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Studies on the sustainability of integrated waste management systems

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Abstract: The EU Waste Management Strategy's requirements emphasize waste prevention; recycling and reuse; and improving final disposal and monitoring. Integrated waste management system (IWMS) can be defined as the selection and application of suitable and available techniques, technologies and management programs to achieve waste management objectives and goals. In this paper, the concept of 'key drivers' are defined as factors that change the status quo of an existing waste management system in either positive or negative direction. Due to the complexity and uncertainty occurring in sustainable waste management systems, we propose the use of the Fuzzy Cognitive Map (FCM) approach to support the planning and decision making process of integrated systems.

Keywords: integrated waste management systems, sustainability, factors, expert workshop, Fuzzy Cognitive Map (FCM)

1. Introduction

Waste is one of the most visible environmental problems in the world. Increasing population, changing consumption patterns, economic development, urbanization and industrialization result in the increased generation of solid waste and a diversification of the types of the waste. Waste management is an umbrella term that refers to a host of interlinked activities such as reduction, recycling, collection, transportation, processing, disposal, and monitoring of waste materials.

Waste management in Hungary is primarily controlled through legal regulations. Legal provisions determine technical requirements for waste management, the applicable economic incentives and sanctions, the responsibilities of the waste generators and managers of waste as well as the licensing and supervisory duties of the authorities. In Hungary, the local government is entrusted with the task of waste management services.

Systems with source control can avoid many problems of the processing technology by respecting different qualities and quantities of the waste streams, by treating them appropriately for reuse and recycling. Sustainable waste management means less reliance on landfill and greater amounts of recycling and composting [1, 2].

2. Methods applied

As a result of the incompleteness and multiple uncertainties occurring in sustainable waste management systems, we propose the use of FCM to support the planning and decision making process. By observation of the model and its time dependent behaviour we determined under what conditions the long-term sustainability of a regional waste management system could be ensured.

The FCM model consists of two different input data. One is the expert system database which is based on human expert experience and knowledge. We set up this database through gathering information from experts of integrated municipal waste management systems. Using this methodology, we extracted the knowledge on the system from the experts and exploited their experience on the system's model and behaviour. The experts were involved in two steps: (1) in a surveying process and (2) in an expert workshop. As a result of these investigations at first we determined the connections of the six factors then in the second one we refined our model and introduced 33 sub-factors with connections. Table 1 shows the six factors and 33 sub-factors.

Table 1. The identified factors and sub-factors and the concept IDs (CID)

Main factor	Sub-factor	CID	Main factor	Sub-factor	CID
Technology (C1)	Engineering knowledge	C1.1	Society (C4)	Public opinion	C4.1
	Technological system and its coherence	C1.2		Public health	C4.2
	Local geographical and infrastructural conditions	C1.3		Political and power factors	C4.3
	Technical requirements in the EU and national policy	C1.4		Education	C4.4
	Technical level of equipment	C1.5		Culture	C4.5
Environment (C2)	Impact on environmental elements	C2.1		Social environment	C4.6
	Waste recovery	C2.2		Employment	C4.7
	Geographical factor	C2.3	Law (C5)	Monitoring and sanctioning	C5.1
	Resource use	C2.4		Internal and external legal coherence (domestic law)	C5.2
	Wildlife (social acceptance)	C2.5		General waste management regulation in the EU	C5.3
	Environmental feedback	C2.6		Policy strategy and method of implementation	C5.4
Economy (C3)	Composition and income level of the population	C3.1	Institution (C6)	Publicity, transparency (data management)	C6.1
	Changes in public service fees	C3.2		Elimination of duplicate authority	C6.2
	Depreciation and resource development	C3.3		Fast and flexible administration	C6.3
	Economic interest of operators	C3.4		Cooperation among institutions	C6.4
	Financing	C3.5		Improvement of professional standards	C6.5
	Structure of industry	C3.6			

On the basis of the gathered data we constructed the connection matrix, including identification of concept nodes and relationships among them that are represented by edges.

The other input data set was the range of historical data consisting of a sequence of state vectors. The trend of the studied 33 factors was assessed between the values 0 and 1 from the 1970s till the 2010s. Given the nature of the problem, computational methods were mixed with human judgment which is a standard approach in natural language processing when it is hard to define the problem in an exact, formal way for machines. Our goal was to determine how each subsystem contributes to the policy making process. Subsystems were identified by experts using their tacit knowledge accumulated over years of professional practice. From a linguistic point of view, these subsystems can be regarded as high level concepts of a field specific knowledge base [3].

Table 2 introduces the trend (time series) of the factor 'environment' and its subfactors from the 1970's to the 2010's.

Table 2. Time series development for the factor representing the environment

	Environment					
	Impact on environmental elements	Waste recovery	Geographical factors	Resource use	Wildlife (social acceptance)	Environmental feedback
1970'	0.77	0.80	0.04	0.09	0.05	0.16
1980'	0.75	0.12	0.12	0.05	0.06	0.37
1990'	1.00	0.13	0.03	0.03	0.23	0.15
2000'	0.57	0.33	0.01	0.09	0.18	0.23
2010'	0.82	0.45	0.00	0.37	0.08	0.13

3. Summary

The goal of our investigation was to present the process of data production necessary for simulation by FCM. We have introduced the refined model of the IWMS and the time series development by content analysis. On the basis of the above we were able to design the initial connection matrix and develop the time series as the two input data group for modelling

4. Further research

Due to the complexity of the connections in the new 'oversize' model, the review and interpretation of the connections is difficult.

One of our future research intention is to further develop the visualisation of the results. The method of that is to merge the factors with the very similar connections. At the same time, it will be able to represent connections between the six-factor model and the 'oversize' model. Furthermore, our future research activities will focus on to make the model dynamic.

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