAIN. Phone: +34 96 387 98 60- Fax. 96 387 98 69- www.dpi.upv.es

David Moya Ramírez, ITENE – Packaging, Transport & Logistics Research Centre. Parque Tecnológico, C/ Albert Einstein, 1 - 46980 Paterna (Valencia) – SPAIN. Phone: +34 96 390 54 00 - Fax. 96 390 54 01 - www.itene.com

Andrea Esteve de Santos, ITENE – Packaging, Transport & Logistics Research Centre. Parque Tecnológico, C/ Albert Einstein, 1 - 46980 Paterna (Valencia) – SPAIN. Phone: +34 96 390 54 00 - Fax. 96 390 54 01 - www.itene.com

ABSTRACT

The aim of this paper is to establish the multicriteria decision methodology as a useful tool for the selection of temperature control technologies in the different stages of the cold chain. For this purpose, two different approaches are studied: cold chain requirements and multi-criteria methodologies with similarities to the problem. The relationship between them takes the first step to obtain a modelling solution for this problem.

It is widely known that the key point of any cold supply chain is the control of the temperature during the different stages that form the chain. Unfortunately, the selection of temperature control systems is usually made by taking into account just economical factors instead of using a multi factor criterion. Thus, the selected option turns into a short-time solution that must be redesigned later or even substituted by another technology to accomplish with the requirements that were not taken into account during the selection process. Commonly, there is not such revision and the companies get a semi-operative multi-problematic temperature tracking system not trusted by the workers and whose potential is partially – if not fully-missed.

To avoid this situation, this paper presents the first step in the design of a multi-criterion decision methodology. This is achieved by giving a brief description of a typical cold supply chain, with peculiarities and legal requirements, complemented with a synthetic recompilation of the different temperature control & RFID technologies developed during the last years. With this problem and its requirements already focused, the core of the presented work is an exhaust revision of multi-criterion decision methodologies used for similar decision problems, but approached under the scope of the Cold Supply Chain.

This research will be applied in a following work to two R+D cold chain projects partnered by ITENE: an ice-cream cold chain project funded by Spanish Government –GLOBALOG- and a fresh hake Chile-Spain supply chain studied under the 6th Framework EU Program –Chill-On-. The data extracted from the two selected cold chains will be applied to the multi-criterion decision methodologies here studied, thus selecting the most suitable solution for this problem.

Keywords: Logistics; Multiple Criteria Decision; RFID; Cold Chain; Supply Chain, Traceability

1. INTRODUCTION

The requirement of systems for tracking and tracing food –especially from January 1, 2005-, the high costs of implementation, the lack of information, the short time frame for action and the complexity of organizational processes have turned traceability into a major concern of the industry. However, many companies have transformed traceability into a competitive advantage that offers new possibilities in an interesting market for suppliers of management software and automatic identification solutions.

In recent years, the emergence of new diseases related to food intake has led health authorities to adopt more strict hygiene and quality measures. Thus, since January 1, 2005, the EU regulation 178/2002 introduced mandatory traceability systems that must be implemented in all companies that manufacture, transport, store or distribute food and feed for human or animal consumption.

The second factor to be taken into account under any cold chain scope is the temperature control. Consumption of perishable products and, above all, frozen and chilled products is increasing every day due to the change in the habits of consumers. The ideal scenario for this chain should ensure that the products with special requirements of temperature can reach the final consumer with the best quality for consumption.

2. COLD SUPPLY CHAIN

A cold supply chain is a specific supply chain based on maintaining temperature under control. The two areas where cold supply chain acquires the greatest importance are food and pharmaceutical sectors. Considering the food sector, a cold chain that is kept intact guarantees that the product received after the production, transport, storage and sale steps has not been out of a given temperature range. In the pharmaceutical area, the cold chain includes the full range of elements and activities required to guarantee the immunizing power of vaccines from manufacturing to their delivery to the population. Therefore, the cold supply chain is a vital part of the modern economy that has direct impact on many issues related to food. In today's society, storage and transport temperature control is one of the most widespread practices for conservation of perishable products.

The importance of cold chains in the current economic scene may be inferred from the data provided in Table 2.1 (DBK S.A., 2009). Thus, the cold logistics market in Spain and Portugal in 2008 reached 4,100 million Euros.

Table 2.1. - Main Figures of the logistics cold market in Spain and Portugal

Number of companies:	17.000
Market (million €)	4.100
- Spain: - Portugal:	3.575 525
Market Growth (% var. 2008/2007):	+3,5
- Spain: - Portugal:	+3,3 +5,0
Combined market share of the top five companies (%):	22,7
- Spain: - Portugal:	24,2 16,1

The expected trend for 2010 is a slightly growth in the cold chain market. Hence, technologies that allow continuous temperature monitoring along the supply cold chain may have an important economic impact in the current scenario, based on the savings achieved by ensuring the robustness of this chain. Therefore, selecting the most appropriate monitoring system from the current technology available is a critical decision, where a number of factors, that directly affect applicability, must be scaled.

2.1 The supply chain

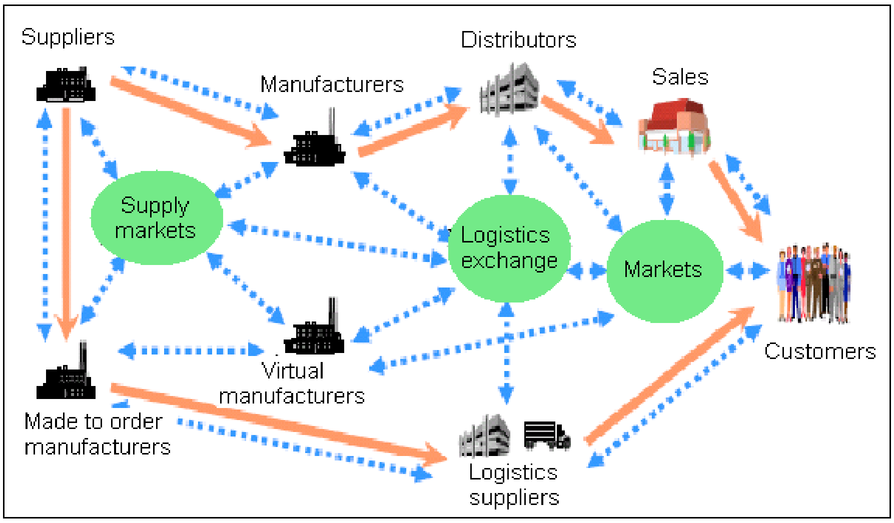

Figure 2.1. Current Supply Chain

The concept of supply chain includes all the processes, activities, actors, technology and physical infrastructure necessary to achieve the transformation of raw materials into finished products and services demanded by the final consumers. However, since the introduction of new concepts in the world of logistics -like Sharing Stocks or Just in Time-, it has evolved into more complex supply chains (Figure 2.1).

2.2. Characteristics of the cold supply chain

The most important aspect of the cold chain is that all operations are carried out under controlled temperature. An example of this chain can be seen in Figure 2.2.

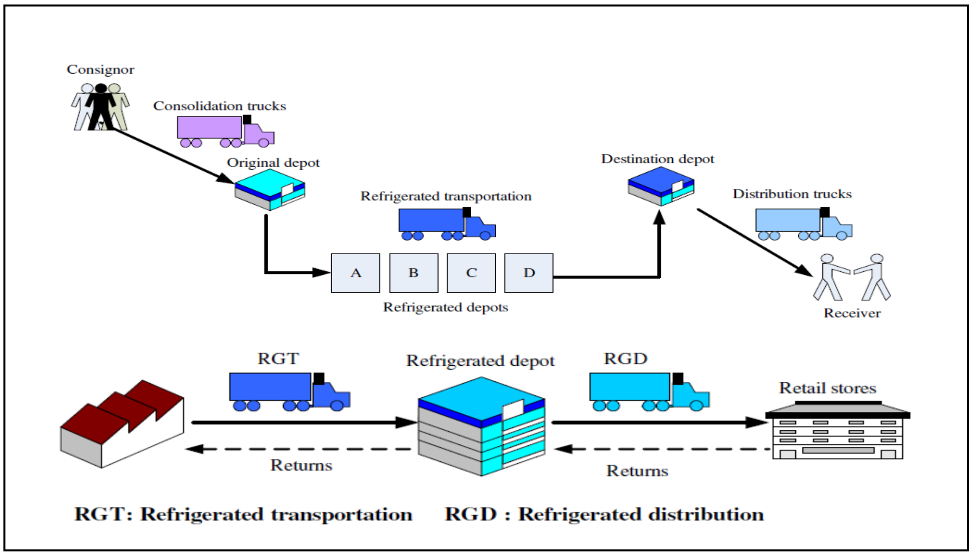

Figure 2.2. Distribution of processes in the cold chain (Kuo, J.-C.; Chen, M.-C., 2009)

The maximum values allowed for this temperature may vary depending on the type of product present in the supply chain. More specifically, they vary according to the effect of a decreasing in temperature on the reduction of the growth rate of microorganisms. Those microorganisms cause the deterioration of each type of refrigerated product and its chemical elements. Therefore, the different types of products are grouped into five types. Depending on the stage of the supply chain, the operating temperature may vary as well (see Table 2.2 below). Operating temperatures for ultra-frozen, frozen and ice cream products are shown in Table 2.3.

Table 2.2. - Operating temperature for refrigerated products

	Type 1	Type 2	Type 3	Type 4	Type 5
Supplier	0^0C-5^0C	1^0C-8^0C	8^0C-12^0C	10^0C-14^0C	12^0C-16^0C
Transport	0^0C-5^0C	1^0C-8^0C	8^0C-12^0C	10^0C-14^0C	12^0C-16^0C
Warehouse	0^0C-5^0C	1^0C-8^0C	8^0C-12^0C	10^0C-14^0C	12^0C-16^0C
Shop	0^0C-5^0C	1^0C-8^0C	8^0C-12^0C	10^0C-14^0C	12^0C-16^0C
Consumer	0^0C-5^0C	1^0C-8^0C	8^0C-12^0C	10^0C-14^0C	12^0C-16^0C

Table 2.3. - Temperature of ultra-frozen, frozen and ice cream products

	Storage	Transport	Point of sale
Ultra-frozen	-20^{o} C	-19^{o} C	-18^{o} C
Frozen	-20^{o} C	-19^{o} C	-18^{o} C
Ice cream	-20^{o} C	-20^{o} C or - 21^{o} C	-18^{o} C

2.3. Legal requirements

Legal requirements are demanded due to the extreme sensitivity of the products involved in the cold supply chain and their effects on human health. These are several of all the considerations and good practices (Raspor, P., 2008) that must be taken into account within this type of chain:

1. On January 1, 2005 was established the EU Regulation 178/2002 on implementing mandatory traceability systems.

2. In parallel, temperature controls are required to ensure that products with special temperature requirements can arrive at their best quality.

3. Thus, traceability and temperature control should work complementarily to ensure the food safety.

4. An important pack of legal requirements associated with the cold chain are grouped under the Food Law.

3. TRACEABILITY AND TEMPERATURE CONTROL

Success in controlling the cold supply chain is linked to an appropriate balance between investment in technology -that can ensure traceability and control of their products-, and the profit that its implementation may bring to the company. Therefore, the main goal of traceability in the cold supply chain is to ensure the quality and integrity of the products delivered to the final customers by increasing the level of control and traceability throughout the supply chain. Thanks to this monitoring and identification, an improvement in logistics management, service, and competitiveness of companies involved in the supply chain is achieved. Thus, the selection of a traceability system must be considered a strategic decision for the company (Yoav Sarig, 2003) that can achieve a series of competitive advantages:

1. Ensure the quality and integrity of products.

2. Minimize non-conformities in distribution.

3. Increase the effectiveness of recording temperature systems.

4. Eliminate unnecessary stocks.

5. Improve logistics management, service and, therefore, competitiveness.

3.1. Temperature Control Technologies

The most representative technologies currently available for temperature control are commented in this point. These devices can determine the temperature range of the product specially in the established control points, which usually are located at the critical points of the supply chain, such as loading and unloading, storage and transport. These technologies will determine the singular points in the critical limits that must not be exceeded to ensure that the product is under control, and they also will enhance the implementation of corrective measures on the recorded events.

Thermograph Technology - SPYco.

Spyco is a brand that exemplifies an unlimited number of autonomous temperature loggers called thermographs. These devices are used to monitor and record temperatures for a period of time. They can be used in any sector that requires monitoring and systematic recording of the cold supply chain throughout its length (Figure 3.1).

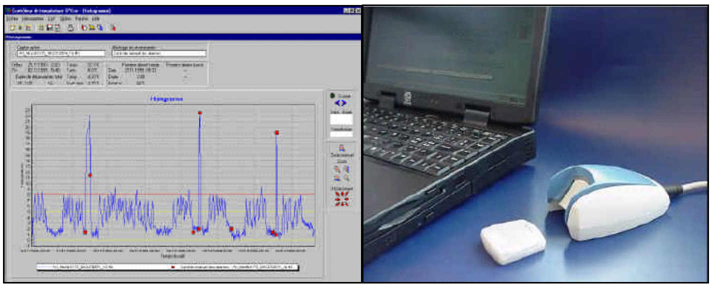

Figure 3.1. SPYCO and graphic device found

Technology Time Temperature Indicator Labels (TTL)

Other devices that can record temperatures at any stage of the process are called Time Temperature indicator Labels (TTL), which are shown in Figure 3.2. They are plane monitoring devices (sticker), which can be stuck to any package to monitor the potential damage to the product due to an excessive exposure to temperatures that differ from the recommended. TTL are activated at the time of installation and they change their colour gradually as time passes; this de-colouration is accelerated in presence of temperatures higher than the required.

Figure 3.2. Time Temperature Indicator Label - TTL (PTC instruments, 2009) (Freshpoint, 2009)

Temperature Datalogger Technology.

Temperature Datalogger is an electronic device that records information during a period of time. The type of information to be recorded is determined by the user. This device has been used a long time ago with different applications. For example, if a refrigerated truck with perishable products is turned off, it is interesting to know at what temperature the products have been kept and for how long. Usually, Datalogger devices are used in places where accessibility is restricted (Labuza, T., 2006). They are very suitable for transport monitoring, problem detection, solutions development, quality education, research, etc. The most common formats used with this technology are sample data tables and graphs (Figure 3.3).

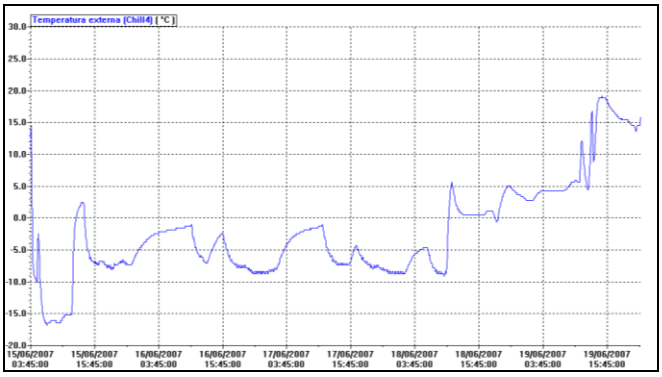

Figure 3.3. Graph obtained from a datalogger during the transport of fresh hake between Chile and Spain

IButton Technology

Another existing technology for temperature control is called iButton, which is designed to give solutions where environmental conditions are adverse, including water and extreme temperatures. This technology provides a high capacity data storage and it consists of a "button" package that incorporates a semiconductor and a temperature sensor, which was put in the freight to record its temperature over time (Figure 3.4).

Figure 3.3. Graph obtained from a datalogger during the transport of fresh hake between Chile and Spain

3.2 Traceability Technology - barcode.

A barcode consists of a coding system created through series of parallel lines and spaces of different thickness. It is mostly used as a control system which facilitates operations between manufacturer and distributor, so it really does not inform the consumer. It is the most widely used tool to identify products, inventory control, loading and unloading of goods or for reducing care time sales along supply chains (EAN International, 2006).

One of the barcode's main advantages is that the data stored can be read accurately and quickly. The device contains a small sensor that detects the reflected light and converts it into electrical energy. The result is an electrical signal that can be interpreted and converted into data (Figure 3.4 and Figure 3.5). The term EAN (Electronic Articulate Number) identifies an electronic identification system through numerical series (AECOC, 2006).

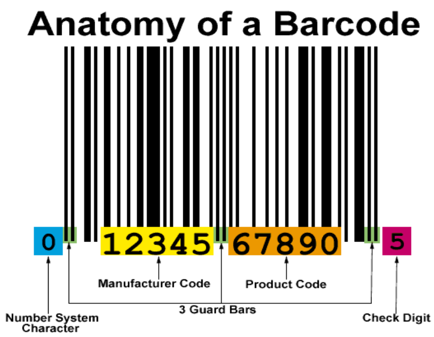

Figure 3.4. One-dimensional barcode

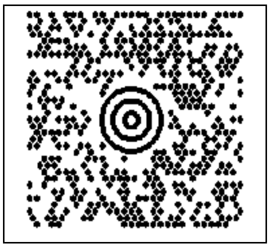

Figure 3.5. Two-dimensional barcode

3.3 Mixed monitoring and traceability technology – RFID

The logical evolution of a system that unifies both concepts of monitoring and traceability should allow remote access to temperature data and traceability. This means that there is no contact between the reader of identifier+temperature data and the identifier+sensor devices that are in contact with the products. There have been several developments (Ning, W. et al, 2006) (Ruiz-Garcia, L. et al, 2009) carried out using different data transmission systems like LAN, Bluetooth, ZigBee (Ruiz-Garcia, L., 2009) or RFID.

The most mature technology in this field is the RFID (Radio Frequency Identification or Radio Frequency Identification). This is a technology that has experienced great development in recent years (Vello, J., 2004), due to the potential benefits of its application in the logistics area. It is based on an automatic identification and data collection that uses radio frequencies to recognize and transfer using air as an interface (see Figure 3.6). RFID can also be complemented with a temperature control system by placing a sensor inside the tag as it has already shown by some authors (Jedermann, R., 2008).

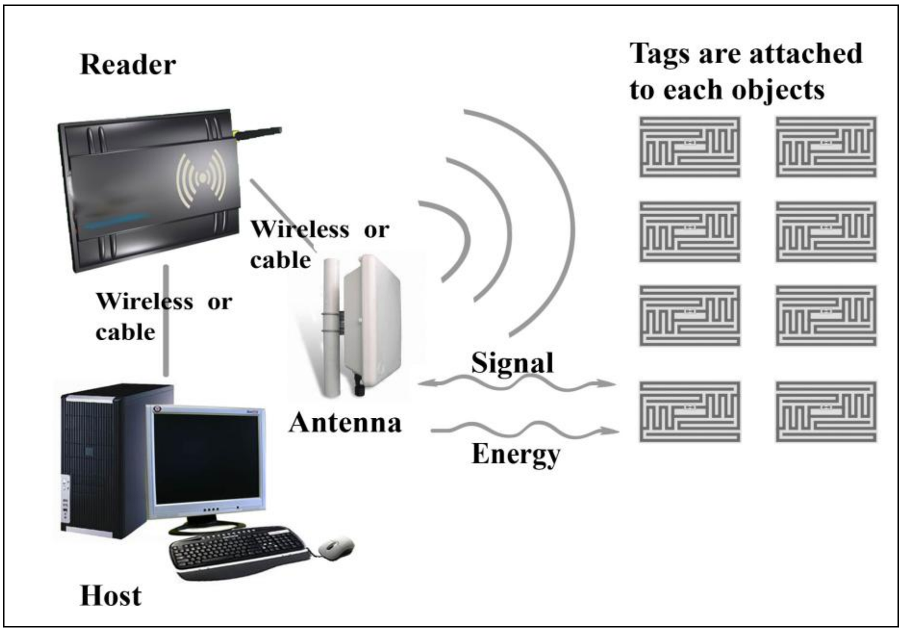

Figure 3.6 RFID Components (Tags at Work, 2009)

4. MULTICRITERIA DECISION MAKING

4.1 Multicriteria decision analysis

The process of decision making, both in business and social environment is becoming more critical, mostly because of the number of factors that can influence different aspects of the problems to solve. Under these circumstances, many of the issues that professionals from diverse fields have to deal with are problems that involve multiple criteria to take into account. Sometimes, these criteria may be in conflict depending on the problem. Therefore, multicriteria decision making techniques have great application in providing solutions for a wide range of problems and projects, and one of them is the selection of technology for traceability and temperature monitoring along cold supply chain, as proposed in this work.

With this purpose, a selection of the most important multicriteria methods is summarized in the table 4.1 of the next section. This selection has been made according to the applicability of the methods to problems similar to the one here considered.

4.2. Multicriteria decision making methods

Table 4.1 – Summary of multi-criteria methodologies

METHOD				PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
DISCRETE	OUTRANKING	ELECTRE	**I** (Benayoun et al., 1966) (Mousseau, V. and Roy, B., 2005)	Transport selection	-Family F of criteria (simple), g_1, g_2…g_f -Weights, concordance and discordance. -It does not work with indifference nor preference threshold -It compares preference between alternatives	-Output: Best alternatives (others are eliminated) -Use of graphs -Tools: ELECTRE I, TRI software (developed by LAMSADE laboratory)
			II (Roy, Bertier, 1971) (Teixeira de Almeida, 2007)	-Solid waste management system (Hokkanen et al., 1995) -Selection of the best project within a portfolio (e.g. Hospital construction) -Selection of the suitable alternative to restore a building	-Family F of criteria (simple), g_1, g_2…g_f -Weights, concordance and discordance. -It compares preference between alternatives -It compares preference between alternatives	-Output: Ranking of the most satisfactory alternatives -Use of graphs
			III (Roy, B., 1978). (Nowak, M., 2004)	-Project selection in a electricity company -Location of a thermal power plant -Strategic resource planning	-Family F of criteria (pseudo), g_1, g_2…g_f -Criteria weight -It compares preference between alternatives -It introduces the "fuzzy concept"	-Output: Ranking of the most satisfactory alternatives -It facilitates handling of uncertainty associated with the evaluation of consequences -Use of graphs -Tools: ELECTRE III-IV software (LAMSADE laboratory)
			IV, IV-A (Roy, B. et al., 1982). (Roy, B. et al.1991).	It is suitable for real situations with imprecision and uncertainty	-Family F of criteria (pseudo), g_1, g_2…g_f -It does not require criteria weight -It compares preference between alternatives	-Output: Ranking of the most satisfactory alternatives -Use of graphs
			IS (Roy, B. and Skalka, J.M,1984). García, M.C. et al, 2002).	Evaluation and selection of investment alternatives	-Family F of criteria (pseudo), g_1, g_2…g_f -Criteria weight -Concordance and discordance test by criterion for each pair of alternatives→Concordance matrix	-Output: Ranking of the most satisfactory alternatives -Use of graphs -Tools: ELECTRE IS (LAMSADE laboratory)

METHOD		PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
	TRI (Mousseau, V., 1999)	-Allocation of public subsidies -Transport evaluation of hazardous materials	-Family F of criteria (pseudo), $g_1, g_2 \ldots g_f$ -Criteria weight -It uses the "fuzzy concept"	-Ranking of alternatives -Use of graphs -Tools: ELECTRE TRI (LAMSADE laboratory)
PROMETHEE	**I** (Brans, J.P., 1984) (Mareschal, B. and Brans, J.P., 1986)	-Special interest in location problems: * Hydroelectric plants * Commercial facilities in a competitive environment * Waste deposits (Briggs, et al., 1990) * Financial evaluation "Selecting new tourism products	-Weight assignment w_j for each criterion x_j -Set of alternatives A_i (eg different locations) -Function P_j (A,A') (generalized criteria) → intensity of preference of alternatives for criterion j -Comparison of preferences among alternatives	-Partial order of alternatives→ Possible appearance of incomparabilities -Tools: Promethee I software
PROMETHEE	**II** (Brans, J.P and Mareschal, B., 1994)			-Complete pre-order of alternatives → Loss of useful information -Tools: Promethee II software
PROMETHEE	**Other** (D´Avignon and Vincke, G., 1988)	More sophisticated situations→ Problems with a stochastic component		Order or pre-order of alternatives -More tools: PROMCALC, GAIA, Decision Lab software
DISCRETE	**The Analytic Jerarchy Process (AHP)** (Saaty, T., 1980) Moreno-Jiménez, J.M., 2008) (Aznar, J., 2009)	-Selection of supply chain (Wang, J.W et al., 2004). -Prioritize projects -Logistics operator selection -Technology selection -Areas of production→ Order processing -Resource allocation -Investment decisions -Medical field -Organizational development -Prioritization of transport	-Construction of a hierarchical model -Definition of alternatives and objectives -Input: Criteria and sub-criteria→ Determination of weights -Alternatives assessment *SCOR model (applied to SP)→12 performance metrics grouped into 4 categories.	-Output: Ranking order of alternatives -Good acceptance and widespread use -Subjective judgments take an important part in the method -Quantitative and qualitative measures -Modelling of complex problems -It works under uncertainty conditions -It is combinable with other method to determine different parameters (e.g. calculation of optimal production quantity by goal programming) -Tools: Expert Choice, HIPRE 3+, Criterium, Inpre software

	METHOD	PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
DISCRETE	**ANP (Analytic Network Process)** (Saaty, T., 2001)	-Supply Chain (Agarwal, A. et al., 2006) -Selection and evaluation of technology -Design for disassembly (Güngör, A., 2006). -Total Quality Management -Environmental management	-Network or cluster structure -Definition of alternatives and objectives -Input: Criteria and subcriteria→ Determination of weights -Paired comparisons in each cluster→ Interdependencies between criteria and alternatives -Alternatives assessment	-Increased complexity and dedication -The network model is obtained by setting priorities among alternatives -Tools: SuperDecisions software
	PRES II Multiexperto (Aragonés Beltrán, P. and Gómez-Senent Martínez, E., 1997)	-Complex cases→ Simplification. e.g: *Strategic planning with conflicting interests *Site location *Project selection with large number of stakeholders (E.g. political parties)	-N criteria (quality of life, environment, social impact, cost, legal requirements, etc.). -M alternatives (e.g. different strategic or different locations) -It requires a group of experts	-Calculus of Pres ranking order -Classification of alternatives from best to worst→key initiatives are obtained -Subjective opinion →imprecision -Tools: Spreadsheet (Excel) and LIGRE software.
DISCRETOS	**TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)** (Yoon, K. P. and Hwang C., 1995) (Wang, Y.J. and Lee, H.S., 2007)	-Geographic Information Systems -Medicine: Surgical wait list	- X_i: i decision variables (e.g. quantity of a resource, cost, time, etc.). -Goals optimization (maximize or minimize)→function objective -Restrictions -Preferences (ideal goals) of the decision maker are introduced into the model -Gap between goals and ideal objectives (define by the decision maker) is minimize	-Identification of near-ideal solutions→Similarity to ideal solutions (commitment) -Obtaining similarity index -Tools: spreadsheet (Excel) and other special software applications
	Cooperative game theory (Von Neumann, J. and Morgenstern, O., 1947) (Cano, M . et al., 2009)	-Political science -Operations research -Military strategy -Analysis of economic problems -Artificial-intelligence -Cybernetics -Wastewater management (Tecle, A. et al., 1988)	-Expected and observed behaviour of individuals in games	-It is difficult to use -It has been criticized by several experts -It requires specialists who have a good command in the methodology

METHOD			PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
DISCRETOS	**Multi-Attribute Utility Theory (MAUT)** (Yu, P.L. and Zeleny, M., 1975) (Keeney, R. L. and Raiffa, H., 1976) (Ross, D., 2007)	**Weighted sum method**	-Nuclear waste disposal location -Nuclear power plant location -Measurement of the partial utility of an alternative in reference to each of the attributes -Decision-maker preferences are known and represented in a utility function U	-x_i alternatives -z_j attributes -Measurement of the partial utility of an alternative considering each of the attributes Decision-maker preferences are known and represented in a utility function U -Possible uncertainty conditions	-Construction of weighted matrix for each alternative -Precise information on decision maker preferences -Output: Ranking of alternatives -Tools: linear programming and use of spreadsheet (Excel)
		UTA (Additive Utility) (Jacquet-Legrèze, E. and Siskos, J., 1982)	-Selection of alternative for groundwater management		-Global preferences of the decision maker are known -Output: Ranking of given alternatives -Complexity: determination of an optimal utility function and its sensitivity analysis -Tools: linear programming and PREFCALC software
		VISA Program	(Few applications have been found)		-Hierarchical structure of criteria -Output: Ranking of given alternatives -Possibility of interactive and visual sensitivity analysis -Tools: VISA software
	Linear weighting		Uncertain situations with limited levels of information (e.g. selection of university)	-Alternatives (University A, B and C) -Criteria established by the decision maker (location, cost, reputation, etc.). -Attributes are known (price university, distance to the centre, number of students, etc.).	-Output: "best" alternative according to the criteria established -Advantage: simplicity -Easily influenced→ Problem of <u>subjectivity</u> -Tools: spreadsheet (Excel)

METHOD		PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
CONTINUOS	**Multi-Objective Programming (Vector optimization)** (Steuer, R.E and Schuler, A.T., 1978)	-Food Sector -Operations -Production -Finance -Transport -Logistics -Determination of optimal strategies for electric capacity expansion	- X_i: i decision variables (e.g. quantity of a resource, cost, time, etc.). -Values of the criteria associated with each alternative are known -Maximization o minimization function -Restrictions -Decision maker preferences are not included.	-Set of efficient solutions -A large number of efficient solutions might be undesirable (complexity) -Tools: Graphic method (complex), ADBASE, MLP and LINGO software, Solver (Excel)
	Compromise programming (Yu, P.L., 1973) (Zeleny, M., 1973).	-Larger scope and field of application: e.g.: Agriculture→ Maximize net present value and minimize labour recruitment -Ranking groundwater (Duckstein, L. et al., 1994) -Optimal power-dispatch resolution -Expansion of electric capacity in one location (e.g. Taiwan)	- X_i: i decision variables (e.g. quantity of a resource, cost, time, etc.). -Objectives to optimize (maximize or minimize)→ Objective function -Restrictions -Preferences (ideal goals) of the decision maker are introduced into the model -Euclidean distances between defined goals and ideal objectives are minimized	-Size reduction of the efficient set -Less utility with complex problems -Tools: Graph method (complex), Solver (Excel), ADBASE and MLP Software, and Simplex method
CONTINUOS	**Goal programming** (Charnes A., Cooper W. and Ferguson R., 1955) (Lee, S.M., 1972)	-Interest in the economic environment (incomplete information, limited resources, conflict of interests, etc.) -Health-environment -Forest resources planning	-Relevant attributes (cost, number days, tons of material, etc.). -Level of achievement of each attribute according to the decision-maker preferences and constraints of the problem.	-Major functionality -Reduced number of efficient and feasible solutions -Tools: Graphic method (complex), ADBASE, MLP and LINGO software, Solver (Excel)
	Based on the Multi-Attribute Utility (MAUT) (Ross, D., 2007).	-It is suitable for problems in environments of uncertainty: -Consequences of adopting each of the alternatives are not known	- x_i Alternatives - z_j Attributes -Measurement of the partial utility of an alternative referring to each of the attributes. -Decision-maker preferences are known and represented in a utility function U.	-Solution: Solve the mathematical program: *Max v (z (x)), x Є X* -Tools: Solver (Excel), mathematical optimization programs, GMMA software (developed by Polytechnic University of Madrid)

METHOD		PROBLEMS ADRESSED	VARIABLES	RESULTS AND COMMENTS
INTERACTIVES	**STEM** (Benayoun, R. et al., 1971)	-Harvest planning -Health sector: Planning of activity and distribution of hospital resources	-It requires an analyst -Decision-makers: they give their opinion on acceptance or rejection of a feasible and efficient solution -It quantifies the level of conflict between objectives (e.g.: Low cost and high reliability)	-Output: Set of solutions -The most used interactive method in practice -It does not reflect decision maker absolute preferences -Tool: PFLMO software
	Zionts and Wallenius (Zionts, S. and Wallenius, J., 1976)	-Health sector: Planning of activity and distribution of hospital resources	-Decision-makers: They have to accept or not a group of trade-offs between objectives	-Output: Set of solutions -Advantage: Information requested from the decision maker is easier to understand
	Geoffrion, Dyer and Feinberg (G-D-F) (Geoffrion, A.M., Dyer, J.S. and Feinberg, A., 1972)	-Management of university activities	-Decision-maker: Provides information on trade-offs between objectives or goals -Use of the Frank-Wolfe algorithm	-Output: Set of solutions -It is difficult to implement -It uses complex mathematical algorithms→<u>iterative process</u> -Tools: linear programming and Simplex method
	Macbeth (Bana e Costa C.A.; Vansnick J-C., 1995)	-Development a policy-selection to optimize resources in a region	-Criteria-function of a fundamental point of view -Information from criteria (cost, distance, reliability, etc.) → <u>Weight determination</u> -It requires judgments of the decision maker about the alternatives→difference in attractiveness to different incentives	-Output: degree of preference of a decision maker on a set of alternatives -Advantage: quantitative information representation -Disadvantage: incomplete information→ less significant results -Tool: use of spreadsheet (Excel)

4.3 Approximations to the problem: methods applied to technology selection

During the implementation of any technological improvement in a company, critical decisions must be taken in the short to medium term. In this case study, the to-establish multicriteria method should facilitate decision making when implementing temperature control technology at critical stages of the cold supply chain. Thus, discrete multi-criteria decision methods are the most suitable for the technology selection problem. Following, there is a brief description of the multi-criteria decision aiding methods that best suit technology selection problems within the logistics field:

AHP (Analytic Hierarchy Process)

AHP decomposes a complex problem into hierarchies, where each level is divided into specific elements. The main objective is placed at the fist level. Considering the cold supply chain, the main objective would be the optimal choice of temperature control technology. Next, AHP lists the criteria, sub-criteria and decision alternatives in the next levels of the hierarchy. Levels of importance or criteria weights are estimated by comparisons between pair of criteria using the Saaty scale (Saaty, T., 1980).

In the field of logistics, the SCOR model, created by the Supply Chain Council, it is frequently used to establish several performance metrics (criteria) for supply chain. This model can be helpful as a model to follow when setting a scheme of hierarchies according to the technology selection in the cold chain. The SCOR model offers 12 performance metrics of the supply chain that are grouped into four categories: delivery reliability, flexibility, cost, and assets. However, other different categories of performance metrics can be added to the hierarchy process of the supply chain problem. At Figure 4.1 there is the hierarchy scheme for selection of a logistics operator using the SCOR model:

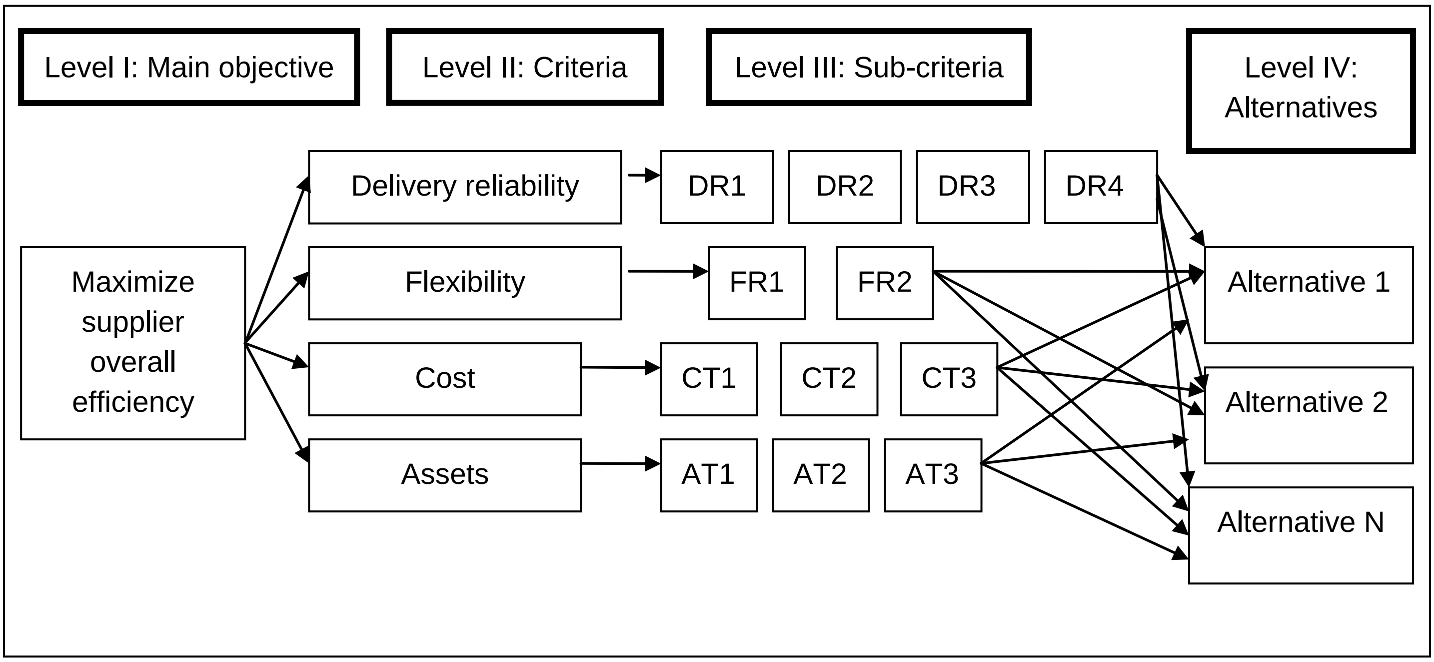

Figure 4.1 SCOR hierarchy scheme to select a logistics operator

ANP (network analysis process)

Sometimes, the strict hierarchical structure of AHP method can not address the complexity of many real problems. As a solution, there is the ANP method, as a generalization of the AHP.

With ANP, a network model where there are interdependencies among criteria and alternatives can be constructed. Therefore, the ANP method allows a multi-criteria approach with complex problems and it achieves better solutions in those cases, where the hierarchies become interconnected. This method preserves most of the advantages of the AHP for technology selection, but the drawback it is its complexity or difficulty in applying it, as it involves more calculations with matrices. There are software applications, such as SuperDecisions, that facilitate the use of ANP, and where the user can see the network structure of the decisional process graphically.

ELECTRE I

Another method that is capable to solve the problem of technology selection is ELECTRE, in its version I. The family of ELECTRE methods is based on outranking relationships in deciding on a solution, not optimal in all cases, but satisfactory. It also allows a ranking of the various technology alternatives that are might be under analysis. The ELECTRE I method is the simplest version of the group of methods but it perfectly suits the problem of technology selection. It provides a solution that will be a selection of the most satisfactory alternatives. Moreover, version I has been chosen because it is the most simple and intuitive to implement, which is an advantage for the decision maker.

MAUT (Multi-Attribute Utility Theory)

This methodology is based on preference aggregation models regarding individual criteria, and it assumes that the decision maker tries to maximize a utility function that adds the criteria involved in the problem. Considering the problem of technology selection, decision makers must establish what criteria are most relevant to the problem. Their preferences are expressed on the set of criteria or attributes in terms of the utility that they have, in a context where there are conditions of uncertainty. The procedure is based on measuring the partial utility of each alternative temperature and control technology, with reference to each of the attributes. Next, partial utilities are aggregated to calculate the overall utility of each alternative under analysis. Then, the solution is a ranking of the alternatives considering the overall utility they give to the decision maker, who has to take a final decision taken into account the feasibility of the most satisfactory alternatives.

5. SELECTION OF THE METHODOLOGY FOR THE PROPOSED PROBLEM

Throughout this chapter, a review of the methods that have greater potential to adapt to the problem has been realised, focusing on the selection of a particular temperature control technology for cold supply chain. As a result, we can infer that it is possible to align the requirements of the problem with the specifications of the models studied. The initial requirements for the model to be developed are explained in the following paragraphs.

5.1 Flexibility

The proposed multi-criteria method for decision aiding should be flexible in parameters. This means that it should be adaptable to similar problems of technology selection or to those types of problems where advances in technology are a key aspect or mean a competitive advantage. Also, it is interesting that the methodology can be applicable to other chains different than the cold one, like food supply chains or even those that deal with different products, for example, in the pharmaceutical industry. The model should be as universal as possible, adaptable to other supply chains and, in particular, it will be validated in two cold supply chain.

5.2 Convenience of use

The methodology should be developed to be as comfortable as possible in its implementation. This will ensure a proper use from the central decision-maker in real problems. In this case, the main objective decision maker is the manager or committee responsible for the company. They will be the head of the decision process and the responsible for the consequences of a successful implementation of a temperature-control technology in the supply chain.

The methodology should be as comfortable as possible due to the rejection that a complex appearance could generate to experienced business users but less technically trained. The purpose of this paper is to present first steps of an advance in a novel knowledge, in parallel with the utility of the system itself. Therefore, comfort should not either limit the complexity of theoretical or mathematical decisional basis of the proposed method.

5.3 Autonomy

The decision making model should be as independent as possible. This means that the actors that are responsible for the decision on the problem must be able to implement the methodology by themselves. Thus, they should be able to obtain an optimal and feasible alternative according to some consistent preferences and constraints that define the system optimally.

This circumstance makes the use of a group of experts for decision making a not-reasonable option in this case. Although this factor could be an exceptional added value in an ideal system, it is very difficult to be implemented in a real situation. The reason is that it is quite complex for a small company to locate a panel of neutral experts with real knowledge of the problem. Moreover, in most cases, available experts may have economical interests involved, which would balance the problem onto a partial solution.

Furthermore, the decision to implement a particular temperature control technology is motivated by the need to increase the competitiveness of a company dealing with the supply chain. Therefore, dissemination of such strategic decision must be necessarily very restricted. In a first stage, only those people directly involved in the problem should be part of the decision-making process due to operational or economic aspects. This type of decision should only be disseminated when the implementation process has finished successfully and it's beginning to produce measurable results.

5.4 Unambiguous and testable solution

A unique solution means that decision-makers must obtain a unique solution to their problem through the selection of a particular technology alternative. This means that the method should not present any degree of uncertainty when establishing the best alternative or alternatives.

In addition, further development adapted to the basic model will be able to provide the decision maker with contrasted results. This will have the advantage that the decision maker will be able to see what results would take place as a consequence of adopting the technological alternative proposed by the method. In this way, the proposed alternative will involve to get results expressed as measurable economical data before taking any final decision.

5.5 Robust implementation of the mathematical method

The criteria decision method to be established wil have a robust base that systematizes a mathematical methodology for input data introduction (characteristics of the problem, constraints and preferences of the decision-maker). It will also obtain and process the output data to determine the final optimum alternative.

Thus, MAUT approach seems to be the most adaptable method to these requirements, primarily because of its easiness of application and mathematical implementation. This methodology is based on maximizing (or minimizing) a given value function. In the case of given conditions of uncertainty, the function would be called utility function. Therefore, the fundamental approach for the decision problem is to establish the correct weights of the criteria to be included in the value function. The decision maker assigns values to a minimum number of predefined variables that collect the characteristics of the problem. By using these variables it is possible to determine which attributes are the most important for the decision maker and the system will assign their level of importance in the shape of weights. Those weights are determined by an internal algorithm that is intended to be the key to future developments of this piece of work.

However, ELECTRE method also seems to be applicable to the established problem, due to its consistent mathematical basis and the robustness of its methodology. In addition, the previously reviewed different versions of the method can be used according to the characteristics of the decisional problem involved. The methodology to be followed would be in line with the ideas previously proposed for the MAUT method.

6. CONCLUSIONS

This paper has documented the reasons for the use of multi-criteria decision making methods (MCMD) in technology selection problems. The evidence suggests that multi-criteria decision aiding methods are a useful tool to take efficient solutions to non-linear problems where different criteria and restrictions are involved. The present study was designed to determine the use and particular application of these methodologies to the cold supply chain in order to adopt a temperature and control technology solution.

With this aim, the particularities and considerations regarding the cold supply chain have been studied, concluding that traceability and temperature control are the two major concerns regarding this type of supply chains. Because of this, several control and traceability technologies that can be applied to this chain have been analyzed. The adoption of any type of these technologies has several competitive advantages, but the selection of one of them is not an easy task. There are several factors and restrictions to be taken into account by the decision maker, such as cost, reliability, social impact or legal requirements. Therefore, taking the best alternative will have a strong impact to the cold supply chain, where parties in the different stages of the chain are involved.

After the establishment of this scenario, a wide bibliography study has been performed in order to research the multi-criteria methods applicable to this problem and their particular characteristics. It has been concluded that some of them have been used in previous works of selection of particular technologies among different alternatives, like the AHP or MAUT methods. Thus, it is possible to set the characteristics of our proposed multi-criteria methodology as an approach for technology selection in the cold supply chain. Future research should, therefore, concentrate on the investigation of the particularities and parameters that affect all the stages of this chain, in order to get to know the key variables to introduce to the cold chain particular model. Finally, further developments will allow to particularise the data extracted from the cold supply chain by using two R+D cold chain projects partnered by ITENE: an ice-cream cold chain project –GLOBALOG- funded by the Spanish Government and also a fresh hake Chile-Spain supply chain studied in the Chill-On project under the 6th Framework EU Program. Hence, this first approach to multi-criteria methodology for technology selection will be analyze and validated by solving possible sensitivities and by applying the final development to these chains.

REFERENCES

AECOC (2006). Guía de calidad en simbología: puntos críticos. Spain.

Agarwal, A., Shankar, R. and Tiwari, M.K. (2006). Modeling the metrics of lean, agile and leagile supply chain: an ANP-based approach. European Journal of Operational Research, Vol. 173 pp.211-25.

Aragonés Beltrán, P. and Gómez-Senent Martínez, E. (1997). Técnicas de ayuda a la toma de decisiones multicriterio. Servicio de Publicaciones Universidad Politécnica de Valencia.

Aznar, J.,Guijarro, F., Moreno-Jimenez, J.M. (2009). Mixed Valuation Methods: A Combined AHP-GP procedure for individual and group multicriteria agriculture valuation. Annals of Operations Research. DOI 10.107/s10479-009-0527-2.

Bana e Costa C.A.; Vansnick J-C. (1995). General overview of the MACBETH approach. Advances in Multicriteria Analysis. Kluwer Academic Publishers, Book Series: Nonconvex Optimization and its Applications, pp. 93-100.

Benayoun et al., (1966). ELECTRE: une Methode pour Guider le Chix en Presence de Vue Multiples.

Benayoun, R., De Montgolfier, J., Tergny, J. and Larichec, O. (1971). Linear Programming with Multiple Objective Functions: Step method (STEM). Matematical Programming, 1, pp 366-375.

Brans, J.P and Mareschal, B (1994). How to decide with PROMETHEE: the PROMETHEE-GAIA Decision Support Systema for Multicriteria Investigations. Discussion Papers 94/03. Service de Mathématiques de la Gestion. Université Libre de Bruxelles.

Brans, J.P. and Vincke P.H. (1984). A Preference Ranking Organisation Method: The Promethee Method for Multiple Criteria Decision-Making.

Briggs, et al., 1990. Nuclear waste management: An application of the multicriteria PROMETHEE method. European Journal of Operational Research, 4, 1, .pp. 1-10.

Cano, M., Mena, C. and Sadka, J. (2009). Teoría de Juegos y Derecho Contemporáneo.

Charnes A., Cooper W. and Ferguson R. (1955). Optimal estimation of executive compensation by linear programming. Management Science, 1, pp. 138-151.

D´Avignon and Vincke, G. (1988). An outranking method under uncertainty. European Journal of Operational Research, vol. 36, nº 3, pp. 311 – 321.

DBK S.A. Logística del Frío en España y Portugal. Special report. May 2009.

Duckstein, L., Treichel, W. and Magnouni, S.E. (1994). Ranking groundwater management by multicriterion analysis". Journal of Water Resources Planning and Management 120(4):546-565; jul.-ago.

EAN Internacional (2006). Guía de implementación para la trazabilidad de productos fresco. Costa Rica, South America.

Freshpoint website. Image available at:

García Centeno, M.C.; Fernández Barberis, G.M.; Escribano Ródenas, M.C. (2002). Comparative analysis between ELECTRE IS and PROMETHEE Methods in the evaluation and the selection of financial investment alternatives. 56ème Journées du Groupe de Travail Européen .Aide Multicritére à la Décision. Coimbra.

Geoffrion, A.M., Dyer, J.S. and Feinberg, A., (1972). An interactive approach for multi-criterion optimization, with an application to the operation of an academic department. Management Science, 19, 4, Part I, pp. 357-368.

Güngör, A. (2006). Evaluation of connection types in design for disassembly (DFD) using analytic network process. Computers & Industrial Engineering, Vol. 50 pp.35-54.

Hokkanen et al., (1995).The Choice of a Solid Waste Management System Using the Electre Ii Decision-Aid Method.

http://www.freshpoint-tti.com/productSpec.asp?id=14&name=OnVu%20Fresh [Accesed 20 August 2009].

Jacquet-Legrèze, E. and Siskos, J. (1982). Assessing a set of Additive Utility Functions for Multicriteria Decision-Making, The UTA Method. European Journal of Operational Research, v.10, pp. 151-164,

Jedermann, R.; Stein, K.; Becker, M.; Lang, W. (2008). UHF-RFID in the Food Chain - From Identification to Smart Labels. In Kreyenschmidt. J. (edt.): Coldchain Manangement. 3rd International Workshop, 2.-3. Bonn, Germany.

Keeney, R. L. and Raiffa, H. (1976). Decisions with multiple objectives: Preferences and value tradeoffs. John Wiley & Sons, New York.

Kuo, J.-C. and Chen, M.C. (2009). Developing an advanced Multi-Temperature Joint Distribution System for the food cold chain. Elsevier academic press, USA.

Labuza, T. (2006). Time-Temperature integrators and the cold chain: what is next?. Proceedings of the Cold Chain Management 2nd International Workshop. pp. 43-52. Bonn, Germany.

Lee, S.M. (1972). Decision Analysis. Auerbach Publishers. Finland.

Mareschal, B. and Brans, J.P (1986). How to select and how to rank projects: The PROMETHEE method. European Journal of Operational Research, vol. 24, n 1, pp. 228-238.

Moreno-Jiménez, (2003). A Spreadsheet Module for Consistent Consensus Building in AHP-Group Decision Making. Group Decision and Negotiation Journal. Kluwer Academic Publishers. Dordrecht, Holland.

Moreno-Jiménez, J.M., Aguarón, J.; Escobar, M.T. (2008). The Core of Consistency in AHP-Group Decision Making. Group Decision & Negotiation Journal, 17, pp. 249-265.

Mousseau, V. and Roy, B. (2005). Electre Methods.

Mousseau, V., Slowinski, R. and Zielniewicz, P. (1999). ELECTRE TRI 2.0a, User Documentation. Université Paris-Dauphine: Cahiers du LAMSADE nº 111.

Ning Wang, Naiqian Zhang and Maohua Wang (2006). Wireless sensors in agriculture and food industry - Recent development and future perspective. Computers and Electronics in Agriculture 50 pp. 1-14. Elsevier academic press, USA.

Nowak, M. (2004). Preference and veto thresholds in multicriteria analysis based on stochastic dominance. European Journal of Operational Research 158(2) pp. 339-350.

PTC Instruments website. Image available at: http://www.ptc1.com/temp-plates%20.html [Accesed 20 August 2009].

Raspor, P. (2008). Total food chain safety: how good practices can contribute?". Trends in Food Science & Technology 19 pp. 405-412. Elsevier, USA.

Ross, D. (2007). Economic theory and cognitive science. MIT Press. Boston.

Ross, D. (2007). Economic theory and congnitive science.

Roy, B. (1978). ELECTRE III: un algorithme de classement fondé sur une représentation floue des préférences en présence de critères multiples.

Roy, B. and Skalka, J.M. (1984). Aspects méthodologiques et guide d' utilisation. Université de Paris-Dauphine: Document du LAMSADE Nº 30.

Roy, B.; Skalka, J.M. and Hugonnard, J.C. (1982). Ranking of suburban line extension projects on the Paris Metro System by a multicriteria method. Transportation research, vol. 16A, nº 4, pp. 301 – 312.

Roy, Bertier, (1971) .La méthode Electre-II.

Roy, Bouyssou and Yu (1991). Decision-aid: an elementary introduction with emphasis on multiple criteria. Document Du Lamsade nº 106. Université Paris Paris, France.

Ruiz-Garcia, L., Barreiro, P., Robla, J.I.(2008). Performance of ZigBee-Based wireless sensor nodes for real-time monitoring of fruit logistics. Journal of Food Engineering 87 pp. 405–415. Elsevier press academic, USA.

Ruiz-Garcia, L., Loredana Lunadei, Barreiro, P., Robla ,J.I (2009). A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends. Sensors 9, pp. 4728-4750. MDPI Publishing, Switzerland.

Saaty, T. (1980). The Analytic Hierarchy Process.

Saaty, T. (2001). The Analytic Network Process; Decision Making with Dependence and Feedback (2 ed.). Pittsburg: RWS Publications.

Steuer, R.E and Schuler, A.T. (1978). A interactive multiple objective linear programming approach to a problem in forest management. Operations Research, Vol. 26, pp 254-269.

Tags at Work website. Image available at: http://www.tagsatwork.com/english/images/RFID.jpg [Accesed 28 August 2009]

Tecle, A., Fogel, M. and Duckstein, L. (1988). Multicriterion selection of wastewater management alternatives. Journal of Wastewater Resources Planning and Management Division, Proceedings of ASCE 114(4), pp. 383-398.

Teixeira de Almeida (2007). Multicriteria decision model for outsourcing contracts selection based on utility function and ELECTRE method.

Vello, J. (2004). RFID, una tecnología madura en un sector dispar. E-business Center PwC&IESE.

Von Neumann, J. and Morgenstern, O. (1947). The Theory of Games and Economic Behavior.

Wang, J.W et al. (2004). Product-driven Supply Chain selection using integrated multi-criteria decision making methodology. International Journal Production Economics 91, pp. 1-15.

Wang, Y.J. and Lee, H.S. (2007). Generalizing TOPSIS for fuzzy multiple-criteria group decision-making.

Yoav Sarig (2003). Traceability of food products. CIGR Journal. Bologna, Italy.

Yoon, K. P. and Hwang C., (1995). Multiple attribute decision making. Sage university paper.

Yu P.L., (1973). A class of solutions for group decision problems. Management Science, 19, pp. 936-946.

Yu, P.L. and Zeleny, M. (1975). The Set of All Nondominated Solutions in Linear Cases and a Multicriteria Simplex Method. J. Math. Anal. Appl., Vol.49, nº 2, pp.430-468.

Zeleny, M., (1973). Compromise Programming. Multiple Criteria Decision Making. Columbia, University of South Carolina Press, pp 262-301.

Zionts, S. and Wallenius, J. (1976). An interactive programming method for solving the multiple criteria problem. Management Science 22, 652–663.