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A decision-making model for waste management in the footwear industry

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The footwear industry, over the last years, has placed significant effort in improving energy and material efficiency, but in comparison little effort has been directed at the recovery and recycling of shoes at the end of their functional life. In reality, most worn and discarded (end-of-life) shoes are disposed of in landfills. Producer responsibility issues and forthcoming legislation as well as increasing environmental consumer demands are expected to challenge the way the global footwear industry deals with its end-of-life waste. This paper presents an investigation into the steps required to consider the end-of-life implication of shoes and promote post-consumer recycling practices in the footwear industry. The paper describes the design and specification of a decision-making model to identify the most appropriate reuse, recovery and recycling option for post-consumer shoes. Such a tool in addition to supporting design and material selection processes could also provide benchmark information for the selection of a best end-of-life practice for a selected range of shoe types. The paper concludes by providing a case study for shoe waste management to demonstrate the practicality of this decision-making model.

Keywords: Footwear industry; End-of-life management; Decision-making model

1. Introduction

The footwear industry is a diverse manufacturing sector which employs a wide variety of materials to make products ranging from different types and styles of shoes to more specialized footwear. Leather, synthetic materials, rubber and textile materials are amongst the basic materials most commonly used in shoe manufacture; each material having its own specific characteristics. These differ not only in their appearance but also in their physical qualities, their service life, the different treatment needs as well as their recycling and recovery options at the end of their useful life. Design and material selection activities significantly influence not only the life of the footwear, but also its end-of-life treatment.

In the recent past, a consumer would own a few pairs of shoes, some for exercising and others for work or fashion. But today's consumer demands a larger

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variety of shoes including options for specialized footwear. To meet the needs of customers and to be competitive, footwear companies face two key challenges: to be responsive to market changes and to establish efficient product development in order to identify or establish new consumer trends. Responsiveness to customer demands leads to a shorter life cycle of shoes, and an increasingly shorter product development cycle. A shorter life cycle means that more shoes will be produced over the years, so leading to a higher level of post-consumer waste. From 1990 to 2004, worldwide footwear production has increased by 70% to around 17 billion pairs of shoes while by 2010 experts in the sector expect the global footwear output to reach 20 billion pairs (World Footwear 2005). In the European Union, footwear consumption has increased by a staggering 22% from 2002 to 2005 to reach 2.3 billion pairs of shoes (EC 2006). Additionally, the footwear per capita consumption has increased considerably, from one pair of shoes for every person in the world in 1950 to almost 2.6 pairs of shoes in 2005. However, footwear consumption differs significantly per country. Although China, due to its large population, has the highest footwear consumption in the world, the United States has the highest per capita shoe consumption with each inhabitant purchasing an average of 6.9 pairs of shoes every year (AAfA 2006). In Europe (including new Member States), the yearly per capita shoe consumption in 2003 was 4.5 pairs of shoes, while in the United Kingdom the average is slightly higher at 5.3 pairs of shoes/person/year (CBI 2004). At the other extreme, in less developed countries the per capita shoe consumption is only 0.6 pairs for India and 0.5 pairs of shoes for Vietnam (all types of shoes included) (SATRA 2003).

In any product recovery application, there are a number of possible end-of-life treatment options with different environmental impacts, economic values and technical requirements. Hence, there is a need for a decision-making process to evaluate these factors and provide support to decision making. This paper has proposed such a decision-making model for end-of-life waste management in footwear industry. Section 2 provides a review of relevant literature on product recovery and section 3 investigates current reuse and recycling practices for post-consumer shoes. Section 4 describes the design and specification of a decision-making model for shoe waste management. In section 5 a case study of a selected shoe type is presented and some conclusions are presented in section 6.

2. Overview of relevant research

The increasing significance of product recovery has brought a corresponding growth in research covering the various stages of the product life cycle (Gupta and Gungor 1999). Therefore, many definitions and categorizations exist in the literature regarding product recovery activities. Thierry *et al.* (1995) present a categorization of product recovery options into repair, refurbish, remanufacture, cannibalization and recycling while Johnson *et al.* (1995) define the product recovery process simply as a combination of remanufacture, reuse and recycling. On the other hand, Moyer and Gupta (1997), Brennan *et al.* (1994), and US EPA (1997), simply classify the recovery of end-of-life products into material recovery (recycling) and product recovery (remanufacturing).

Additionally, a number of studies have investigated a range of different factors such as economic, environmental, technical and social criteria, which influence product recovery options (Krikke *et al*. 1998, Goggin *et al*. 2000, Erdos *et al*. 2001, Lee *et al*. 2001 and Bufardi *et al*. 2003). Different methodologies have also been developed to find a balance between the time and money invested in product recovery operations and value gained from the recovered products and materials. Johnson *et al*. (1995) suggest a methodology which aims to identify a preferred sequence of disassembly steps whilst maximizing the value gained from recovery products, while Hentschel *et al*. (1995) present an approach to recycling system planning for used products at their end-of-life phase. Also, Rahimifard *et al*. (2004) suggested a novel systematic five-stage methodology, called PRIME, to support product end-of-life management in different manufacturing applications based on an integrated view of a product supply and recovery chain.

3. Current reuse and recycling practices in the footwear industry

In the UK, more than 330 million pairs of shoes are consumed every year (SATRA 2003). It is estimated that the amount of waste generated from post-consumer shoes in the UK could reach 200 000 tonnes per year, with most of it ending up in landfills. The figure for the European Union is almost 1.5 million tonnes per year. The footwear industry's response to this increasing problem of post-consumer shoe waste has been negligible. In fact, only one major shoe manufacturer, Nike®, has taken measures to manage its waste. Nike's recycling programme 'NikeGO-Places®' (formerly 'Reuse-A-Shoe®') is the only product take-back and recycling scheme currently established by a shoe manufacturer. This programme has been operating for over a decade in the United States and has just started operating in the UK, Australia and Japan Nike (2006). Their reuse and recycling programme involves a series of collection points in retail centres where people can deposit their worn-out and discarded athletic shoes. The shoes are then collected and taken to a central recycling facility where they are shredded, producing a material called 'Nike-Grid®', which can be used in the surfacing of tennis and basketball courts, playgrounds and running tracks. According to Nike (2006), since its inception in 1993, the 'Reuse-A-Shoe' programme has recycled more than 16 million pairs of worn-out and defective athletic shoes in total.

Another form of reuse activity in the footwear sector is the collection and distribution of worn or unwanted shoes to developing countries. Reuse schemes are mainly supported by charity organizations, local authorities and municipalities such as the Salvation Army Trading Company Ltd. (SATCOL®), Oxfam and others. In the UK, SATCOL alone, with its 2300 banks and door-to-door collections and donations, have managed to collect around 971 tonnes of worn or unwanted shoes during the years 2000–2001 (Woolridge *et al*. 2006). However, there is a strong debate about such reuse activities in terms of their overall environmental impact and the economic consequences for the local communities. It has been argued that collection and distribution of worn or unwanted shoes in developing countries diverts post-consumer waste from the developed world to poor countries with no infrastructure to deal with it. According to Wicks *et al*. (1996), re-distribution of second-hand products into developing countries may also lead to net economic damage to the local economies due to 'dumping' of cheap used footwear. In the case of Uganda, the import of large volume of second hand shoes in recent years has significantly reduced the size of the local footwear industry. About 7 million pairs of second-hand shoes are imported into Uganda annually while only 240 000 pairs of shoes are produced by the local footwear industry (Temsch *et al*. 2002). However, as the cost of producing new shoes reduces and the markets are flooded with lower quality shoes, it is expected that the price difference between new shoes and second-hand shoes will shrink in less-developed countries. The demand for second-hand shoes might then drop in these countries, leading to an increase in post-consumer shoe recycling and disposal in the developed world.

However, not all materials used in footwear manufacturing can be recycled or reused. Once post-consumer waste is collected, separated and converted into a form that can be used by either the footwear industry or other industrial sectors, it must compete with virgin materials both on price and performance. Although in the case of other industrial sectors (i.e. metal and glass industry) established recycling markets already exist, in other material markets such as leather, textiles and plastics the situation is more complex.

4. Decision-making model for shoe waste management

This study presents a decision-making model for end-of-life shoe waste management. This model has been developed to simultaneously consider quantitative and qualitative waste management factors. For this reason, the analytic hierarchy process (AHP), which is a multi-criteria decision-making (MCDM) method, has been applied to construct the basic framework for analysing these factors. Additionally, a number of other decision-making techniques have been utilized to calculate economic and environmental criteria such as cost-benefit analysis (CBA) and life cycle assessment (LCA), as described in figure 1.

Multi-criteria decision making is a scientific field which has seen a considerable development during the last decades. As its name indicates, multi-criteria decision-making aims to give decision makers tools to enable them to advance in solving problems where several, often contradictory, criteria must be taken into account (Vincke 1992). The AHP method, developed by Saaty (1980), is one of the most widely used MCDM methods and has been applied in a variety of applications in different fields such as planning, selecting the best alternative option, resources allocation, and optimization (Vaidya *et al*. 2006). In addition, a number of researchers have investigated the combined application of AHP and LCA in various industrial case studies (Daniel *et al*. 2004, Huang *et al*. 2004 and Hermann *et al*. 2006). According to Henson *et al*. (2002) the AHP is consistent with the LCA concept because the environmental factors can be hierarchically structured into impacts and improvement options.

The proposed decision-making model for end-of-life shoe waste management, as depicted in figure 1, outlines the main steps, and the decision aid method that has been applied in each step. Economic criteria are calculated using CBA to identify

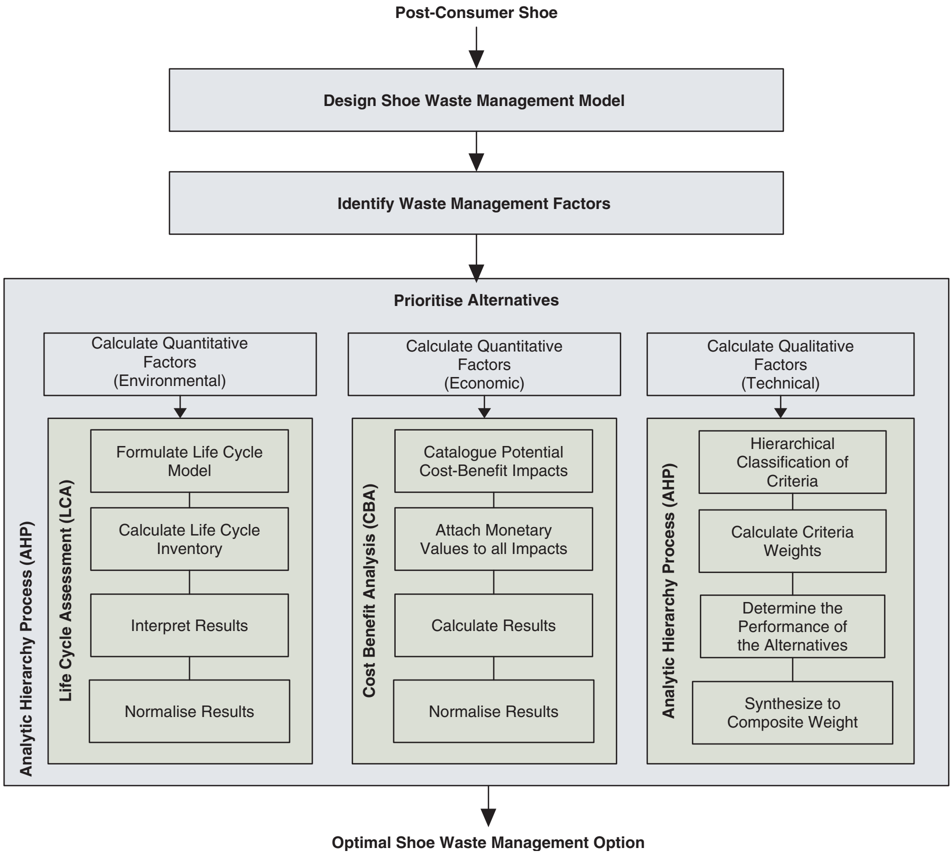

Figure 1. Decision making model for shoe waste management.

cost and benefits for each end-of-life management scenario, while environmental impacts are calculated by a streamlined LCA.

4.1 *Design shoe waste management model*

A waste management model for post-consumer shoes determines the different end-of-life management options, giving priority to recycling and reuse and minimizing cost and environmental impacts. The output of such a model would identify potential treatments for post-consumer shoes depending on the type of shoe. However, a shoe waste management model does not optimize the waste management treatments for each type of shoe; it simply lists the options available for treating the post-consumer waste as well as identifying potential applications for recycled materials.

In general, a shoe waste management model consists of the following end-of-life management options (Staikos *et al*. 2006):

(a) Reuse
(b) Recycling

(c) Energy recovery
(d) Disposal

Reuse of post-consumer shoes is a possible option but there are variables that need to be considered such as the condition of the shoe at the end of its functional life, the collection and distribution system as well as the purpose of its reuse (see section 3). Recycling involves the reprocessing of post-consumer shoes, parts or materials, either into the same product system (closed loop) or into different ones (open loop). The waste is, therefore, re-introduced back into the market through a series of destructive and non-destructive recycling processes. Energy recovery is another possible waste management option for post-consumer shoes and includes a number of established and emerging technologies such as incineration, gasification and pyrolysis. Finally, disposal of waste to landfills is currently the most common waste management option for post-consumer shoes.

4.2 *Identify waste management factors*

This decision-making model takes into consideration both quantitative (environmental and economic criteria) and qualitative (technical criteria) factors. Environmental criteria include a number of well-recognized environmental impact category indicators (i.e. global warming potential, human eco-toxicity etc). Economic criteria are simply divided into costs and benefits for each end-of-life management scenario (i.e. resale price of reused shoe, cost of land filling, etc). The list of technical criteria is almost endless and could be easily changed by the user depending on the requirements of the analysis and the type of shoe under consideration.

4.3 *Prioritize alternatives*

Although many multi-criteria decision-making methods can be applied to prioritize alternatives, AHP is considered as one of the most comprehensive MCDM methods (Triantaphyllou 2000). In general, the AHP method decomposes a complex decision problem into a hierarchy and allows the consideration of both quantitative and qualitative (objective and subjective) factors in selecting the best alternative option (Saaty 1980). It also provides a methodology to calibrate the numeric scale for the measurement of quantitative and qualitative performances. Application of the AHP method requires the following steps: structuring of the problem into a hierarchy, making pairwise comparisons, calculating criteria weights, and synthesizing the priorities (Saaty and Vargas 2001).

4.3.1 Structuring the problem into a decision hierarchy. In applying the AHP method, the first step is decomposition or the structuring of the problem into a hierarchy. Decomposition requires that the decision problem be decomposed into a hierarchy that captures the essential variables (factors, criteria, sub-criteria) of the problem. The decision hierarchy is structured so that the top level represents the overall objective or goal of the problem. Factors, criteria and sub-criteria upon which this goal is dependent are assigned to the lower levels of the hierarchy.

The lower level contains the alternatives or options though which the goal may be achieved.

4.3.2 Making pairwise comparisons. The next step is to make pairwise comparisons of any two decision variables belonging to the same hierarchical level. The pairwise comparison of the decision variables is performed using the fundamental Saaty scale shown in table 1.

The relative weights or priorities of decision criteria and alternatives need to be identified. From the set of pairwise comparison of the variables, a judgment matrix A is generated with n rows and n columns, where n is the number of variables being considered.

$$A = \begin{bmatrix} A11 & . & . & A1n \\ . & . & . & . \\ . & . & . & . \\ A1n & . & . & Ann \end{bmatrix}$$

4.3.3 Calculate waste management criteria weights. Based on the developed judgement matrix A, a series of calculations are then performed in order to identify the relative weight of each waste management criterion.

4.3.3.1 Environmental criteria. Environmental criteria for end-of-life management scenarios are calculated using the LCA methodology. The environmental impact (EI) score of each scenario is expressed in eco-indicator points (mPt) and computed as follows:

$$EI_j = \sum_{i=1}^{n} ICIi \tag{1}$$

where IC_i is the impact category indicator I; n the number of impact category indicators; and j the number of waste management scenarios

The life cycle inventory (LCI) data is derived from a streamlined LCA study of average shoes, which was based on generalized manufacturing data found in commercial databases. The LCI calculations and the life cycle impact assessment (LCIA) phase are conducted in SimaPro 7 LCA software using recognized impact assessment methods.

Table 1. The AHP pairwise comparison scale (Saaty 1980).

Numerical rating	Definition
1	Both criteria equally important
3	Very slight importance of one criterion over the other
5	Moderate importance of one criterion over the other
7	Demonstrated importance of one criterion over the other
9	Extreme or absolute importance of one criterion over the other
2, 4, 6, 8	Intermediate values between two adjacent judgements

Finally, for the sake of consistency, the environmental impact score (EI_j) of each scenario requires normalizing and expressing in unit-free numbers. The normalized environmental impact score (NEI_j) for each scenario is calculated as follows:

(i) calculate the reciprocal of each environmental impact score (REI_j);
(ii) divide the reciprocal of each environmental impact score (REI_j) by the sum of all reciprocal scores.

$$NEI_j = \frac{REIj}{\sum_s REIj} \tag{2}$$

where

$$REI_j = \frac{1}{EIj}$$

and EI_j is the environmental impact score of each scenario(s).

4.3.3.2 Economic criteria. Economic values for each end-of-life management scenario are calculated using the benefit-to-cost ratio (BCR) approach. The BCR ratio must be greater than or equal to 1, i.e. $B/C > 1$, where B is the benefit and C is the cost of each alternative. The end-of-life economic value and benefit/cost ratio are calculated based on the following methods:

(i) Reuse benefit/cost ratio (BCR_{RE})

The revenue of the reuse scenario (B_{RE}) derived from the resale value of the shoe (B_{resale}) while the costs (C_{RE}) arise from collection costs ($C_{\text{collection}}$), transportation costs (C_{trans}) and refurbishing costs (C_{refurb}). Therefore, the reuse benefit/cost ratio (BCR_{RE}) can be obtained as follows:

$$BCR_{RE} = \frac{\sum B_{RE}}{\sum C_{RE}} = \frac{B_{\text{resale}}}{C_{\text{collection}} + C_{\text{trans}} + C_{\text{refurb}}} \tag{3}$$

(ii) Recycling benefit/cost ratio (BCR_{RC})

The revenues of the recycling scenario (B_{RC}) is a function of the weight of the recovered material (B_{weight}) and the market value of the material (B_{value}). The costs (C_{RC}) arise from collection costs ($C_{\text{collection}}$), transportation costs (C_{trans}), separation costs ($C_{\text{separation}}$) and shredding costs (C_{shred}). Therefore, the recycling benefit/cost ratio (BCR_{RC}) can be obtained as follows:

$$BCR_{RC} = \frac{\sum B_{RC}}{\sum C_{RC}} = \frac{B_{\text{weight}} * B_{\text{value}}}{C_{\text{collection}} + C_{\text{trans}} + C_{\text{separaton}} + C_{\text{rshred}}} \tag{4}$$

(iii) Energy recovery benefit/cost ratio (BCR_{ER})

The revenues of the energy recovery scenario (B_{ER}) are a function of the net energy produced (B_{energy}) and the unit price of the produced energy (B_{price}). The costs (C_{ER})

arise from collection costs ($C_{\text{collection}}$) and transportation costs (C_{trans}). Therefore, the energy recovery benefit/cost ratio (BCR_{ER}) can be obtained as follows:

$$BCR_{ER} = \frac{\sum B_{ER}}{\sum C_{ER}} = \frac{B_{\text{energy}} * B_{\text{price}}}{C_{\text{collection}} + C_{\text{trans}}} \tag{5}$$

(iv) Disposal benefit/cost ratio (BCR_{DS})

There are no projected revenues in the disposal scenario (B_{DS}). The costs (C_{DS}) arise from transportation costs (C_{trans}) and landfilling costs (C_{land}). Landfilling cost (C_{land}) is a function of the weight of the shoe (W_{shoe}) and the actual cost of landfilling per tonne of material (C_{al}). Therefore, the disposal benefit/cost ratio (BCR_{ER}), which is always zero, can be obtained by the following formula:

$$BCR_{DS} = \frac{\sum B_{DS}}{\sum C_{DS}} = \frac{0}{C_{\text{trans}} + (W_{\text{shoe}} * C_{\text{al}})} = 0 \tag{6}$$

The benefit-to-cost ratio (BCR_j) for each shoe waste management scenario is then normalized for consistency purposes. The normalized benefit/cost ratio ($NBCR_j$) is calculated by dividing each benefit/cost ratio by the sum of all benefit/cost ratios as given in equation (3):

$$NBCR_j = \frac{B_{CR_j}}{\sum_j \mathrm{B_{CR_j}}} \tag{7}$$

where $NBCR_s$ is the normalized benefit/cost ratio for each scenario; BCR_s the benefit/cost ratio for each scenario; and j the number of waste management scenarios.

4.3.3.3 Technical criteria. The technical criteria are calculated by using the AHP method. In fact, a micro-AHP analysis is performed to calculate these criteria weights as part of a macro-AHP method for the overall analysis. In this respect, the same AHP steps are performed as described before (see section 4.3): structuring the problem into a hierarchy, making pairwise comparisons, calculating criteria weights and synthesizing the priorities.

It should be mentioned that the weight value of the technical criteria relies less on numbers and statistics but more on interviews, questionnaires, subjective reports and case studies. In this respect, the technical criteria and their weights can be easily changed by the user depending on the requirements of the analysis.

4.3.4 Synthesize the priorities. The final step in applying the AHP method is to calculate the composite weight factor (W_j) of each alternative shoe waste management scenario. A simple additive method is utilized to synthesize the AHP priorities (P_i) and the weights of the alternatives with respect to each decision variable (K_{ij}).

$$W_j = \sum P_i \times K_{jjI} \tag{8}$$

where $i = 1, \ldots, n$ is the decision variables (factors, criteria, sub-criteria); W_j the composite weight of alternative option j; P_i the relative weight of variable i with respect to the overall goal; and K_{ij} the relative weight of alternative j with respect to variable i.

5. Illustrative example of decision-making model

The proposed decision-making model is applied to evaluate a real shoe waste management problem. The selected shoe is a men's casual shoe (MCS), as depicted in picture 1, with the following characteristics:

MCS upper: Leather
MCS lining: Leather
MCS sole: Rubber
MCS weight: 350gr

This type of shoe has been selected because it is made of leather and rubber, two of the most common materials used in shoes. This illustrative example demonstrates the practicality of the decision-making model for shoe waste management.

5.1 *MCS waste management model*

Figure 2 presents the MCS waste management model. Five end-of-life management scenarios have been selected for this type of shoe:

1. *Reuse scenario:* reuse of shoe to less-developed countries.
2. *Recycling scenario 1:* shredding of shoe as a whole.
3. *Recycling scenario 2:* disassembly of shoe to isolate materials and then shredding of separated materials.
4. *Incineration scenario:* incineration of shoe in municipal solid waste incinerators to generate heat and electricity.
5. *Disposal scenario:* land filling of shoe.

Picture 1. Men casual shoe (MCS).

5.2 *MCS waste management factors*

Quantitative (environmental and economic) and qualitative factors are being considered in this case study. Environmental criteria include a number of well-recognized impact category indicators such as global warming potential, human eco-toxicity, ozone depletion, etc. Economic criteria are simply divided into costs and benefits for each end-of-life management scenario. Finally, the technical factors comprise of technical feasibility, compliance with legislation, market pressures and public opinion.

5.3 *Prioritize alternatives*

As previously described (see section 4.3), the application of the AHP method requires the following steps: structuring of the problem into a decision hierarchy, making pairwise comparisons, calculating criteria weights and, finally, synthesizing the priorities.

5.3.1 Structuring the problem into a decision hierarchy. Figure 3 presents the AHP hierarchy of the MCS waste management problem.

The hierarchy is structured into four levels:

1. At the first (or top) level is the overall goal of the decision-making problem. In our case, the goal is to identify optimal end-of-life management option for MCS.

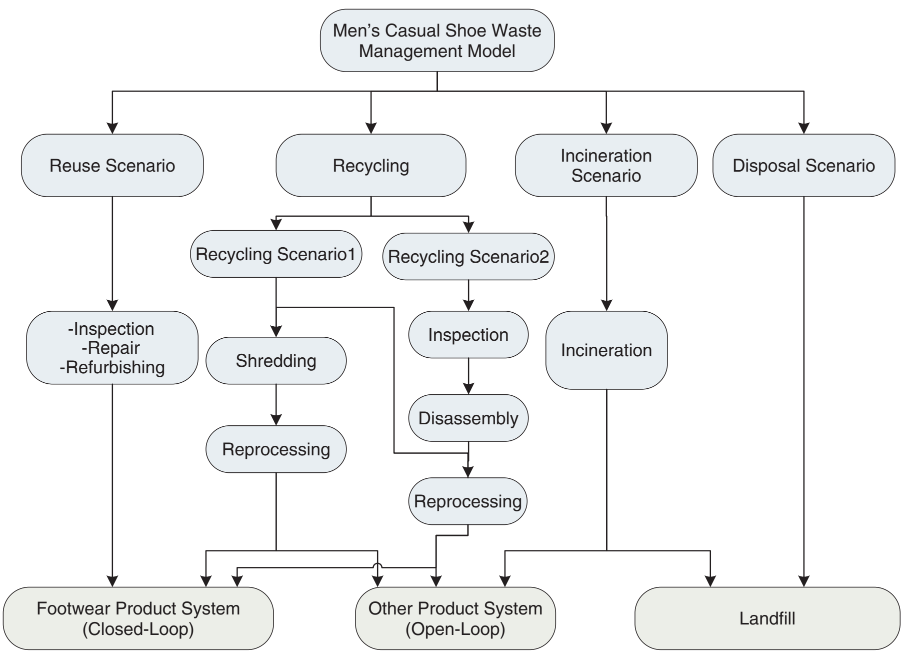

Figure 2. MCS waste management model.

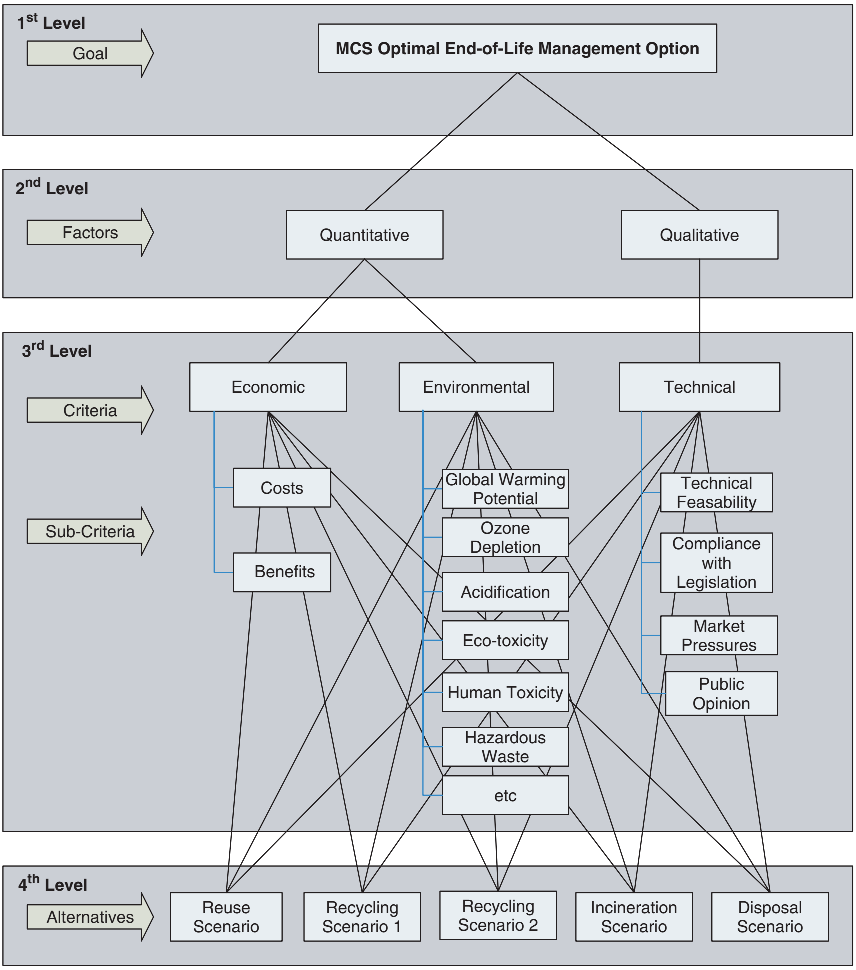

Figure 3. AHP hierarchy of men's casual shoe waste management problem.

2. At the second level, the goal is broken down using quantitative and qualitative factors.
3. At the third level, the quantitative and qualitative factors are divided into criteria and sub-criteria.
4. At the fourth (or bottom) level are the five MCS end-of-life management options that are to be evaluated in terms of the criteria and sub-criteria of the third level.

5.3.2 Making pairwise comparisons. To estimate the significance of each end-of-life management scenario (level 4) in achieving the overall goal (level 1), pairwise comparisons of the decision variables within a lower level of the hierarchical structure with respect to the variables in the next higher level are performed.

Table 2. Pairwise comparison matrix for Level 2.

	Economic	Environmental	Technical	Priority weight
Economic	1	1/2	3	0.3196
Environmental	2	1	4	0.5584
Technical	1/3	1/4	1	0.1220

These decision variable weights could be determined by using questionnaires to obtain stakeholders (governmental, experts, public, business, etc.) opinions.

The judgement matrix of pairwise comparisons of the factors in the upper level of the hierarchy is shown in table 2, along with the resulting weight of priorities. This weight gives the relative priority of the factors measured on a ratio scale. In our case, environmental factors have the highest priority, with 0.559.

Note, for example, that in comparing the economic factors row with the environmental factors column, a value of 1/2 is assigned. However, when comparing it with technical factors it is preferred, and a value of 3 is entered in the first row. At the same time, the reciprocal value 1/3 is automatically entered in the third row under technical factors.

In the same way, analysis can be done at the lower level. Pairwise comparisons of each end-of-life management scenario are performed with respect to each of the decision variables. For example, the five end-of-life management scenarios are compared with one another; first relative to economic criteria, then relative to environmental criteria and, finally, relative to technical criteria.

5.3.3 Calculate criteria weights

5.3.3.1 Environmental criteria. Sixteen (16) potential impact category indicators (ICI_i) have been selected (i.e. global warming potential, acidification potential, eco-toxicity factors in water etc.), as depicted in table 3. The LCI data is derived from a streamlined LCA of a men's casual shoe, which was based on generalized manufacturing data. The total environmental impact (EI_j) of each MCS waste management scenario and the score of each impact category indicator (ICI_i), are calculated by using equation (1), and presented in table 3.

The disposal scenario has the highest environmental impact score with 282.59 mPt while recycling scenario 1 (shredding of the shoe as a whole) has the lowest impact score of 23.16 mPt. The LCA calculations were conducted in SimaPro 7 using the EDIP (Environmental Design of Industrial Products) impact assessment method (Wenzel *et al*. 1997). The total environmental impact (EI_j) score for each scenario is, then, normalized, by using equation (2), and expressed in unit-free numbers as shown in table 4.

5.3.3.2 Economic criteria. An experimental data set based on average values for costs and benefits has been used to calculate the benefit/cost ratio for each MCS end-of-life management scenario. Each scenario is calculated as follows:

(i) Reuse MCS scenario

Table 3. Total environmental impact (EI_j) of each scenario.

Impact Category Indicator (ICI)	Unit	Re-use Scenario	Recycling Scenario 1	Recycling Scenario 2	Incineration Scenario	Landfill Scenario
Total (EI_j)	mPt	29.33	23.16	23.26	221.88	282.59
Global warming (GWP 100)	mPt	1.10	0.61	0.61	0.81	0.70
Ozone depletion	mPt	0.04	0.03	0.03	0.03	0.03
Acidification	mPt	0.64	0.12	0.12	0.12	0.12
Eutrophication	mPt	0.05	0.04	0.04	0.05	0.11
Photochemical smog	mPt	0.71	0.21	0.21	0.21	0.22
Ecotoxicity water chronic	mPt	7.60	6.67	6.68	102.00	121.00
Ecotoxicity water acute	mPt	7.33	6.39	6.40	99.90	130.00
Ecotoxicity soil chronic	mPt	2.66	1.64	1.65	3.62	1.63
Human toxicity air	mPt	1.66	1.15	1.15	1.16	1.15
Human toxicity water	mPt	1.50	1.49	1.50	8.05	20.80
Human toxicity soil	mPt	2.86	2.20	2.20	2.54	3.22
Bulk waste	mPt	1.52	1.02	1.08	1.05	1.99
Hazardous waste	mPt	0.95	0.95	0.95	0.95	0.95
Radioactive waste	mPt	0.71	0.64	0.64	0.68	0.68
Slags/ashes	mPt	0.00	0.00	0.00	0.71	0.00
Resources (all)	mPt	0.00	0.00	0.00	0.00	0.00
SimaPro 7.0						
Method:	EDIP/UMIP 97 V2.03/EDIP World/Dk					

Table 4. Normalized environmental impact (NEI_j) score.

	Environmental impact score (mPt)	Normalized results
Reuse scenario	29.33	0.2656
Recycling scenario 1	23.16	0.3367
Recycling scenario 2	23.26	0.3351
Incineration scenario	221.88	0.0351
Disposal scenario	282.59	0.0273

Calculations are based on equation (3) taking into consideration the following values:

$$B_{RE} = B_{\text{resale}}$$
$$C_{RE} = C_{\text{collection}} + C_{\text{trans}} + C_{\text{refurb}}$$

(ii) Recycling MCS scenario 1

Calculations are based on equation (4) taking into consideration the following values:

$$B_{RC1} = (B_{\text{weight}}) * (B_{\text{value}})$$
$$C_{RC1} = C_{\text{collection}} + C_{\text{trans}} + C_{\text{shred}}$$

(iii) Recycling MCS scenario 2

Calculations are based on equation (4) taking into consideration the following values:

$$B_{RC2} = (B_{\text{weight}}) * (B_{\text{value}})$$
$$C_{\text{RC2}} = C_{\text{collection}} + C_{\text{trans}} + C_{\text{separation}} + C_{\text{shred}}$$

(iv) Incineration MCS scenario

Calculations are based on equation (5) taking into consideration the following values:

$$B_{ER} = (B_{\text{energy}}) * (B_{\text{price}})$$
$$C_{ER} = C_{\text{collection}} + C_{\text{trans}}$$

(v) Disposal MCS scenario

Calculations are based on equation (6) taking into consideration the following values:

$$B_{DS} = \text{nil}$$
$$C_{DS} = C_{\text{trans}} + [(W_{\text{shoe}}) * (C_{\text{land}})]$$

Benefit-to-cost ratio is then normalized, by using equation (7), in order to be used by the AHP method. Table 5 presents the benefit to cost ratio and the normalized results for each end-of-life management scenario.

5.3.3.3 Technical criteria. The technical criteria are calculated by applying the AHP method in a local scale. Once again, a series of pairwise comparisons are performed in order to identify the weight of each criterion. The MCS waste management scenarios are then compared to each other with respect to each criterion, again by making a series of pairwise comparisons. The final result is a score (composite weight) for each alternative MCS waste management scenarios with respect to technical criteria. The results of the pairwise comparison of alternative scenarios with respect to each technical criterion as well as the final composite weight of each scenario are presented in table 6.

5.3.4 Synthesize the priorities. Finally, the composite weight factor (W_j) of each MCS waste management option need to be calculated. The results of the pairwise comparison of the five end-of-life management scenarios with respect to each decision variable as well as the final composite weight of each scenario are presented

Table 5. Normalized MCS benefit/cost ratio.

	Benefit/cost ratio*	Normalized results
Re-use scenario	2.00	0.3200
Recycling scenario 1	1.66	0.2667
Recycling scenario 2	1.75	0.2800
Incineration scenario	0.83	0.1333
Disposal scenario	0.00	0.0000

*An experimental data set has been used for these values.

Table 6. Synthesis of technical criteria weights.

	Technical criteria				
	Technical feasibility	Public opinion	Market pressures	Compliance with legislation	
Relative weight of technical criteria	0.07	0.15	0.43	0.35	
End-of-life management scenarios	Relative weight of scenarios with respect to criteria				Composite weight
Re-use scenario	0.16	0.18	0.26	0.26	0.2415
Recycling scenario 1	0.44	0.33	0.33	0.32	0.3353
Recycling scenario 2	0.29	0.37	0.26	0.29	0.2882
Incineration scenario	0.08	0.09	0.11	0.09	0.0969
Disposal scenario	0.04	0.03	0.04	0.04	0.0381

in table 7. This table synthesizes the results of both the relative weights of decision variables with respect to the overall goal (*Pi*), and the relative weights of alternative with respect to each decision variable (*Kij*). To calculate the composite weight (*Wj*) for each scenario the equation (1) has been utilized as described in section 4.3.4.

The composite weight (*Wj*) indicates the overall significance of each end-of-life management option after considering the importance of the decision variables. In fact, composite weight represents the cumulative weights of each alternative option throughout the entire AHP hierarchy, as described in figure 3. For example, the composite weight of reuse scenario after considering the entire hierarchy is 0.2800. This is the cumulative weight after considering the relative weight of reuse scenario with respect to each decision variable and the relative weight of the decision variables to overall goal. This is calculated in equation (8) as follows:

$$\begin{aligned} W_{\text{MCS reuse scenario}} &= \sum P_{\text{MCS reuse scenario}} \times K_{i\,\text{MCS reuse scenario}} \\ &= (0.2656 \times 0.5584) + (0.3200 \times 0.3196) \\ &\quad + (0.2415 \times 0.1220) \\ &= 0.2800 \end{aligned}$$

The graphical representation of the aggregated results for each MCS end-of-life management scenario is shown in figure 4.

Results indicate that recycling scenario 1 (shedding the shoe as a whole) is the most preferable option for a men's casual shoe, whereas disposal scenario (land filling) is the least. However, the priority weight given to each decision variable clearly influences the final results. If a waste management option received the least weight with respect to most of the criteria, then it will most likely be the least preferable option, as in the case of disposal. Based on the results, the priority weight given to environmental criteria (0.5584) as the most important factor in evaluating the end-of-life management options of a men's casual shoe, corresponds to the high composite weight given to MCS reuse and recycling scenarios.

Table 7. Synthesis of priorities.

	Decision variables for men's casual shoe			
	Environmental	Economic	Technical	
Relative weight of decision variables (*Pi*)	0.5584	0.3196	0.1220	
End-of-life management scenarios	Relative weight of scenarios with respect to variables (*Kij*)			Composite weight (*Wj*)
Reuse scenario	0.2656	0.3200	0.2415	0.2800
Recycling scenario 1	0.3367	0.2667	0.3353	0.3141
Recycling scenario 2	0.3351	0.2800	0.2882	0.3118
Incineration scenario	0.0351	0.1333	0.0969	0.0740
Disposal scenario	0.0273	0.0000	0.0381	0.0199

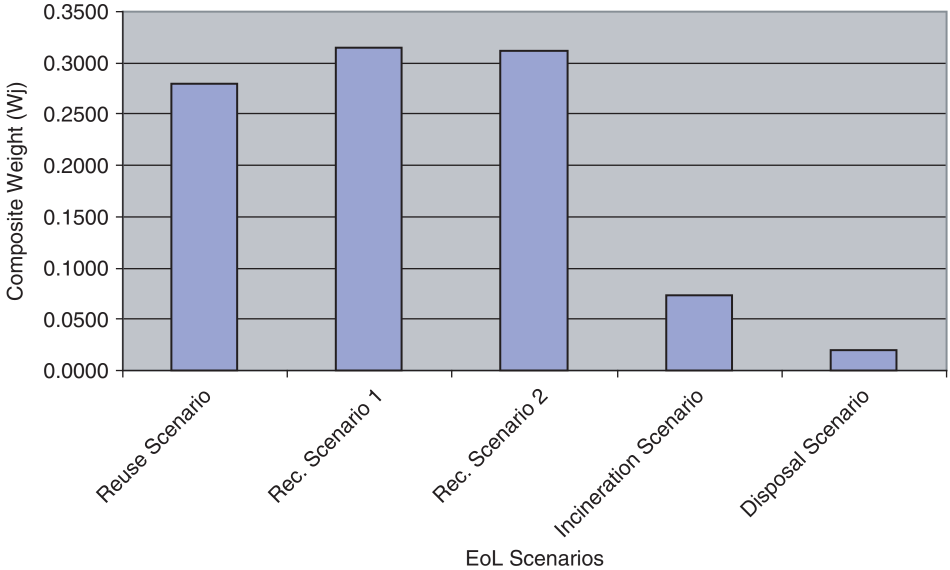

Figure 4. Aggregated results for MCS end-of-life management scenarios.

6. Conclusion

The growing number of post-consumer shoes and the wide range of materials and construction methods used in shoe manufacturing, highlight the need for a systematic approach to deal with end-of-life shoe waste. However, the viability of recovery and recycling scenarios has always been subject to a number of factors including economical, environmental and technical considerations. This paper has presented a decision-making model to identify the most appropriate end-of-life management option for a selected range of shoe types. The decision-making model provides an integrated approach to evaluate a number of related factors which influence the final decision for a shoe waste management option. Although this decision-making model has been applied in the footwear industry, it can also be utilized in other industrial sectors. However, a holistic approach to waste management requires commitment by various actors within the supply chain, including material suppliers, manufacturers, retailers and even consumers. The authors' future research will focus on a number of specific challenges in establishing a sustainable shoe recovery and recycling chain which includes consideration on sustainable reverse logistics, identifying new generation of recycling processes in footwear industry and, finally, establishing value recovery chains for shoe recycled materials.

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