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Title: A Fuzzy DEMATEL Approach to Assess Determinants of Efficient Kerbside Waste Management in an Urban Context

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A Fuzzy DEMATEL Approach to Assess Determinants of Efficient Kerbside Waste Management in an Urban Context

SHAMS RAHMAN and QINGDA YUAN

Abstract: The management of waste is critical to the health, environmental integrity and longevity of a community. Regulation on waste management in Australia has over the last decade focused on reduction of environmental impact from waste collection and conservation of resources from waste. This study aims to identify the critical determinants of successful implementation of a kerbside waste management system in metropolitan city councils in Melbourne. The critical case sampling method is used to identify three city councils for this study. Through a literature review, eight determinants of kerbside waste management are identified and used in this study. The fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) approach is used for data analysis and to prioritize determinants and investigate direct and indirect causal relationships between all determinants. Results show, appropriate level of infrastructure, monitoring and evaluation and legislation are the three top-ranked determinants, while legislation and administrative leadership are the two major drivers for a successful implementation of kerbside waste management systems.

Keywords: DEMATEL approach, Determinants, Waste management, Urban context

1. Introduction

Municipal solid waste (MSW) is generated from municipal or residential activities and comprises hard waste, recyclables, organics and residual materials (commonly referred to as garbage). MSW may also include materials from municipal activities, such as emptying litter bins, sweeping streets, maintaining parks and some quantities of materials from municipal construction and demolition works. MSW is mostly collected by councils from the kerbside. The management of waste is critical to the health, environmental integrity and longevity of a community. In 2005, the Victorian State Government in Australia introduced a strategy called *Towards Zero Waste* (TZW 2005), which as the name suggests, commits the State to the goal of achieving 'Zero Waste'. It seeks to minimize the amount of waste generated and maximize opportunities for recovering materials. This strategy sets the direction and vision for a more sustainable Victoria. The goals of the TWZ strategy are to (DSE 2009):

- Generate less waste;
- Increase the amount of materials for recycling and reprocessing; and

- Reduce damage to our environment caused by waste.

The aim of this study is to identify the critical determinants of successful implementation of kerbside waste management (KWM) systems in metropolitan city councils. The rest of the paper is organized as follows. Section two provides a brief discussion on the waste profile of Victoria. Section three reviews relevant literature and identifies determinants of successful implementation of kerbside waste management systems. This is followed by the research methodology in section four. Section five presents the results of the analysis and discusses the findings and sensitivity analysis. Finally, a series of conclusions are drawn in section six.

2. Waste profile of Victoria

Waste is categorized as three types (DSE 2009):

- Municipal solid waste (MSW) (from households and council operations);
- Construction and demolition (C&D); and
- Commercial and industrial (C&I).

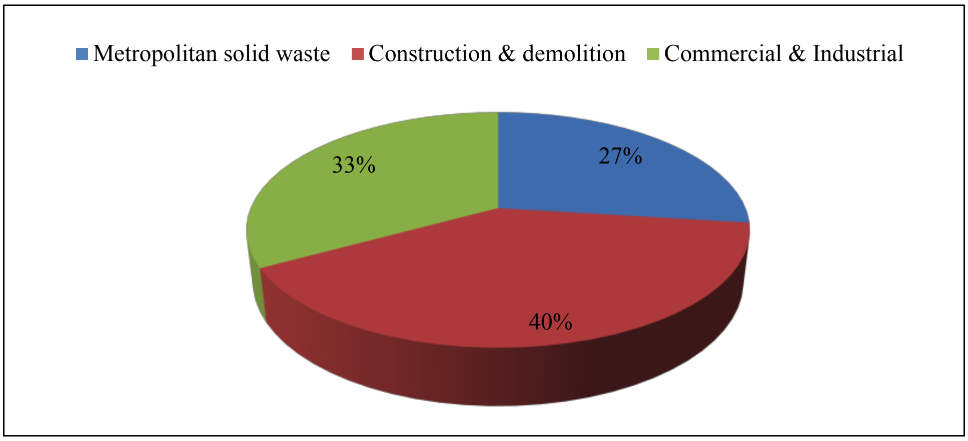

Figure 1: Solid waste generated in Victoria by weight, 2006–07

C&D and C&I waste account for 73 per cent of the total waste stream. MSW accounts for 27 per cent (Refer to *Figure 1*). This study deals with the kerbside waste management system of MSW in metropolitan city councils. The amount of MSW generated is measured by proxy, through the amount of waste that municipal councils collect. The statistics on MSW collected from kerbsides between 2001–02 and 2008–09 show that (VAR 2011):

- The amount of municipal waste collected from households through garbage, recycling and organic kerbside collections increased from around 1.6 million tonnes to 1.9 million tonnes (around 0.3 million tonnes, or 19 per cent increase);
- The majority of this increase (0.2 million tonnes, or 76 per cent) occurred in metropolitan Melbourne; and
- Waste collected in regional Victoria increased by around 0.07 million tonnes, contributing the remaining 24 per cent.

Of the 1.9 million tonnes of municipal solid waste collected in 2008–09, around one million tonnes (54 per cent) was garbage, followed by recyclables and organics (32 per cent and 14 per cent respectively).

Melbourne's population has continued to grow significantly during the life of the Strategic Plan (spanning the years 2006–07 to 2013–14), and so has its waste generation. *Figure 2* shows the projected waste generation in metropolitan Melbourne from 2005–30. Assuming a continuation of trends expected under TZW, initial projections suggest that some 2.3 million tonnes more waste from all sources will be produced in metropolitan Melbourne in 2030 compared to 2006–07. In other words, total waste will increase to 9.7 million tonnes or a further 31 per cent in 23 years. The projections show a declining need for landfill, compared to the amount of material being recovered. However, landfills will be required for the foreseeable future.

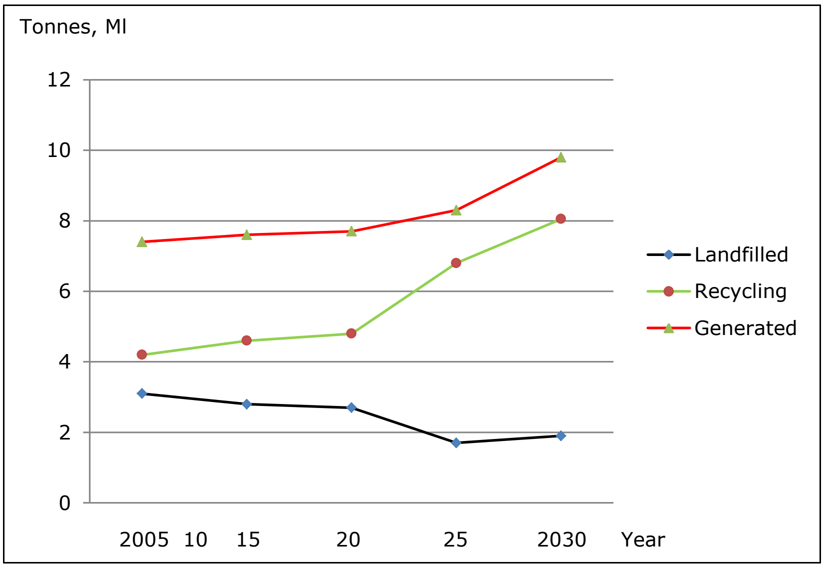

Figure 2: Projected waste generation, recycling and landfill in metropolitan Melbourne, 2005–30
Source: DSE 2009

3. Literature review

3.1 Determinants of kerbside recycling in the context of reverse logistics

Several conceptual models that suggest ways to design and implement reverse logistics have been developed. The model developed by Carter and Ellram (1998) identified two sets of determinants—internal and external. The two external factors of government regulations and customer demands, and internal factor of policy entrepreneur were considered by Carter and Ellram (1998) to be the main drivers of reverse logistics systems. The principal internal driver is the existence of a policy entrepreneur within the company who is personally committed and willing to take responsibility for reverse logistics activities. Other determinants to the implementation of reverse logistics systems include the support of top management, stakeholder commitment, incentive systems, quality of inputs and vertical integration. Stock (1998) suggested that factors related to management and control, measurement and finance determine the success of a reverse logistics program. Dowlatshahi

(2005) suggested a five-factor strategic framework to design and implement recycling operations in reverse logistics. These factors included strategic costs, strategic quality, customer service, environmental concerns and legal concerns. Using these studies, Rahman and Subramanian (2012) proposed a conceptual model of reverse logistics systems comprised of eight determinants categorized as the internal and external environments of reverse logistics systems. In this study we have adapted Rahman and Subramanian's model to investigate the determinants of kerbside waste management in the context of a metropolitan city council. These determinants are explained as follows:

3.1.1 Legislation

Legislation refers to regulations or Acts passed by government agencies to ensure firms take back, recycle and reuse the products at the end of its life cycle. The major aim of this initiative is to protect the environment, avoid landfill and prevent contamination of water. Research suggests that government legislation is one of the main drivers for a firm's environmental efforts. Walker (*et al.* 2008) stated that environmental regulations can be seen as a motivator to innovate and reduce the environmental impact at low cost rather than cause for litigation.

3.1.2 Community education and engagement

Education and engagement are vital components of waste minimization. Raising awareness amongst householders, businesses and across government is an essential part of resource efficiency and resource recovery programs. Education and information about resource recovery services that result in participants supporting, and correctly using, such services can significantly affect the quantity and quality of materials being supplied to facilities.

3.1.3 Administrative leadership

Stock (1998) suggested that the commitment of the senior management is the key driver in reverse logistics activities. As allocation of resources towards environmental and educational programs increases, it is more likely that a firm institutes a system of environmental management, which would determine the direction to reverse logistics and environmental activities. While legislation is the milestone of any change, administrative leadership with effective management process is crucial.

3.1.4 Monitoring and evaluation

Effective implementation of KWM requires sound planning and monitoring. Typically this produces a plan that aligns policy objectives with implementation. To assess the performance, it is essential to develop monitoring, evaluation and reporting frameworks.

3.1.5 Quality and quantity

Guide Jr. (*et al*. 2006) stressed that the volume of returns and quality of products are major drivers for recycling. Pokharel and Mutha (2009) emphasized that the pricing of products should be based on the quality of the returned products. They also found that good quality products require fewer processes to reuse it. The volume of return products is critical for implementation of reverse logistics (Carter and Ellram 1998).

3.1.6 Incentive/levy/funding

Literature suggests that the right incentives would enhance return rates. For instance, through the $10 million Victorian Advanced Resource Recovery Initiative (VARRI), the state government is currently exploring the use of new technology to process waste into clean energy and products, such as compost. The importance of having incentives (eg. landfill levy) to drive further resource recovery remains a critical determinant of successful KWM operations.

3.1.7 Infrastructure

Dowlatshahi (2005) stated that the overall success of reverse logistics systems depends on the effective use of available resources. The available resources are referred to as facilities, personnel, material handling/processes capabilities and computer systems.

3.1.8 Alliance and coordination

The lack of a structured approach to coordination may result in a range of inefficient and ineffective practices across the municipal waste sector. The role of coordination and the importance of communication in both speedy and early disposition of returned products have been discussed extensively (Daugherty *et al*. 2005, Fleischmann 2003, Hess and Meyhew 1997, Yalabik *et al*. 2005). Few attempts have been made to also improve integration and coordination with the use of an information support system (Chouinard *et al.* 2005, Daugherty *et al.* 2005). Efficient information systems are needed to individually track and trace product returns to forecast returns and for inventory management (de Brito *et al*. 2002).

The conceptual model that we have developed and used in this study is shown in *Figure 3*.

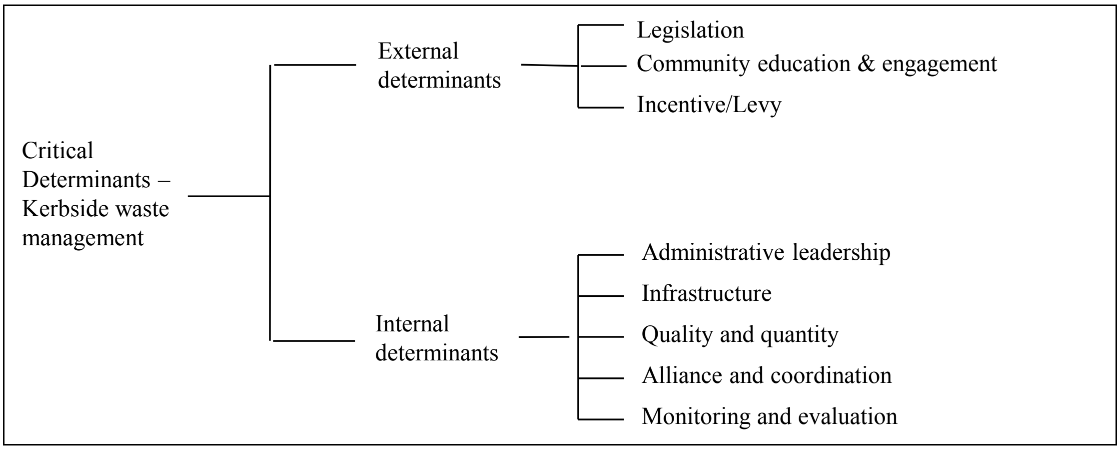

Figure 3: Model for kerbside waste management
Adapted from: Rahman and Subramanian (2012)

4. Research methodology

4.1 The fuzzy DEMATEL method

This study employs the fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) approach method for analysis. This method was developed at the Battelle Memorial Institute, Geneva between 1972 and 1976 (Fontela and Gabus 1976, Gabus and Fontela 1973). It is an effective procedure for analyzing problem structure and developing causal relationships between factors or sub-systems (Fontela and Gabus 1974). In the recent past, the DEMATEL method has been applied in different fields, such as sustainable development (Tsai and Chou 2009), alternative fuel selection (Lin *et al*. 2009), supplier selection (Büyüközkan and Çifçi 2012, Chang *et al*. 2011, Dalalah *et al*. 2011), hospital service quality (Shieh *et al*. 2010), green management practices evaluation (Lin 2013) and managers' competency development (Wu and Lee 2007). The advantage of the DEMATEL method is that it not only identifies the critical determinants but also has the capacity of revealing the relationships between determinants, thus provide more valuable information for decision-making for a problem with complex interdependencies.

4.1.1 DEMATEL Method

The procedural steps of DEMATEL methodology are as follows:

Step 1: *Generate direct-relation matrix*: Suppose there are *R* decision-makers (experts) involved in the study and *n* number of decision-making determinants. Each decision-maker *k* is asked to indicate the degree to which a determinant *i* affects determinant *j.* These pairwise comparisons between any two determinants can be denoted by x^k_{ij} and given an integer score ranging from 0, 1, 2, 3, and 4, representing 'No influence', 'Low influence', 'Medium influence', 'High influence', and 'Very high influence' respectively. The elements for $i = j$ are set to zero. Responses from each decision-maker give rise to a $n \times n$ non-negative matrix, $[x^k_{ij}] = X^k$, where k = number of decision-makers varying between *1* and *R*. An initial direct-relation matrix *A* with individual element a_{ij}, can therefore be expressed as:

$$\left[a_{ij}\right]_{nxn} = \frac{1}{R}\sum_{k=1}^{R} x^k{}_{ij} \qquad \text{(equation one)}$$

Step 2: *Normalizing the direct-relation matrix:* The normalized direct-relation matrix M can be obtained by the following expression:

$$M = \frac{A}{\mu} \text{; where } \quad \mu = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}, \max_{1 \le j \le n} \sum_{i=1}^{n} a_{ij}\right) \quad \text{(equation two)}$$

Step 3: *Obtaining the total-relation matrix*: Once the normalized direct-relation matrix is obtained, the total relations matrix *T* can be derived from the following expression:

$$T = M + M^2 + M^3 + \ldots . M^{\infty} = \sum_{i=1}^{\infty} M^i$$

$$T = M(I - M)^{-1}, \text{ where } I \text{ is an identity matrix} \qquad \text{(equation three)}$$

Step 4: *Compute dispatcher group and receiver group*: Define *S* and *C* as *nx1* and *1xn* vectors representing the sum of rows and sum of columns of the total-relation matrix *T*, respectively. Suppose S_i be the sum of *i*th row in matrix *T*, then S_i summarizes both direct and indirect effects given by determinant *i* to the other determinants. Similarly, suppose C_j be the sum of *j*th column in matrix *T*, then C_j summarizes both direct and indirect effects given by determinant *j* to the other determinants. The expression $(S_i + C_j)$ indicates the degree of importance that determinant *i* plays in the entire system, whereas, $(S_i - C_j)$ indicates the net effect that determinant *i* contributes to the system. If $(S_i - C_j)$ is positive, determinant *i* is net dispatcher, and if $(S_i - C_j)$ is negative, determinant *i* is a net receiver.

Step 5: *Set threshold value and obtain the cognition map*: The cognition map can be derived by mapping the dataset of the $(S_i + C_j)$ and $(S_i - C_j)$, where $(S_i + C_j)$ is the horizontal axis and $(S_i - C_j)$ is the vertical axis. To construct an appropriate map, decision-maker must assign a threshold value for the influence level. Only some determinants whose influence level in matrix *T* is higher than the threshold value, will be chosen to construct the map. If the threshold value is too low, the map will be too complicated, whereas, if the threshold value is too high, many determinants will remain independent without showing the relationships with other determinants.

4.1.2 Fuzzy theory and triangular fuzzy numbers

Zadeh (1965) proposed the fuzzy set theory and introduced the concept of membership function in order to deal with the ambiguity associated with linguistic judgments of decision-makers. Unlike Boolean logic which defines whether or not a judgment belongs to a crisp set (0 or 1), a fuzzy set defines a judgment's degree of belongingness by a membership function. In this study we use triangular fuzzy numbers (shown in *Figure 4*) as defined by the following expression:

$$\tilde{U}(x) = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \leq x \leq m, \\ (r-x)/(r-m), & m \leq x \leq r, \\ 0, & x > r \end{cases}$$

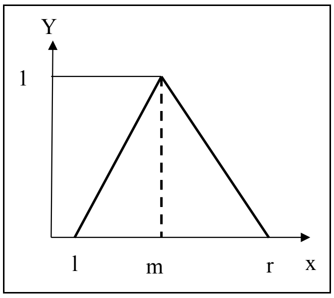

Figure 4: A triangular fuzzy number

The pairwise comparisons between any two determinants can be expressed by integer scores ranging from 0, 1, 2, 3, and 4, representing 'No influence', 'Low influence', 'Medium influence', 'High influence', and 'Very high influence' respectively. We translate these crisp scores as fuzzy numbers based on *Figure 5* and *Table 1*.

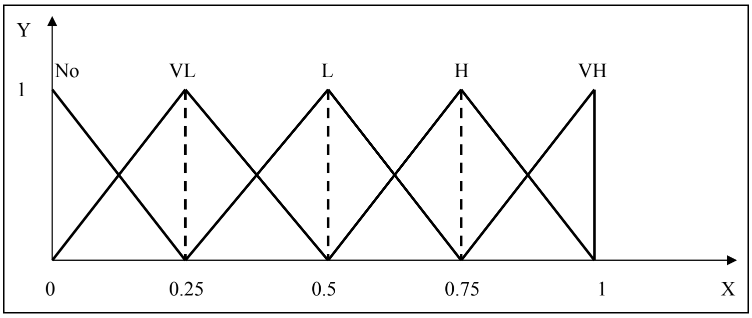

Figure 5: Triangular fuzzy number for linguistic variables

Table 1: The correspondence of linguistic terms and linguistic values

Linguistic term	Influence score	Triangular fuzzy number
Very high influence (VH)	4	(0.75, 1.0, 1.0)
High influence (H)	3	(0.50, 0.75, 1.0)
Low influence (L)	2	(0.25, 0.50, 0.75)
Very low influence (VL)	1	(0.0, 0.25, 0.50)
No influence (No)	0	(0.0, 0.0, 0.25)

The fuzzy numbers are required de-fuzzification for the purpose of fuzzy aggregation. It refers to the selection of a specific crisp score using the output of the fuzzy set. We applied the Converting Fuzzy data into Crisp Scores (CFCS) approach suggested by Opricovic and Tzeng (2004) for defuzzification.

4.2 Sample councils and respondents

The critical case sampling method was used to identify municipal councils for this study. Critical case sampling is a type of purposive sampling (Neuman 1991) that looks for cases that are 'particularly information rich' in relation to the questions under consideration (Yin 2003). We investigated three municipal councils for this study (see *Figure 6*). Six senior managers were chosen from these councils (two from each council) who have reasonably long experience in waste management in the municipal waste management context. The interviews and data collection for the DEMATEL Methodology were conducted on two separate days. All six interviews were conducted face-to-face by the first author and each interview lasted approximately 45 minutes. A two-part questionnaire was employed for data collection. Part A contained questions (in DEMATEL format) designed to capture respondent opinions on the relative influence of determinants, whereas, Part B contained general questions about the councils and respondents background, and related management issues. Interviewee answers were recorded and then transcribed. Respondents were assured that their answers would be kept confidential.

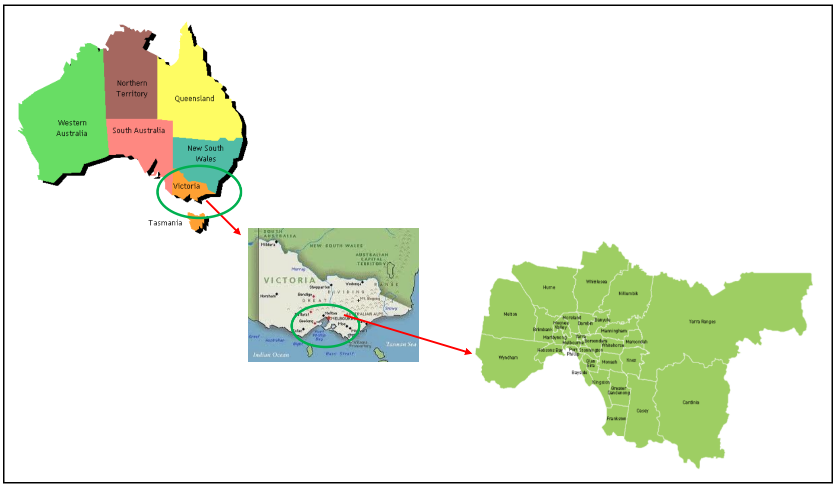

Figure 6: A map of councils in metropolitan Melbourne

None of the respondents were familiar with the DEMATEL data collection procedure. Therefore, the following two steps were considered:

- Respondents were explained the meaning of the linguistic terms.
- Respondents were explained how these terms need to be considered while making the pairwise comparisons between any two determinants.

These two steps were critical to ascertain the accuracy of data.

5. Results and Discussion

From three focus groups' (one from each council) responses, three matrices were developed using pairwise comparison procedure of DEMATEL. These were then used to generate an average matrix. An example of how DEMATEL captures managers' opinions and convert opinions into fuzzy numbers are shown in *Table 2* and *Table 3* respectively.

Table 2: Direct relationship matrix using linguistics terms

	D1:Legislation	D2:Community	D3:Incentive	D4:Adm Leadership	D5:Infrastucture	D6:Quality	D7:Alliance	D8:Monitoring
D1:Legislation	N	H	VL	H	H	VL	L	H
D2:Community education	N	N	N	VL	L	VH	VL	L
D3:Incentive	N	VL	N	H	L	H	L	H
D4:Adm Leadership	N	L	VL	N	H	L	H	VH
D5:Infrastucture	VL	VL	N	VL	N	VH	H	H
D6:Quality & quantity	VL	N	VL	VL	N	N	N	L
D7:Alliance & coordination	N	L	N	L	H	VH	N	VH
D8:Monitoring & evaluation	N	VL	N	H	H	VH	L	N

Table 3: Direct relationship matrix using fuzzy numbers

	D1:Legislation	D2:Community	D3:Incentive	D4:Adm Leadership	D5:Infrastucture	D6:Quality	D7:Alliance	D8:Monitoring
D1:Legislation	0, 0, 0.25	0.5, 0.75, 1.0	0, 0.25, 0.5	0.5, 0.75, 1.0	0.5, 0.75, 1.0	0, 0.25, 0.5	0.25, 0.50, 0.75	0.5, 0.75, 1.0
D2:Community education	0, 0, 0.25	0, 0, 0.25	0, 0, 0.25	0, 0.25, 0.5	0.25, 0.50, 0.75	0.75, 1.0, 1.0	0, 0.25, 0.5	0.25, 0.50, 0.75
D3:Incentive	0, 0, 0.25	0, 0.25, 0.5	0, 0, 0.25	0.5, 0.75, 1.0	0.25, 0.50, 0.75	0.5, 0.75, 1.0	0.25, 0.50, 0.75	0.5, 0.75, 1.0
D4:Adm Leadership	0, 0, 0.25	0.25, 0.50, 0.75	0, 0.25, 0.5	0, 0, 0.25	0.5, 0.75, 1.0	0.25, 0.50, 0.75	0.5, 0.75, 1.0	0.75, 1.0, 1.0
D5:Infrastucture	0, 0.25, 0.5	0, 0.25, 0.5	0, 0, 0.25	0, 0.25, 0.5	0, 0, 0.25	0.75, 1.0, 1.0	0.5, 0.75, 1.0	0.5, 0.75, 1.0
D6:Quality & quantity	0, 0.25, 0.5	0, 0, 0.25	0, 0.25, 0.5	0, 0.25, 0.5	0, 0, 0.25	0, 0, 0.25	0, 0, 0.25	0.25, 0.50, 0.75
D7:Alliance & coordination	0, 0, 0.25	0.25, 0.50, 0.75	0, 0, 0.25	0.25, 0.50, 0.75	0.5, 0.75, 1.0	0.75, 1.0, 1.0	0, 0, 0.25	0.75, 1.0, 1.0
D8:Monitoring & evaluation	0, 0, 0.25	0, 0.25, 0.5	0, 0, 0.25	0.5, 0.75, 1.0	0.5, 0.75, 1.0	0.75, 1.0, 1.0	0.25, 0.50, 0.75	0, 0, 0.25

Table 4: Degree of influence of determinants

Notation	Determinant	Si + Ci	Si - Ci
D1	Legislation	2.849	1.338
D2	Community education and Engagement	2.590	0.108
D3	Incentive/Levy	1.390	0.103
D4	Administrative Leadership	2.556	0.531
D5	Infrastructure	3.450	-0.602
D6	Quality and Quantity	2.533	-0.418
D7	Alliance and Coordination	1.289	-0.930
D8	Monitoring and Evaluation	2.860	-0.007

The DEMATEL analysis produced two categories of results. Firstly, it prioritized the determinants based on their degree of importance in the decision-making context under consideration. As explained earlier (Section 3) the importance of determinants is assessed by (S_i + C_j) values. The degree of influence of determinants is shown in *Table 4*. The higher the value, the more important the determinant is. Based on (S_i + C_j) values, the importance of eight determinants can be prioritized as D5 > D8 > D1 > D2 > D4 > D6 > D3 > D7. The results show that the three most important determinants are: D5: infrastructure (weight = 3.450), D8: monitoring and evaluation (weight = 2.860) and D1: legislation (weight = 2.849).
Secondly, DEMATEL analysis classified determinants either as net dispatchers/drivers or as net receivers depending on the net influence to the context. As mentioned in section 4.1, if (S_i - C_j) is positive, determinant *i* is net dispatcher, and if (S_i - C_j) is negative, determinant *i* is a net receiver. The results are shown in *Table 5*. The results indicate that the two most influential drivers are: D1: Legislation ((S_i - C_j) = 1.338) and D4: administrative leadership ((S_i - C_j) = 0.531).

Table 5: Drivers and receivers

Drivers	Si - Ci
D1: Legislation	1.338
D4: Administrative Leadership	0.531
D2: Community education and Engagement	0.108
D3: Incentive/Levy	0.103
Receivers	
D8: Monitoring and Evaluation	- 0.007
D6: Quality and Quantity	- 0.418
D5: Infrastructure	- 0.602
D7: Alliance and Coordination	- 0.930

The results of the analysis can also be used to develop a cognition map of casual relationships between determinants. To construct a cognition map based on the DEMATEL results, selection of a particular threshold value is said to be a critical criterion. Following the procedure suggested by Tamura (*et al.* 2002), a threshold value of more than the average of the elements of matrix, was considered to construct the cognition map (Refer to *Figure 7*).

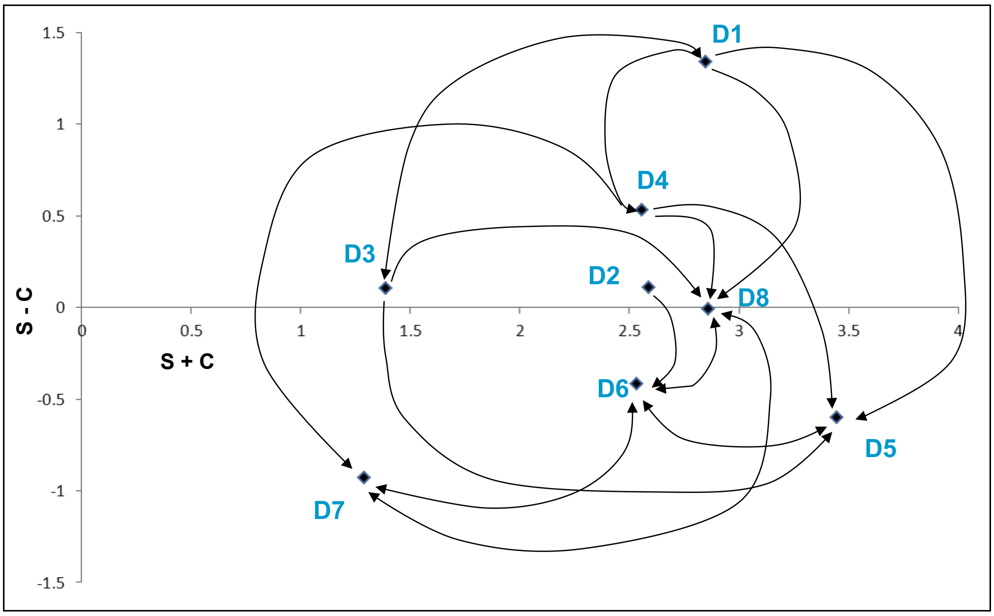

Figure 7: The cognition map of total relationship

The map has been constructed using *(Si + Ci*) as the X-axis and (*Si - Ci*) as the Y-axis. The locations of the determinants with respect to X and Y-axis determine the degree of importance that the determinants play and indicate the net effects that they contribute to the context of the study. The map indicates that among the drivers, D1: Legislation is the main determinant followed by D4: Administrative leadership. Legislation directly impacts on D3: Incentive/Levy, D4: Administrative leadership, D5: Infrastructure, and D8: Monitoring and evaluation. Determinant D4: Administrative leadership impacts on D5: Infrastructure, D7: Alliance and coordination and D8: Monitoring and evaluation. Also D5–D6; D6–D7; D7–D8, and D6–D8 influence one another.

This study assists us to understand the interrelationships between determinants more systematically. Understanding of the dynamic nature of the decision-making process through these causal relationships is critical to the formulation of kerbside recycling system implementation strategies.

Conclusion

The population in the metropolitan Melbourne is growing and so is its waste. The Victorian Government's *Towards Zero Waste* (TZW) Strategy seeks to minimize the amount of waste being generated and to maximize opportunities recovering materials. This study investigates the critical determinants of successful implementation of TZW strategy in city councils. The results show that councils involved in kerbside recycling operations should pay more attention to the determinants legislation, administrative leadership of the managers and community education and involvement. One of the limitations of this study is the sample size. Analysis was conducted based on the responses from six managers. Future research must consider a larger sample size to assess the effectiveness of the proposed solution to enable generalization.

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