INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 1, No 4, 2010

Review article ISSN 0976 – 4402

Development of Decision Support System for Municipal Solid Waste Management in India: A Review

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ABSTRACT

The complexity of issues involved in municipal solid waste management necessitates development and application of new tools capable of processing data inputs of varying formats, numerical models and expert opinions in multi objective decision making scenario. Decision Support Systems (DSS) are among the most promising approaches to confront such situations. After adoption of Municipal Solid Waste (Management and Handling) Rules, 2000 in India, the necessity of development of an environmental decision support system (EDSS) has further increased. Most DSS for solid waste management (SWM) constructed in the past deal with one or a few components of the whole process. This segmented approach does not provide a complete view of the interactions and effects of all functional elements in the whole complex system. In constructing the DSS, various elements must be integrated and optimized as per the required regulative, technical and social framework to produce a viable model that has practical applications. The DSS models should ideally be integrated with geographical information system (GIS) to optimize collection, transportation, processing and disposal processes. This paper attempts to present an overview of DSS in the area of solid waste management with specific reference to their development and applications in India. There appears a definite need for development of a comprehensive and user friendly EDSS for solid waste management in Indian regulative and social set up. A conceptual frame work for one such proposed decision support system, named 'EDSS-MSWI' has been discussed.

Key words: DSS, EDSS, GIS, Municipal Solid Waste Management, Review.

1. Introduction

The management of municipal solid waste (MSW) is a high priority issue for many communities throughout the world including India. Rising MSW generation rates and disposal costs, environmental and health concerns, limited landfill space, legislative changes, political climate, and social attitudes have a significant impact on waste management efforts. Increasingly, many communities are adopting the concept of integrated solid waste management as a means of better management of their MSW. Rather than relying solely on landfills for disposal, integrated solid waste management (ISWM) is a practice using several alternative waste management techniques to manage and dispose of the various components comprising the municipal solid waste stream (USEPA, 1999). Without proper management and better technology applications, waste cannot be handled efficiently and can damage the environment or habitat (Bani et al., 2009).

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Decision Support Systems (DSS) are a specific class of computerized information system that supports decision-making activities in a structured and logical way based on scientific facts. It compiles useful information from raw data, documents personal knowledge and/or business models to identify and solve problems and suggest appropriate decisions. The basic structure of DSS consists of three components: database management, model base management, and user interface (Bani et al., 2009), as shown in Figure 1.

Environmental Decision Support Systems (EDSS) is a specific branch of DSS which started developing in late 80's in an effort to integrate different tools and models related with multitude of issues concerning environment. EDSSs incorporate an explicit decision procedure based on a set of theoretical principles that justify the "rationality' of this procedure (Fox and Das, 2000).

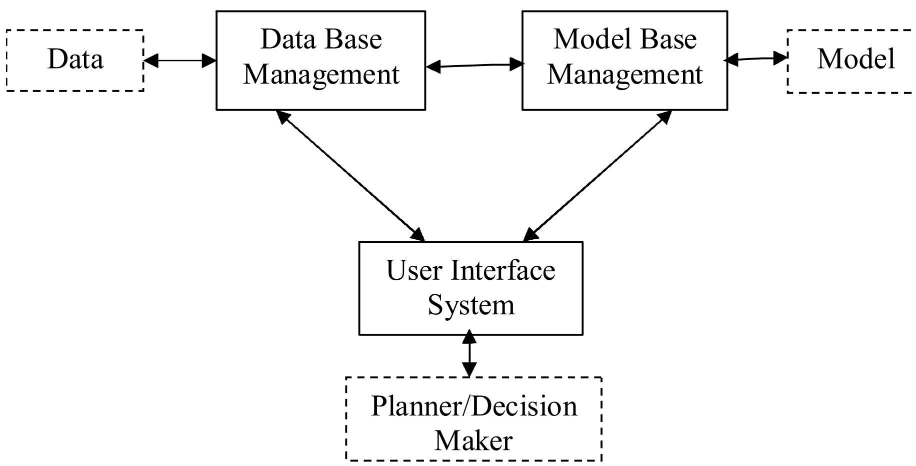

Figure 1: The basic structure of Decision Support Systems (DSS) (Modified from Bhargava and Tettelbach, 1997)

Moreover, EDSSs reduce the time in which decisions are made in an environmental domain, and improve the consistency and quality of those decisions (Haagsma and Johanns, 1994; Comas, 2000; and Cortes et al., 2001). In contemporary applications, EDSS is interactive, flexible and adaptable software, which has the capabilities to link environmental observations, data, numerical models and expert knowledge with tools such as geographical information systems to evaluate alternatives and assist decision making process.

2. Status of municipal solid waste management in India

Solid waste management is usually related to materials produced by human activities, and is generally undertaken to reduce their effect on health, environment or aesthetics. Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial environments. Management of non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities. Solid Waste Management is a part of public health and sanitation, and according to the Indian Constitution, falls within the purview of the State list (MoEF, 2000). This activity being local in nature is entrusted to the Urban Local Bodies (ULBs). The ULB

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undertakes the task of solid waste service delivery with its own staff, equipment and funds. In a few cases, part of the work is given to private enterprises on contract basis. A World Bank report estimated that in the year 2000 urban India produced approximately 100,000 metric tons of MSW daily or approximately 35 million metric tons of MSW annually (Hanrahan et al., 2006). Various studies reveal that about 90% of MSW is disposed off unscientifically in open dumps and landfills, creating problems to public health and the environment (Kansal, 2002; Rathi, 2006; Sharholy et al., 2008; Nishanth et al., 2010). Generally local bodies suffer from non-availability of adequate resources, staff and expertise in proper SWM. In India, most of the municipalities are currently unable to fulfill their obligation to ensure environmentally sound and sustainable handling of waste generation, collection, transportation, treatment, and disposal of MSW. To improve upon the situation and develop a proper infrastructure for SWM, Government of India sanctioned 2500 Crores (approx. US$500 million) exclusively for solid waste management from the 12th Finance Commission grants. Starting from December 2005, it has also earmarked Rs 100,000 Crores (approximately US$20 billion) over a period of seven years for development of infrastructure in 63 cities under Jawaharlal Nehru National Urban Renewal Mission (JNNURM). For medium and small towns, funds have been provided under Urban Infrastructure Development for Small and Medium Towns (UIDS & MT) schemes. Thus, finance does not appear to be a constraint in proper solid waste management. However, the growing complexities of the issues involved in integrated solid waste management demands advanced knowledge based tools to support the complete solid waste management system. The application of Decision Support System (DSS) appears appropriate at this stage to streamline the whole process for effective outcome.

3. International scenario on decision support systems for solid waste management

The development of DSS for SWM started in mid '90s and still remains a subject of interest and research worldwide. Various approaches have been used in the development of DSSs for solid waste management. To build a complete model of waste management system, a wide knowledge and deep analysis must be done on all aspects, including characteristic of waste, possible treatment options, resource conservation, conversion, recovery versus disposal cost analysis etc.

Many DSS were proposed for SWM in 1996. Barlishen and Baetz (1996) developed a prototype decision support system to assist the preliminary planning of MSW management. This planning tool combines knowledge-based system components with spreadsheet, optimization and simulation models for waste forecasting, technology evaluation, recycling and compost design, facility sizing, location and investment timing including waste allocation and municipal solid waste management (MSWM) system analysis.

Chang and Wang (1996a) developed an innovative graphical, interactive, problem-structuring tool for management planning of solid waste collection, recycling and incineration systems in Taiwan. In the same year, they developed another DSS using a fuzzy goal programming (FGP) approach, based on the considerations of economic and environmental impacts of noise, traffic congestion, air pollution, and material recycling within the long term planning program for siting landfills, incinerators, and transfer stations in a typical solid waste management system. Interactions among the effects of waste generation, source reduction, recycling, collection, transfer, processing, and disposal are tied together within such an

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analytical framework (Chang and Wang, 1996b). Wang et al. (1996) also reported development of computer model for integrated solid waste management, SWIM. It can assist decision makers to evaluate the economic and environmental impacts of various solid waste management options. The SWIM model has been verified and validated against operations in the City of Nunawading, Melbourne (Australia). A Geographical Information System (GIS) based spatial decision support system (SDSS) was developed by the MacDonald (1996) to address the multi-attribute and geographical nature of solid waste systems. This SDSS helped planners understand the spatial nature of particular programs and their impact on the public and the environment. The system included mathematical programming model to suggest scenarios or to make optimization analysis (recycling and trash systems from collection to transportation and disposal). This system was used in managing the solid waste problem in Philadelphia, Pennsylvania (USA).

Bhargava and Tettelbach (1997) developed a web based DSS for recycling and waste disposal to give better access to information and decision models. In Finland, Hokkanen and Salminem (1997) developed a multi-attribute decision making (MADM) model for the selection of the most adequate technologies like landfill, incineration, composting, refuse-derived fuel production and corresponding centralized/ decentralized management model.

Chang and Chang (1998) developed a non-linear model taking into account waste streams from facilities, landfills, transfer stations and incinerators. Berger et al. (1999) developed a sophisticated mixed-integer linear programming model and Huang et al. (2001) have developed an integrated fuzzy-stochastic linear programming model for municipal solid waste management. Weitz et al. (1999) and Harrison et al. (2001) developed the Life-cycle assessment (LCA) based decision support tool to evaluate integrated municipal solid waste management. Thorneloe et. al (2001) have developed municipal solid waste decision support tool (MSW-DST) based on both life-cycle inventory (LCI) analysis and full-cost accounting. The processes that can be modeled using DSS include waste generation, collection, transfer, separation, material recovery facilities (MRFs) and drop-off facilities, composting, waste combustion (waste to energy), refuse-derived fuel production, and landfilling. In Italy, Fiorucci et al. (2003) and Costi et al. (2004) developed a decision support system (DSS) to help decision makers of a municipality in the development of incineration, disposal, treatment and recycling integrated programs based on the solution of a constrained non-linear optimization problem.

Witlox (2005) made the assessment of how knowledge-based decision support systems could be used for urban land-use planning while Zeng and Trauth (2005) developed an internet-based user-interactive fuzzy multicriteria decision support system to use in conducting local and regional integrated solid waste management planning.

Simonetto and Borenstein (2006) developed SCOLDSS, a decision support system applied to the operational planning of solid waste collection. The main functionality of the system is the generation of alternatives to the decision processes concerning the allocation of separate collection vehicles, as well as the determination of their routes and daily amount of solid waste to be sent to each sorting unit in order to avoid waste of labor force and reduce the amount of waste to be sent to the landfills.

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Kirkeby et al. (2006) reported development of EASEWASTE, an decision-support model for evaluating the overall resource consumption and environmental impacts of municipal solid waste management systems by the use of life cycle assessment. EASEWASTE is able to compare different waste management strategies, waste treatment methods and waste process technologies to identify the most environmentally sustainable solution. The EASEWASTE model takes a very holistic approach to the assessment of the impacts by attempting to cover all relevant resources, environmental impacts, economic costs, odor, dust, noise, ethical issues and social willingness towards a waste management system.

Hung et al. (2007) developed a sustainable decision making model for MSWM to overcome conflict arises from the stakeholders' complex web of value. The proposed model combines multicriteria decision making (MCDM) and a consensus analysis model (CAM). The main feature of CAM is the assessment of the degree of consensus between stakeholders for particular alternatives. Abeliotis et al. (2009) reported the development of ReFlowse for detailed analysis of the collection subsystem and in particular the source separation and collection programs for recyclables. ReFlows utilizes mathematical equations for material and financial flows, organized in several subroutines to simulate the various sub-systems of an integrated solid waste management system and may be applied to any geographical scale from local to the national.

Galante et al. (2010) addressed the issues of the localization and dimensioning of transfer stations and determination of the number and type of vehicles to carry waste from municipalities to the incinerator. Two conflicting objectives are evaluated, the minimization of total cost and the minimization of environmental impact measured by pollution. To determine the best means of compromise, goal programming, weighted sum and fuzzy multi-objective techniques have been employed. The model was applied to the waste management of optimal territorial ambit (OTA) of Palermo (Italy).

4. Development and application of DSS for solid waste management in India

Municipal Solid Waste Management (MSWM) is by far the most prominent area where the concept of Environmental Decision Support System (EDSS) has been used and applied in India. Solid waste transport route planning and sanitary landfill site selection are the fields where many researchers have attempted to use EDSS in Indian context.

Sudhir et al. (1996) discussed the problem of implementing a solid waste collection system in India. They considered multi-objective decision making approach taking economic (budgetary constraint), environmental (amount of waste for landfill), technical (vehicle and plants) and social (human waste collectors) aspects. The approach is based upon multi-objective lexicographic goal programming taking into account several possible scenarios. The proposed model considers a single planning period of 5 years, and was used to study SWM in Madras city.

Natesan and Suresh (2002) developed a GIS based decision support system for sanitary landfill site selection. The themes identified for the purpose included land use, geology, geomorphology, drainage density, slope, soil and runoff. The factors considered for selecting the themes were permeability characteristics, susceptibility to erosion, runoff, settlement and load carrying capacity of the strata, lineaments, absence of faults and joints, slope of the

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ground, and ground water potential. The scores for various themes and their attributes were assigned using four Multi Criteria Evaluation (MCE) models viz. Analytical Hierarchy Process (AHP), Factor Importance Coefficient (FIC), Artificial Neural Networks (ANN) and Delphi. The results of all the models were compared to find out the best possible site. The method was applied in the Chennai Metropolitan Development Area (CMDA), Chennai, India.

Reddy (2005*) described development of a Multi-Criteria Decision Support System (MCDSS) for optimum solid waste management. The developed DSS was designed for the towns and municipalities in Medak district (India). The work involved examining the status of solid waste generation by assessing the existing solid waste management system and creation of digital database on ArcGIS platform to develop multi criteria Decision Support System (DSS) for optimal solid waste management. The design and development of DSS comprised of data management module, data validation and analysis module, module that is capable of analyzing the generated data in to different categories, transfer station capacity module, module to calculate site sensitivity index (SSI), and selection criteria for disposal site evaluation.

Ghosh et al. (2006) considered allocation of available resources (man power and vehicles) and suggested an expert system based decision support tools for solid waste transportation management. A case study of Asansol district revealed that the cost of collection and transportation of MSW could be reduced by 60% using GIS based route planning of vehicles for the purpose.

Padmaja et al. (2006) described development of Decision Support System (DSS) for identification of solid waste disposal sites in Hyderabad using Remote Sensing and GIS. The role of GIS techniques in mapping and analyzing the thematic layers prepared from remote sensing data for identification of suitable solid waste disposal site was demonstrated. The study also demonstrated how the required *in situ* data and remotely sensed data can be placed in a GIS system to model and identified the waste disposal sites for Hyderabad City. The methodology developed for finding suitable waste disposal site provide information regarding the existing solid waste disposal sites as well as probable sites suitable for waste disposal around Hyderabad. The DSS developed was suggested to be useful for decision makers in Municipal Corporation of Hyderabad and urban developmental activities.

Reddy and Padmaja (2007) worked on development of a GIS based decision support system for optimal route analysis for transportation of solid waste. The objective was to develop a decision support system for finding a suitable route for transportation of solid waste in Hyderabad using remote sensing (RS), GIS and GPS technologies. The DSS gives information regarding the existing solid waste collection points, existing waste disposal sites in and around Hyderabad, detailed transportation network of the city and probable routes suitable for transportation of wastes. The methodology developed may help urban developmental activities planners and State road transport corporations for finding the shortest route to reach a particular destination.

Sumathi et al. (2008) developed a GIS-based system for optimized municipal solid waste landfill site selection. The selection of a new landfill site was done using a multi-criteria decision analysis (MCDA) and overlay analysis in GIS environment. The proposed system

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can accommodate new information on the landfill site selection by updating its knowledge base. The guidelines of Central Pollution Control Board, India (CPCB, 2003) and Central Public Health and Environmental Engineering Organization (CPHEEO, 2000) were considered for landfill site identification. The selection of disposal site was carried out through a multi-level screening process. A GIS-based constraint mapping was employed to eliminate the environmentally unsuitable sites and to narrow down the number of sites for further consideration. Analytic hierarchy process (AHP) was employed to give weights to different criteria based on expert opinion. Using the comparison matrix among the alternatives and the information on the ranking of the criteria, AHP generated an overall ranking of the sites. The multi-criteria analysis was performed using the Spatial Modeler of ArcGIS. The effectiveness of the developed system was tested at Union Territory of Pondicherry (India).

Singh and Ohri (2009) reported the development of a standalone GIS based EDSS for Solid Waste Management using VB.NET and ArcGIS Engine programming tools. The developed EDSS consisted of six modules dealing with six functional elements of SWM: 'Estimation of Waste Generation', 'Onsite Operation', 'Primary Collection', 'Transportation', 'Resource Recovery' and 'Disposal'. The developed EDSS-MSW was test checked for municipal solid waste management of Varanasi city.

John (2010) considered a sustainability-based decision-support system for solid waste management. A sustainable alternative for diversion of household waste from the landfill site in Sahibzada Ajit Singh (SAS) Nagar, a planned growing town of Punjab (India) was explored. Backyard composting or vermin-composting, Centralized composting of source-segregated organic waste, and Centralized composting of mixed waste were considered as the three alternatives for analysis. Based on six identified criteria for sustainability of municipal solid waste processing methods, multi-criteria decision matrix was formulated. The development of the multi-criteria decision matrix involved the identification of different sustainability factors and parameters on the basis of socio-technical survey in the study area. Centralized composting of source-segregated organic waste was found to be the most feasible alternative under given conditions. Backyard composting or vermin-composting and centralized composting of mixed waste were found second and third in successive preferences on sustainability criteria in decision making.

Saxena et al. (2010) developed a DSS for sustainable municipal solid waste management of Allahabad City (India). Both environmental as well as economical sustainability of municipal solid waste management were considered. Technological aspects, institutional aspects and financial aspects were taken in the framework of integrated approach. Technological aspects included incorporation of GIS in the database for waste related procedures such as waste generation, collection, treatment and disposal. The conceptual framework for the technological aspect of overall solid waste management were categorized and worked out with four modules, namely: waste generation module, waste collection module, waste transportation module and waste disposal module. Institutional aspect considered identification of strengths, weaknesses, opportunities and threats (SWOT) of working bodies governing the solid waste management system. The financial aspect considered factors for reducing the direct economic burden on the municipal authorities by option of tariff from households, commercial places, academic institutions and other waste generators.

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Katpatal and Rao (2010) reported development of a computer based information systems which offers decision making capabilities based on expert knowledge available through integration of alphanumeric information with geographical parameters. The main emphasis of the study was to characterize the solid waste within Nagpur urban area and generate coefficients for estimating quantities of the waste components for various land use classes spatially. Satellite data and linear regression analysis technique was used to generate indices for computing physical and chemical characteristics of solid waste for residential land use classes.

Kanchanabhan et al. (2010) have proposed a GIS based collection and transportation model for MSWM and test checked it for Pallavapuram municipality. A GIS-based optimal routing model was used to develop an optimal route map for efficient transport system. The parameters considered included population density, waste generation capacity, road network, storage bins and collection vehicles. The developed route map could be used to trace the minimum distance as well as efficient collection paths for transporting the solid waste from collection points to final disposal site through transfer stations. The proposed model can be used as a decision-support tool by the municipal authorities for efficient management of the daily operations for moving solid waste, load balancing within vehicles, managing fuel consumption and generating work schedules for the workers and vehicles.

Table 1 summarizes some of the works on EDSS in solid waste management area in recent years.

5. The need of a comprehensive EDSS for MSWM of India

An overview of the development and application of DSS for municipal solid waste management around the world including India reveals that significant attempts have been made to apply the concept and models in different sectors of MSWM in different countries at several locations. However, as correctly noted by Bani et al. (2009), "The approach made by many researchers in DSS modeling is to isolate a few key factors that have a significant influence to the DSS. This segmented approach does not provide a thorough understanding of the complex relationships of the many elements involved. The various elements in constructing the DSS must be integrated and optimized in order to produce a viable model that is marketable and has practical application". Municipal Solid Wastes (Management and Handling) Rules, 2000 of Government of India puts the whole process of MSWM under six broad parameters and suggest compliance criteria for each of them. Schedule II defines these parameters as: collection, segregation, storage, transportation, processing and disposal; and prescribes procedures for compliance of each parameter. Schedule III of the said rule gives specifications for landfill and demands compliance in terms of site selection, facilities at the sites, specifications for landfilling, pollution prevention, water quality monitoring, ambient air quality monitoring, plantation at site, closure of landfill site and post closure care. Similarly, Schedule IV provides standards for composting, treated leachate and incineration. Compliance of the standards regarding ground water, ambient air, leachate quality and the compost quality including incineration are monitored by Central/ State Pollution Control Boards. Collection and transportation are the steps in municipal solid waste management which take largest share of expenditure. The degree of segregation affects not only the choice of treatment technology but also landfill area requirement and transportation costs. CPCB (2003) has prescribed 32 parameters for estimating site sensitivity index (SSI) for sanitary

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Table 1: Summary of DSS for Municipal Solid Waste Management in India

S. No	Authors	Techniques/ tools used	Functional element(s) of SWM covered	Application Area
1	Sudhir et al. (1996)	Multi-objective decision making approach	Waste collection system	Chennai (Tamil Nadu)
2	Natesan and Suresh (2002)	GIS based decision support system. MCE models: AHP, FIC, ANN and Delphi.	Sanitary landfill site selection.	Chennai (Tamil Nadu)
3	Reddy (2005*)	ArcGIS platform	Data management module, Data validation and analysis module, Module capable of analyzing the generated data in to different categories, Transfer station capacity module, Module that calculates site sensitivity index (SSI), and selection criteria for disposal site evaluation.	Medak (Maharashtra)
4	Ghose et al. (2006)	Expert system, GIS based route planning	Collection and transportation route planning.	Asansol (West Bengal)
5	Padmaja et al. (2006)	Remote Sensing and GIS	Waste disposal site.	Hyderabad (Andhra Pradesh)
6	Reddy and Padmaja (2007)	Remote sensing (RS), GIS and GPS	Optimal route analysis for transportation.	Hyderabad (Andhra Pradesh)
7	Sumathi et al. (2008)	GIS-based system, MCDA, Overlay, AHP.	Optimized landfill site selection.	Pondicherry (UT)
8	Singh and Ohri (2009)	Standalone GIS based, AHP	Six functional modules: 'Estimation of Waste Generation', 'Onsite Operation', 'Primary Collection', 'Transportation', 'Resource Recovery' and 'Disposal'. Each module has sub modules.	Varanasi (Uttar Pradesh)
9	John (2010)	Multi-criteria decision matrix to propose the sustainable alternative for diversion of household waste from the landfill site.	Waste Processing Units: Backyard composting (vermin-composting), Centralized composting of source-segregated organic waste, and Centralized composting of mixed waste taken as three alternatives for analysis.	Sahibzada Ajit Singh (SAS) Nagar (Punjab)
10	Saxena et al. (2010)	GIS, SWOT	Technological aspects, Institutional aspects and Financial aspects; Waste generation module, Waste collection module, Waste transportation module and Waste disposal module.	Allahabad (Uttar Pradesh)

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11	Katpatal and Rao (2010)	GIS-based system, Satellite data and linear regression analysis.	Characterization of MSW	Nagpur (Maharashtra)
12	Kanchanabhn et al. (2010)	GIS-based system, Optimization	Collection and Transportation	Pallavapuram (Tamil Nadu)

landfill site selection. Thus, selection of a suitable disposal site itself requires a vast amount of data and considerable expertise, if all relevant environmental concerns are to be properly addressed. Although significant amount of work has been done on different aspects of MSWM, a wholesome unit of EDSS dealing with all relevant parameters applicable under Indian regulatory frameworks appears very much desirable and necessary. Towards this objective, an attempt has been made by the authors to develop a GIS based environmental decision support system, named 'EDSS-MSWI' for municipal solid waste management in India. Figure 2 gives the framework of the proposed EDSS. It includes six modules, named - Primary Collection,

Segregation, Secondary Storage, Transportation, Processing, and Disposal, as per the parameters named in Municipal Solid Wastes (Management and Handling) Rules, 2000. The guidelines of Central Public Health and Environmental Engineering Organization (CPHEEO, 2000), Central Pollution Control Board, (CPCB, 2003) and all other relevant published knowledge base in the field have been compiled to guide the decision maker for making a solid waste management plan. An additional module on 'Financial Aspects' helps in estimating the possible income from user fees, recycling, processing, carbon credit earning and expenditure on staff, vehicles and disposal. Each module has sub modules to address different areas specific to it.

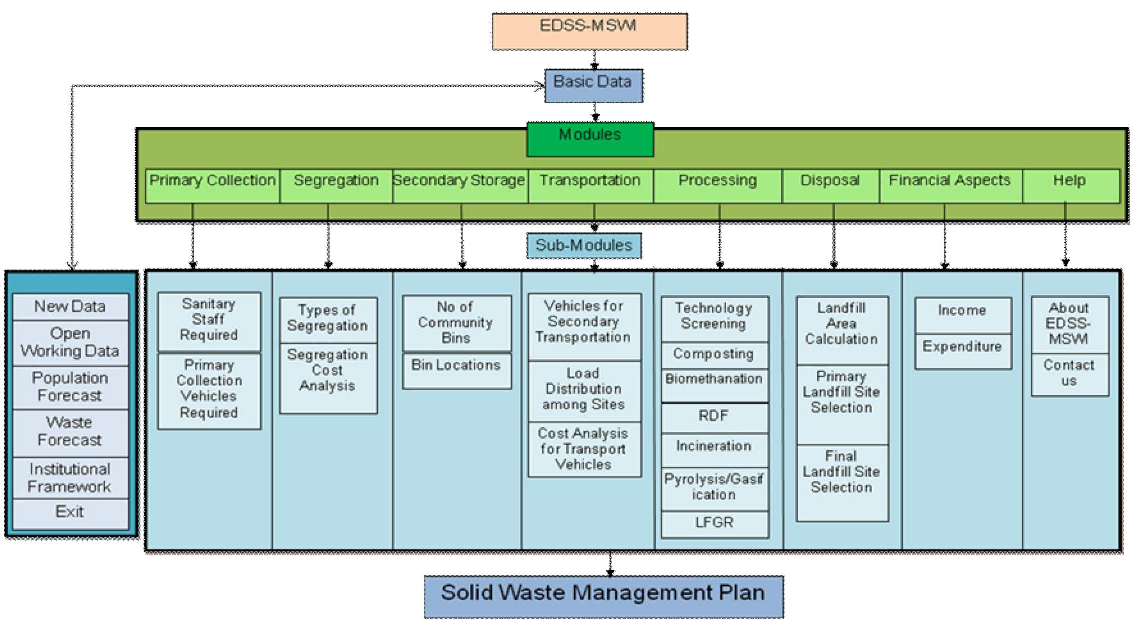

Figure 2: Frame work of EDSS-MSWI

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6. Concluding remarks

The available literature indicates that in India, a number of decision support systems (DSS) have been developed and applied in the area of municipal solid waste management since mid '90. Most of them address one or a few segment of the process. Development of a comprehensive and user friendly EDSS for solid waste management in Indian regulative and social frame work appears very much necessary and timely to take full advantages of the planned investments in infrastructure and health sectors. A conceptual frame work for one such proposed decision support system, named 'EDSS-MSWI' has been presented.

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