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# An integrated approach for the management of demolition waste in Cyprus

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This study investigated the generation and management of demolition waste (DW) in Cyprus. A methodology has been developed and applied for the estimation of the quantities of the waste stream under examination, since quantitative primary data were not available. The existing situation relating to the practices applied for the management of DW was investigated and assessed. Furthermore, a multi-criteria analysis method (PROMETHEE II) was developed and applied in order to examine alternative systems that could be implemented for the management of the DW in the country. In particular, nine management systems (scenarios) were examined, evaluated and ranked according to their efficiency using seventeen individual criteria, divided into four groups (social–legislative, environmental, economic and technical). The ranking of the alternative waste management scenarios indicated that the optimum management system for possible implementation in the island included complete selective demolition procedures and transfer of mixed recyclable materials to the recycling centre and non-recyclable material to landfill.

**Keywords**: Waste management, demolition waste, multi-criteria analysis, Cyprus, wmr 1353–5



## Introduction

Demolition waste (DW) is generated from the total or partial demolition of buildings and civil infrastructure, as well as from activities related to the renovation and maintenance of buildings.

Some fractions of DW are categorized as hazardous in the European Waste Catalogue (European Commission 2001) due to their content (e.g. asbestos, PCBs or other dangerous substances). In addition, natural resources are consumed for the production of building and construction materials. Reserves are not abundant in all cases and there may also exist problems related to the extraction of these materials. Furthermore, materials contained in DW, such as bricks, tiles and concrete, could be recovered and utilized instead of being disposed at landfills.

Moreover, DW is generated in very large quantities and, compared to other waste types, it is relatively simple to divert the main portion of this waste from landfilling. This diversion can be achieved by applying practices for the recovery of materials from the DW stream for reuse or/and recycling.

Demolition waste has been identified as a priority waste stream, according to the European Union Waste Strategy, and in the framework of the Sixth Environment Action Program entitled *Environment 2010: Our future, Our choice*, actions need to be taken concerning its effective management (EC 2001). This means that particular attention will be paid to policies and measures to ensure increased recycling of materials from the DW stream. DW contains a significant fraction of recyclable materials and the technology used for the separation and recovery of these materials is well established, readily accessible and in general inexpensive. Finally, there is a reuse market for aggregates derived from construction waste and DW in roads, drainage and other construction projects.

Taking into consideration the issues mentioned above, this article presents the research that was developed for the management of DW that is generated in Cyprus, a new member state of the EU. The approach that was followed is based on the development and application of a multi-criteria analysis decision-making method.

## Methodology

The methodology that was applied for the purpose of this work included the following actions.

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### Collection, recording and assessment of primary data that was used for the estimation of the quantities of the waste under study

The main parameter for the development of an appropriate scheme for the management of every waste stream is the knowledge of their generated quantities. DW is one of the waste streams for which data related to the quantities that are generated is not easily available. As a result, supporting calculation tools must be developed and applied in order to estimate the quantities that are generated during demolition activities in order to gain the necessary information.

In particular, for the case study of Cyprus, the following actions have taken place: all the actors and authorities involved in the generation and management of DW were listed, and the sources for the collection of data related to this waste stream were selected (it must be mentioned that the primary data kept by the actors and authorities do not refer to waste quantities, but could be used as a basis for the extraction of quantitative data). The inventory program was carried out through visits, personal contacts and discussions with the representatives of the actors involved as well as with the personnel of the authorities that keep data and information necessary for the determination of the quantities of DW.

Figure 1 presents the primary collected data that were necessary for the estimation of the quantity of DW (number of the buildings that were demolished during the time period from 1990 to 2002).

### Estimation of the generated quantities using appropriate tools

The primary collected data, which were gathered via the records kept by the relevant authorities, was evaluated and processed for the estimation of the quantities of DW. This estimation was carried out using a mathematical model that has been developed by the NTUA working team (NTUA 2002), which is based on the following equation:

$$DW = ND \times ANF \times AS \times DWB \times D \qquad (1)$$

where *DW* is the generated quantities of demolition waste (tonnes); *ND* is the number of buildings that were demolished; *ANF* is the average number of floors per demolished building (1.3); *AS* is the average surface of building which is going to be demolished (130 $m^2$); *DWB* is the volume of the generated waste per 100 $m^2$ of surface of demolished building (80 $m^3$ per 100 $m^2$); and *D* is the density of generated waste (1.6 t $m^{-3}$).

### Recording and assessment of the existing situation related to the practices that are applied for the management of DW

The information on the practices and techniques that are currently applied for the management of this waste stream in Cyprus were recorded through meetings and discussions with all the Cypriot government authorities (Department of Urban Planning of the Ministry of Interior, Environmental Service of the Ministry of Agriculture, Natural Resources and Environment, Statistic Service) and actors involved in the field (companies that deal with construction and demolition activities, Association of Contractors, Technical Chamber of Cyprus, environmental companies).

The aim was to obtain a clear and representative picture on the existing management schemes as well as to determine their effectiveness and the level of harmonization with the provisions of the European and national environmental policy.

### Development of a multi-criteria method for the selection of the optimum system for the management of demolition waste

#### The PROMETHEE method

Several multi-criteria decision-making (MCDM) methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations are employed for waste management planning decisions (Macharis *et al.* 2004, Pohekar & Ramachandran 2004). Applications of MCDM include areas, such as integrated manufacturing systems, evaluations of tech-

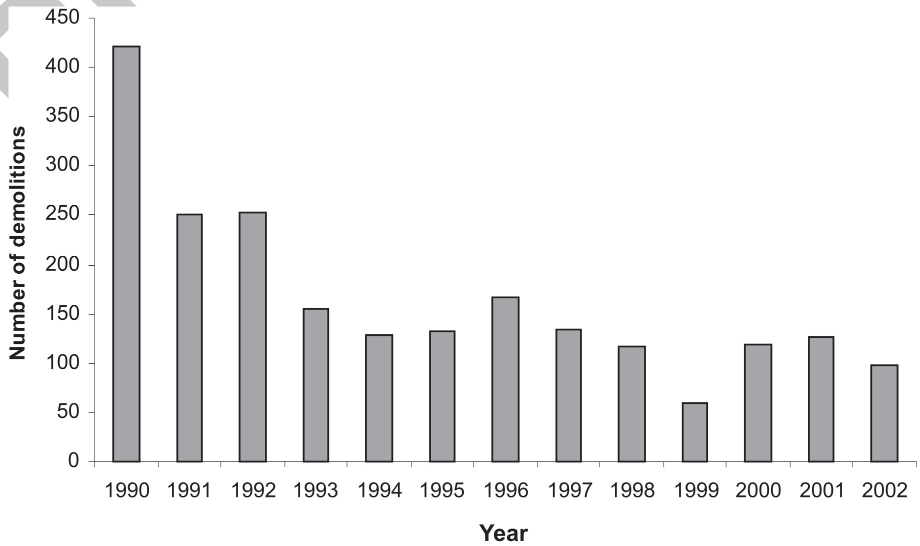


Fig. 1: Number of buildings that were demolished per year.

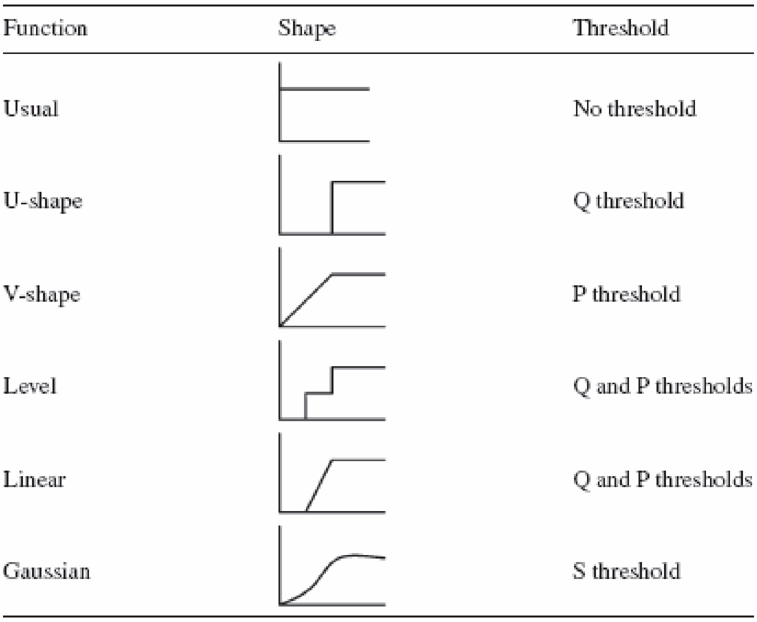


Fig. 2: Preference functions in PROMETHEE.

nology investment, solid waste and wastewater management, agriculture management and energy planning (Haralambopoulos & Polatidis 2003, Khalil *et al*. 2005).

For the purposes of this study, the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) II method was developed and applied. This is one of the most efficient multi-criteria methods, based on the outranking relations concept (Kalogeras *et al*. 2005).

A number of modelling options have to be chosen before PROMETHEE can be implemented on any problem. These options include the choice of an appropriate preference function and the weighting given to each variable. The preference function defines how one object is to be ranked relative to another and translates the deviation between the evaluations of two samples on a single parameter into a preference degree. The preference degree represents an increasing function of the deviation; hence, smaller deviations will contribute to weaker degrees of preference and larger ones to stronger degrees of preference (Herngren *et al*. 2006).

Six preference functions represented by specific shapes are available in the PROMETHEE method (Figure 2). Each shape is dependent on the use of two thresholds, Q and P. Q is an indifference threshold representing the largest deviation that is considered negligible and the preference threshold P represents the smallest deviation that is considered as decisive. P cannot be smaller than Q. The use of indifference ($q$) and preference ($p$) thresholds facilitates the decision-maker to express his preferences, without the need of determining functions of value. The type and the value of thresholds depend on: (i) the nature of the criterion; (ii) the grade of dissemination of the alternative choices; (iii) the objective uncertainty relatively to the precision of data; and (iv) the subjective hesitations of the decision-maker when he encounters low-grade differences between alternative choices. According to Figure 2, Usual function is applied without using the Q or P threshold, the U-shape and V-shape functions utilize the Q and P threshold, respectively, and the Level and Linear functions use both Q and P thresholds. The Gaussian threshold S is a middle threshold value that is only used with the Gaussian preference function (Kalogeras *et al*. 2005).

The resolution of the multiple-criteria problem with the PROMETHEE method follows the successive stages which are presented below (Diakoulaki 2003; Araz *et al*. 2007; Wang & Yang 2007):

**A. Binary comparison of alternatives per criterion:** in this stage all pairs of alternatives ***a*** and ***b*** are examined successively in each criterion $j$. The extracted indicators of preference $p_j(a, b)$ take value in the interval [0–1] and show the degree in which alternative ***a*** is preferred in comparison to alternative ***b*** according to the particular criterion. The result of binary comparison of all pairs of examined alternatives in a criterion is expressed in a square matrix of $n \times n$ dimensions (n: the number of alternative solutions). The preference indicator for each pair of alternatives (a, b) ranges between 0 and 1. The higher it is (closer to 1), the higher is the strength of the preference for ***a*** over ***b***. The first stage is completed when all the criteria of evaluation are examined and, as a result, $m$ square tables are derived ($m$: the number of criteria).

**B. Calculation of total preference indicators:** for each pair of alternatives ***a*** and ***b***, a total preference indicator $P(a, b)$ is calculated as sum of the partial preference relations in each criterion $p_j(a, b)$, levelled depending on the weight factors of the criteria. The total preference indicators $P(a, b)$ take values in the interval [0,1] and imply whether and how much alternative ***a*** surpasses against alternative ***b***, taking into consideration all the criteria. The results of the calculation of total preference indicators are recorded in a matrix of $n \times n$ dimensions.

**C. Calculation of positive and negative flows:** in this stage two measures of evaluation are calculated for each solution ***a***, that show in which degree this solution surpasses or is falling short against all the rest of alternatives. These are named positive and negative flow, respectively. Preference flows are used to compare the alternatives with each other so that a positive preference flow (Φ+) expresses the degree to which one alternative is preferred to the other alternatives, whereas the negative flow (Φ•) expresses the degree to which all the other alternatives are preferred to the specific alternative.

**D. Complete ranking of alternatives:** The complete ranking flow is given by the net flow (Φ), which is the difference between the positive and negative flow. The higher the net flow, the better the alternative. This is the PROMETHEE II version of the method. The net flow constitutes a measurement of the supremacy of each choice and recognizes only situations of preference and indifference allowing the complete ranking of the alternatives.

The steps which were followed for the selection of the optimum DW management system are presented below. The steps are listed here.

Step 1: Choice, classification and calibration of the evaluation criteria.
Step 2: Estimation of the criteria weight factors.
Step 3: Setting of alternative DW management systems.
Step 4: Grading of alternative DW management systems.
Step 5: Determination of indifference and preference thresholds.
Step 6: Use of multi-criteria software tool (Decision Lab program based on PROMETHEE II method).
Step 7: Ranking of alternative DW management systems.

*Determination and description of criteria*

All the possible criteria were examined and the appropriate ones were selected/set. The setting/selection of the criteria was made according to existing experience from similar applications in order to: (i) ensure that all the parameters are used for the examination of each alternative scenario; (ii) ensure the extraction of a representative picture related to the characteristics of each alternative scenario; and (iii) avoid overlapping among the criteria. In particular, 17 criteria were selected and described in order to obtain a representative view concerning their characteristics, which allows the precise calibration of the criteria as well as the adequate grading of the alternative management schemes.

*Calibration of the criteria*

All the selected criteria were calibrated according to their characteristics and performance (covering all the alternative cases, with designation of higher grade for the favorable cases and lower grade for the unfavorable ones, in a scale from 1 to 10). The calibration of the criteria is summarized in Table 1.

Table 1: Calibration of the criteria.

| Group | Criterion | Characteristic | Rate |
|---|---|---|---|
| SOCIAL | $K_1$ | Complete harmonization | 10 |
| | | Partial harmonization | 5 |
| | | No harmonization | 1 |
| | $K_2$ | Full respect of the priorities of legislation | 10 |
| | | Partial respect | 5 |
| | | Respect at low level | 3 |
| | | No application of legislative priorities | 1 |
| | $K_3$ | Full acceptance after informing the public | 10 |
| | | Partial public acceptance | 5 |
| | | Acceptance without informing the public | 3 |
| | | No social acceptance because of a lack of informing | 3 |
| | | No social acceptance after informing | 1 |
| | $K_4$ | Creation of new jobs at significant level | 9 |
| | | Creation of new jobs at low level | 4 |
| | | No creation of new jobs | 1 |
| ENVIRONMENTAL | $P_1$ | Environmental impacts at minimum level | 7 |
| | | Environmental impacts at low level | 4 |
| | | Environmental impacts at very high level | 1 |
| | $P_2$ | Air emissions in significant degree | 6 |
| | | Air emissions in limited degree | 8 |
| | | Air emissions in very low degree | 9 |
| | $P_3$ | Significant generation of wastewater | 6 |
| | | Limited generation of wastewater | 8 |
| | | Very low generation of wastewater | 9 |
| | $P_4$ | Significant generation of solid waste | 6 |
| | | Limited generation of solid waste | 8 |
| | | Very low generation of solid waste | 9 |
| | $P_5$ | Minimum level of noise pollution | 9 |
| | | Noise pollution at limited level | 7 |
| | | Noise pollution at quite high level | 4 |
| | | Noise pollution at very high level | 1 |
| | $P_6$ | Non-existence of visual nuisance | 9 |
| | | Visual nuisance at minimum level | 7 |
| | | Visual nuisance at quite high level | 4 |
| | | Visual nuisance at very high level | 1 |
| ECONOMIC | $O_1$ | Low investment cost | 10 |
| | | Medium investment cost | 8 |
| | | High investment cost | 5 |
| | $O_2$ | Low operational cost | 9 |
| | | Medium operational cost | 7 |
| | | High operational cost | 4 |
| | | Very high operational cost | 1 |
| | $O_3$ | High land demands | 1 |
| | | Relatively high land demands | 3 |
| | | Moderate land demands | 7 |
| | | Low land demands | 9 |

Table 1: Calibration of the criteria. *(Continued)*

| Group | Criterion | Characteristic | Rate |
|---|---|---|---|
| TECHNICAL | $T_1$ | High performance | 9 |
| | | Quite high performance | 7 |
| | | Performance at medium level | 5 |
| | | Low performance | 3 |
| | | Very low performance | 1 |
| | $T_2$ | High existing experience | 10 |
| | | Quite high existing experience | 7 |
| | | Existing experience at medium level | 5 |
| | | Low existing experience | 3 |
| | | Very low existing experience | 1 |
| | $T_3$ | High adaptability to local conditions | 10 |
| | | Quite high adaptability to local conditions | 7 |
| | | Adaptability to local conditions at medium level | 5 |
| | | Low adaptability to local conditions | 3 |
| | | Very low adaptability to local conditions | 1 |
| | $T_4$ | High flexibility | 10 |
| | | Quite high flexibility | 7 |
| | | Moderate Flexibility | 5 |
| | | Low flexibility | 3 |
| | | Very low flexibility | 1 |

*Determination of weight factors*

The determination of the criteria weight factors was made after discussions with all involved authorities and actors who further were requested to answer a questionnaire, rating each criterion to reflect its relative importance in the consideration of choosing an appropriate DW management system. The weighing of the criteria is presented in Table 2.

*Setting of alternative management systems for DW management*

The alternative management systems were set, taking into account the following fundamental parameters: (i) type of demolition procedure; (ii) location of waste management (on and/or off-site); and (iii) type of technology. Analytical data and information concerning these parameters are given elsewhere (Kourmpanis *et al*. 2008).

The development of the alternative management systems was based on state-of-the-art technology as well as on the experience gained from applications at European and international level. Then, reference was made to the specific characteristics of the country (e.g. annual generated quantities of DW, existing infrastructures and relative market) that are necessary for the determination of the most favourable management schemes for possible implementation in Cyprus.

The nine alternative management schemes that were selected are presented below (Figure 3).



Table 2: Determination of criteria weight factors.

| Criteria group | Group weight | Criteria description | Weight of criterion in group (%) | Weight factor (%) |
|---|---|---|---|---|
| Social | 15.00% | Harmonization with the existing legislative framework ($K_1$) | 30.00 | 4.50 |
| | | Application of priorities of legislation ($K_2$) | 30.00 | 4.50 |
| | | Social acceptance ($K_3$) | 25.00 | 3.75 |
| | | Possibilities of new job positions ($K_4$) | 15.00 | 2.25 |
| | | Subtotal | 100.00 | 15.00 |
| Environmental | 30.00% | Level of possible environmental repercussions ($P_1$) | 25.00 | 7.50 |
| | | Air emissions ($P_2$) | 20.00 | 6.00 |
| | | Production of humid waste ($P_3$) | 20.00 | 6.00 |
| | | Production of solid outcast ($P_4$) | 20.00 | 6.00 |
| | | Noise pollution ($P_5$) | 10.00 | 3.00 |
| | | Aesthetic harmful effect ($P_6$) | 5.00 | 1.50 |
| | | Subtotal | 100.00 | 45.00 |
| Economic | 30.00% | Total investment cost ($O_1$) | 40.00 | 12.00 |
| | | Operation and maintenance cost ($O_2$) | 40.00 | 12.00 |
| | | Land requirement ($O_3$) | 20.00 | 6.00 |
| | | Subtotal | 100.00 | 75.00 |
| Technical | 25.00% | Functionality ($T_1$) | 25.00 | 6.25 |
| | | Existing experience-reliability ($T_2$) | 30.00 | 7.50 |
| | | Adaptability in the local conditions ($T_3$) | 25.00 | 6.25 |
| | | Flexibility ($T_4$) | 20.00 | 5.00 |
| | | Subtotal | 100.00 | 100.00 |
| Total | 100.00% | Total | | 100.00 |

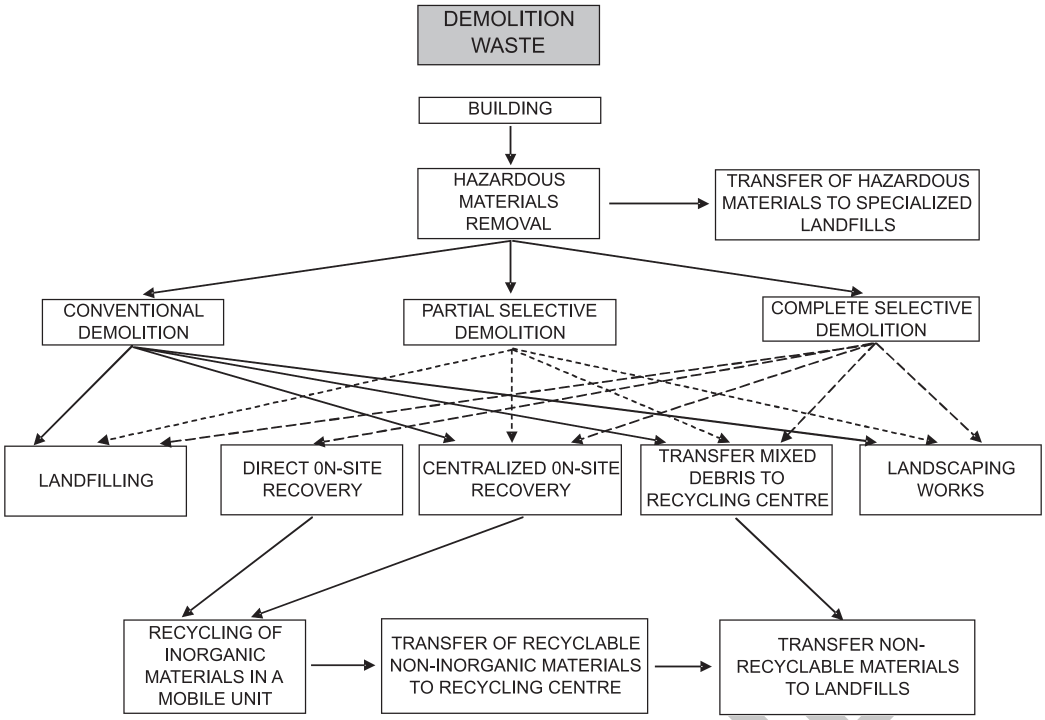


Fig. 3: Alternative management systems for demolition waste.



**Management system 1:** Demolition → landfilling.

**Management system 2:** Demolition → use of materials for banking up and other landscaping works.

**Management system 3:** Conventional demolition → transfer of mixed recyclable materials to recycling centre → transfer of non-recyclable material to landfill.

**Management system 4:** Conventional demolition → centralized recovery of mixed recyclable materials on site and recycling of inorganic materials in a mobile recycling unit → transfer of recyclable organic materials to recycling centre and non-recyclable material to landfill.

**Management system 5:** Partial selective demolition → transfer of mixed recyclable materials to recycling centre → transfer of non-recyclable material to landfill.

**Management system 6:** Partial selective demolition → centralized recovery of mixed recyclable materials on site and recycling of inorganic materials in a mobile recycling unit → transfer of recyclable organic materials to recycling centre and non-recyclable material to landfill.

**Management system 7:** Complete selective demolition → transfer of mixed recyclable materials to recycling centre → transfer of non-recyclable material to landfill.

**Management system 8:** Complete selective demolition → centralized recovery of mixed recyclable materials on site and recycling of inorganic materials in a mobile recycling unit → transfer of recyclable organic materials to recycling centre and non-recyclable material to landfill.

**Management system 9:** Complete selective demolition → direct recovery of individual recyclable materials, separately, on site and recycling of inorganic materials in a mobile recycling unit → transfer of recyclable organic materials to recycling centre and non-recyclable material to landfill.

*Grading of alternative management systems/actions*

The evaluation of the alternative management systems was one of the biggest challenges of the present study. The rating process took place with particular attention, since this stage constitutes the heart of the problem. In particular, the input data related to all groups of criteria was, primarily, gathered through interviews that the working group had with experts in the field at European and international level, as well as by utilizing relevant technical studies. These data were finalized after discussions with all the Cypriot actors involved in the field (Department of Urban Planning of the Ministry of Interior, Environmental Service of the Ministry of Agriculture, Natural Resources and Environment, companies that deal with construction and demolition activities, Association of Contractors, Technical Chamber of Cyprus, environmental companies). The outcome is presented in Table 3.

*Determination of indifference and preference thresholds*

Generally, indifference thresholds are appreciated as 5–15% and preference thresholds as 10–30% of this difference. In this work 10 and 30% were selected, respectively, for each threshold type. The indifference and preference thresholds for each criterion are presented in Table 4.

*Use of multi-criteria software tool (Promethee II method) – ranking of alternative DW management systems*

All the data were inserted into the multi-criteria software tool (Decision Lab), which is based on the PROMETHEE II method, and the nine alternative management systems were ranked according to their efficiency. The method was developed with the utilization of linear, level and Gaussian preference functions.

Table 3: Grading of alternative management systems/actions based on social, environmental, economic and technical criteria.

| Alternative management systems/actions | Social | | | | Environmental | | | | | | Economic | | | Technical | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ($K_1$) | ($K_2$) | ($K_3$) | ($K_4$) | ($P_1$) | ($P_2$) | ($P_3$) | ($P_4$) | ($P_5$) | ($P_6$) | ($O_1$) | ($O_2$) | ($O_3$) | ($T_1$) | ($T_2$) | ($T_3$) | ($T_4$) |
| Action 1 | 1 | 1 | 2 | 1 | 1 | 4 | 6 | 4 | 4 | 1 | 7 | 7 | 1 | 5 | 9 | 9 | 3 |
| Action 2 | 5 | 3 | 3 | 1 | 1 | 3 | 4 | 4 | 4 | 7 | 7 | 6 | 3 | 3 | 9 | 5 | 1 |
| Action 3 | 10 | 6 | 8 | 5 | 4 | 5 | 9 | 7 | 5 | 6 | 5 | 6 | 6 | 6 | 8 | 9 | 8 |
| Action 4 | 10 | 5 | 7 | 4 | 3 | 4 | 8 | 6 | 4 | 5 | 7 | 7 | 7 | 5 | 6 | 8 | 5 |
| Action 5 | 10 | 8 | 9 | 7 | 7 | 7 | 9 | 8 | 6 | 6 | 5 | 5 | 6 | 7 | 7 | 8 | 8 |
| Action 6 | 10 | 7 | 8 | 6 | 6 | 6 | 8 | 7 | 5 | 5 | 7 | 6 | 7 | 6 | 5 | 7 | 5 |
| Action 7 | 10 | 10 | 10 | 9 | 8 | 9 | 9 | 9 | 7 | 7 | 5 | 4 | 6 | 9 | 6 | 8 | 8 |
| Action 8 | 10 | 9 | 9 | 8 | 7 | 8 | 8 | 8 | 6 | 6 | 7 | 5 | 7 | 8 | 4 | 7 | 5 |
| Action 9 | 10 | 9 | 9 | 8 | 7 | 8 | 8 | 9 | 6 | 7 | 7 | 5 | 7 | 8 | 4 | 7 | 5 |

Table 4: Indifference and preference thresholds.

| Criteria group | Criterion | Thresholds | |
|---|---|---|---|
| | | $q$ | $p$ |
| Social | $K_1$ | 0.9 | 2.7 |
| | $K_2$ | 0.9 | 2.7 |
| | $K_3$ | 0.8 | 2.4 |
| | $K_4$ | 0.8 | 2.4 |
| Environmental | $P_1$ | 0.7 | 2.1 |
| | $P_2$ | 0.6 | 1.8 |
| | $P_3$ | 0.5 | 1.5 |
| | $P_4$ | 0.5 | 1.5 |
| | $P_5$ | 0.3 | 0.9 |
| | $P_6$ | 0.6 | 1.8 |
| Economic | $O_1$ | 0.2 | 0.6 |
| | $O_2$ | 0.3 | 0.9 |
| | $O_3$ | 0.6 | 1.8 |
| Technical | $T_1$ | 0.6 | 1.8 |
| | $T_2$ | 0.5 | 1.5 |
| | $T_3$ | 0.4 | 1.2 |
| | $T_4$ | 0.7 | 2.1 |

## Results and discussion

### Estimation of the quantities of DW

Based on the primary collected data presented in Figure 1 and using equation (1), the quantities of waste generated from demolition activities were calculated and the results are illustrated in Figure 4. From the results obtained through the implementation of the procedure described above, it was concluded that the quantities of construction waste generated in Cyprus were characterized by a decreasing trend during time. These quantities decreased from more than 90 000 tonnes per year (year 1990) to approximately 20 000 tonnes per year (year 2002). The reduction that was observed in the generated quantities of DW in Cyprus, over that time was due to the fact that the demolition activities in the island approached a peak at the end of the decade of 1980 and then decreased at a constant rate.

### Existing management practices of DW in Cyprus

The existing practices that are applied for the management of DW in the island are presented below. Those responsible for the demolition work must take care of the transport and the management of the generated waste. Materials that are in relatively good condition are collected (doors, shutters, tiles, bricks, porcelain, ceramics, etc.) and sold, whereas all the remaining portion of waste (cement, broken bricks, soil, etc.) is transported to landfill sites for final disposal or is subjected to uncontrolled disposal. The percentage of materials that is recovered from construction and demolition waste in the country is very low (below 10% of the quantity that is generated, on annual basis), a value that is ranked among the lower ones that are recorded at European level. It is obvious that the practices applied for its management do not comply with the provisions of the European environmental policy that place stress on the recovery, recycling and reuse of waste materials. As a result, a national plan related to the management of this waste stream must be developed for setting and implementing the appropriate schemes and systems (Peng *et al*. 1997; Kartam *et al*. 2004).

### Implementation of PROMETHEE II using the linear preference function

The implementation of PROMETHEE with the use of the linear preference function led to the results that are presented in Table 5.

Table 5: Ranking of alternative management systems using linear function.

| Management system | Net flow (Φ) |
|---|---|
| Management system 7 | 0.19 |
| Management system 9 | 0.16 |
| Management system 8 | 0.14 |
| Management system 5 | 0.11 |
| Management system 6 | 0.05 |
| Management system 3 | 0.04 |
| Management system 4 | 0.00 |
| Management system 1 | –0.24 |
| Management system 2 | –0.45 |

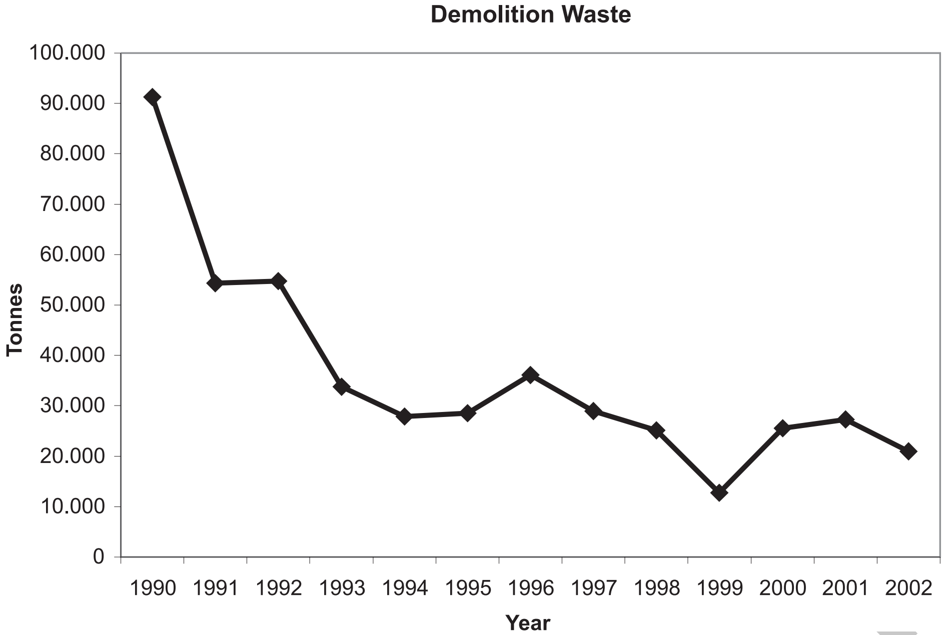


Fig. 4: Estimated annual quantities of DW.

It must be noted that Preference flows were used to compare the alternatives with each other. The positive preference flow ($\Phi+$) expresses the degree to which one action outranks other actions, whereas the negative flow ($\Phi$• ) expresses the degree to which one action is outranked by other actions. The net flow ($\Phi$) constitutes a measurement of the supremacy of each choice and recognizes only situations of preference and indifference allowing the complete ranking of the actions. According to the results management system 7 was the optimal solution followed by management systems 9 and 8. Management systems 2 and 1 appeared to be the worst choices.

### Implementation of PROMETHEE II using the level preference function

The results from the implementation of PROMETHEE using the level preference function are presented in Table 6. According to the results that were obtained it was concluded that management system 7 was the optimum solution, followed by the management systems 9 and 8. Again, management systems 2 and 1 appeared to be the worst choices. Comparing the results with those obtained using the linear preference function, a slight increase in the net flows of the two preferable actions was observed. Nevertheless, the difference between their net flows remained constant.

### Implementation of PROMETHEE II using the Gaussian preference function

The implementation of PROMETHEE applying the Gaussian preference function led to the results that are presented in Table 7. It is obvious that the ranking of the alternative management systems had not changed. Once again, management system 7 was selected as the optimal solution and management system 9 as the second desirable solution. Concerning the case of level preference function a slight increase in the net flows of the two preferable actions was observed. The difference between their net flows was increased; consecutively the superiority of management system 7 was strengthened.



Table 6: Ranking of alternative management systems using level function.

| Management system | Net flow ($\Phi$) |
|---|---|
| Management system 7 | 0.20 |
| Management system 9 | 0.17 |
| Management system 8 | 0.14 |
| Management system 5 | 0.10 |
| Management system 6 | 0.04 |
| Management system 3 | 0.04 |
| Management system 4 | –0.01 |
| Management system 1 | –0.24 |
| Management system 2 | –0.44 |

Table 7: Ranking of alternative management systems using Gaussian function.

| Management system | Net flow ($\Phi$) |
|---|---|
| Management system 7 | 0.23 |
| Management system 9 | 0.19 |
| Management system 8 | 0.16 |
| Management system 5 | 0.13 |
| Management system 6 | 0.04 |
| Management system 3 | 0.03 |
| Management system 4 | –0.04 |
| Management system 1 | –0.29 |
| Management system 2 | –0.45 |

Taking into account the results that were obtained from the implementation of the PROMETHEE II multi-criteria method, it is shown that for the three preference functions of the PROMETHEE method (linear, level and Gaussian) the most favourable management systems, in decreasing efficiency order, were the following.

- Management system 7 that included complete selective demolition procedures and transfer of mixed recyclable materials to the recycling centre and non-recyclable material to landfill
- Management system 8 that referred to complete selective demolition, centralized recovery of mixed recyclable materials on site, recycling of inorganic materials in a mobile recycling unit, transfer of recyclable organic materials to the recycling centre and non-recyclable material to landfill.
- Management system 9 that included complete selective demolition, direct recovery of individual recyclable materials separately on site, recycling of inorganic materials in a mobile recycling unit, transfer of recyclable organic materials to the recycling centre and non-recyclable material to landfill.

Taking into consideration the ranking of the management systems, the relatively low quantities of the generated DW waste in Cyprus and the existing infrastructures for the management of this type of waste in the country, it is concluded that the management system 7 is the most favourable for implementation in the country.

## Conclusions

The development of an effective system for the management of DW has to take into consideration the actual characteristics of the served area (e.g. quantities of generated DW and existing infrastructures) as well as an adequate number of other parameters of social-legislative, environmental, economic and technical nature). The development and application of such AN approach in the case of Cyprus (by using a multi-criteria analysis method – PROMETHEE II) showed that an effective DW management system should be selected for possible implementation in Cyprus, based on the application of complete selective demolition procedures and then the mixed recyclable materials should be transferred to a recycling centre that has to be established in the country, while the non-recyclable materials should be disposed at a landfill site.

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