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Retrospective Reconstruction of Time Series Data for Integrated Waste Management

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Abstract**—**The development, operation and maintenance of Integrated Waste Management Systems (IWMS) affects essentially the sustainable concern of every region. The features of such systems have great influence on all of the components of sustainability. In order to reach the optimal way of processes, a comprehensive mapping of the variables affecting the future efficiency of the system is needed such as analysis of the interconnections among the components and modeling of their interactions. The planning of a IWMS is based fundamentally on technical and economical opportunities and the legal framework. Modeling the sustainability and operation effectiveness of a certain IWMS is not in the scope of the present research. The complexity of the systems and the large number of the variables require the utilization of a complex approach to model the outcomes and future risks. This complex method should be able to evaluate the logical framework of the factors composing the system and the interconnections between them. The authors of this paper studied the usability of the Fuzzy Cognitive Map (FCM) approach modeling the future operation of IWMS's. The approach requires two input data set. One is the connection matrix containing all the factors affecting the system in focus with all the interconnections. The other input data set is the time series, a retrospective reconstruction of the weights and roles of the factors. This paper introduces a novel method to develop time series by content analysis.

Keywords**—**Content analysis, factors, integrated waste management system, time series.

I. Introduction

DECISION problems are usually characterized by numerous issues or concepts interrelated in a complex way. They are often dynamic, i.e., they evolve through a sequence of interactions among related concepts. Feedback plays a dominant role in updating the concepts states by propagating causal influences through multiple pathways. Formulating a quantitative mathematical model for such system may be difficult or impossible due to lack of numerical data and dependence on imprecise verbal expressions. An FCM is able to represent unstructured knowledge through causalities expressed in imprecise terms [1].

FCM offers many advantages for sustainability modeling including the ability to include abstract and aggregate variables in models, the ability to model relationships which are not known with certainty, the ability to model complex relationships which are full of feedback loops, and the ease and speed of obtaining and combining different knowledge sources. In case of integrated waste management (IWMS), problems are complex, involve many parties, and have no easy solutions or right answers. However, decision must be made. [2].

Movement towards more sustainable waste management practice has been identified as a priority in the whole of EU. 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.

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.

The IWMS has to be an economically affordable, environmentally effective and socially acceptable system. Among others, it includes the practical aspects of waste management (i.e. transport, treatment and disposal) and the attitudes of citizens (how they feel about source separation, recycling, incineration, etc.). The evolution of waste management from truck and dump, to the highly integrated systems requires an investment of both time and resources [17].

Due to the complexity and uncertainty occurring in sustainable waste management systems, we intend to use the Fuzzy Cognitive Map (FCM) method to support the planning and decision making process of integrated systems. Since the FCM is formed for a selected system by determining the concepts and their relationships, it is possible to quantitatively simulate the system considering its parameters. We used several techniques in order to produce the input data of the simulation process.

The methodology of FCM simulation starts with an expert workshop and a content analysis procedure as these are the input data to the simulation of the system in question. A time series is developed for approaching data in a range of research

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settings. This paper now focuses on presenting the methodology tool for developing retrospective reconstruction of the weights and roles of the factors in IWMSs.

II. Literature Review

Many environmental problems would benefit from models based on experts' knowledge [2], among them IWMS modeling as well. Several models have been developed in recent decades to support decision making in IWMS to monitor present conditions, to assess future risks and to visualize alternative futures [12], [13]. According to [2], [14], [15], early waste management models developed during the 1960s and 1970s focused on studying individual functional elements, i.e. optimizing waste collection routes for vehicles or locating appropriate transfer stations. In the 1980s, the investigation was extended to encompass waste management on the system level, minimizing waste treatment costs. In the 1990s, the waste management models focused principally on economic (e.g. system cost and system benefit), environmental (air emission, water pollution) and technological (the maturity of technology) aspects. An environmental impact assessment model, the life cycle assessment (LCA) is also often used to aid the decision-making in waste management. Numerous studies applied the LCA method to evaluate the environmental impact of waste treatment alternatives. In several strategic planning models, both costs and emissions of waste management systems have been included in the research. In some models, the whole life cycle of products has been studied instead of only the waste management system when searching for environmentally optimal waste management strategies.

The increasing demand for types of models which combine environmental, economic and further aspects (like social, technological aspects) has led to the development of a latest generation of computerized models, which are similar to the LCA-based models, but include additional cost effects and/or social effects. In this case, cost effects can be regarded as an additional impact category. Examples of this type of models are GABI and Umberto [16], well known computerized tools especially in the German speaking community. From both methodological and practical point of view, it is a complex task to compare alternatives with respect to environmental effects, costs and social aspects. In most cases, the antagonistic targets of cost minimization, reduction of environmental effects and high convenience for the user (mainly of the waste collection scheme) cannot be met by one single scenario. It is increasingly likely that a scenario in which high costs are linked with high environmental standards and high convenience will be involved, whereas low-cost scenarios prove to be less environmentally friendly or less convenient. Time series methodological approach had been used mainly in the field of psychotherapy, education, psychophysiology, operant research [4], [5], etc. where the data consist of dependent observations over time. The design makes a significant and unique contribution to the total simulation package. It provides an external criterion measure of the outcome of the problem in focus. This design involves successive observations throughout the project and assesses the characteristics of the change process. The descriptive function of the time series is particularly important. The time series is the only design to furnish a continuous record of the changes of the variables over the entire course of the investigation. Time series design function as a heuristic device [3]. When coupled with a carefully selected tool, time series is a valuable source for FCM simulations.

III. Applied Method

A. Fuzzy Cognitive Maps

FCM is a very convenient and simple tool for modelling complex systems. It is rather popular due to its simplicity and user friendliness. Its one disadvantage is that it is not able to extrapolate properly from the available time series data; it always converges to a set of "plateaus", i.e. an assumed stable state. The present research deploys the FCM and applies the BEA for parameter optimization.

FCMs are fuzzy graph structures representing causal reasoning. Causality is represented here as a fuzzy relation of causal concepts. FCM may be used for dynamic modeling of systems. The FCM approach uses nodes corresponding to the factors and edges for their interactions, to model different aspects in the behavior of the system. These factors interact with each other in the FCM simulation, presenting the dynamics of the original system [18]. FCMs have been described as the combination of Neural Networks and Fuzzy Logic. Thus, learning techniques and algorithms can be borrowed and utilized in order to train the FCM and adjust the weights of its interconnections [19].

B. Content Analysis to Develop Time Series

The FCM model consists of two different input data. One is the expert system database which is based on human expert experience and knowledge and consists of 33 factors. 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 behavior.

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 [6]. Each high level concept is a collection of related words, synonyms, homonyms, antonyms etc. Knowledge bases tries to capture the relationship between concepts of specific field and can be seen as a formal representation of the practitioners tacit knowledge by listing all the relevant entity and predicates which can be applied to entities (such as properties of entities, how we can form groups from these entities and how we can talk about these groups and etc). Hence knowledge bases contain mainly concepts and words describing relations.

Although knowledge bases are usually structured as mentioned above, here we are not interested in the systematic relation between words under high level concepts, but we can rely on this feature of conceptual structure. We operationalized the contribution of a subsystem to the policy making process as the frequency of the words under a high level concept in the text.

So, the systematic relationships between items of high level concepts were abandoned and terms were simply listed under each subsystem.

Why content analysis? The author intended to eliminate the subjectivity of expert workshop [7], to validate the results with another method and to make a more objective approach to analyze and model the changes of importance.

This paper outlines and reflects on the process of undertaking a content analysis on policy and strategic documents in the waste management sector in Hungary.

Content analysis is a research method for rigorously and systematically analyzing the contents of written documents. The approach is used in interdisciplinary research to analyze political, strategic and legal documents to facilitate as objective and consistent analysis of written policies.

The authors' process entitled the following steps: (a) setting inclusion criteria for documents; (b) collecting documents; (c) articulating key areas of analysis; (d) document coding; and (f) analysis. An overview of what each steps entailed is provided below.

In selecting documents for the analysis, the team had to consider: which types of documents would be included and reviewed, and the publication and release of those documents.

Types of documents reviewed for the content analysis included policy, strategic document, laws and directives and guidelines of the European Union.

Publication and date of release was considered to be able to use the exercise as a baseline so as to track changes and progress in policy and practice over time. Therefore, the authors determined for the duration of the study the last 30 years (1970'-2010').

Documents were collected mainly from the intranet. When the authors were not able to find the appropriate documents online, the university library and support of experts proved to be good solution.

The policy documents were originally reviewed and analyzed to be important and relevant also validated by experts for ensuring sustainable waste management.

Each document was analyzed to determine the extent to which the policy or strategy is described, addressed or considered of the identified terms and expressions for IWMS. Words relevant for one of the predetermined concepts were highlighted and coded. Based on the analysis of the words of the text, their meaning, relevance and context, each word was classified into one predetermined concept.

To ensure consistency and reliability of the coding and assessment process, the analysis of every word was verified by a second person.

This data was then analyzed to determine trends and to compare policy vs. practice.

IV. Results

At first, linguist experts compiled a list of keywords for each subsystem and the frequency of these words was measured. As a matter of fact, legal texts represent a special register of language [8] and the above-mentioned method yielded very poor results, i.e. no, or extremely low frequency for each keyword.

This negative results shows that legal texts operates with a slightly different vocabulary and use concept which are lower ranked on the conceptual hierarchy in the experts knowledge base.

At the second stage, word frequency tables were generated from the texts, and human experts classified items on those lists as members of a subsystem. This method ensures that keywords are represents real usage patterns in the texts under investigations.

The collection of laws and decrees were stored in portable document file format, and it was grouped according to decades. Plain text was extracted from the files using the open source Apache Tika library [9]. The extracted text went through standard pre-processing i.e.

- every non-alphabetic character (e.g. numbers, punctuation marks and extra whitespace) was removed
- every character was transformed into its lower case equivalent
- stop words were filtered out based on our custom list of Hungarian stop words
- each word went through stemming, an automatic process for determining the root or dictionary stem of a word, using the magyarlanc 2.0 package [10], [11].

TABLE I
Example for a Frequency Table

Word	Occurrences	Relative frequency
Háztartási (communal)	247	0.070
Érdek (interest)	702	0.200
Felelősség (responsibility)	141	0.040
Gazdasági (economic)	467	0.133
Költség (cost)	326	0.093
Támogatás (subsidy)	472	0.134
Gyártó (Producer)	570	0.162
Környezet (environment)	458	0.130
Felhasználás (consumption)	455	0.129
Hasznosítás (recovery)	1020	0.290

Following the standard methods of corpus linguistics1, frequency tables were generated from the pre-processed plain text files that contain each unique word, its occurrences and its relative frequency (occurrences divided by the total number of words in the corpus) as shown in Table I.

In the frequency table, occurrences were divided by the total number of words in the corpus; it resulted in the relative frequency. On the basis of the frequency table, the time series were developed for each predetermined factors and sub-factor see examples in Table II).

TABLE II
CONNECTION MATRIX CREATED BY EXPERTS AS A RESULT OF THE WORKSHOP

	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

V. SUMMARY AND CONCLUSIONS

The content analysis was undertaken as part of FCM simulation of IWMS. Overall, the authors found that the content analysis provided useful information about trends and gaps in the Hungarian waste management sector. The core of this research methodology was the time series design which was presented as a powerful approach to be used in research settings where human knowledge is too subjective. The aim of this paper was to show a possible design for retrospective time series development of IWMS. In this paper, a content analysis method was presented as a tool to generate input data for FCM modelling. The time series design has been shown to be a dynamic design, responsive to feedback in the sense that antecedent information can be used for subsequent planning and evaluation within an investigation.

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