Application of Systems Engineering Models in Solid Waste Management

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Abstract

Solid waste management system has become a serious issue of concern for the countries with rising population. Increase in population has lead in increase in consumption of resources as well as it has significantly increased the amount of waste generated and disposed by its people. In the past few years, solid waste management systems over the globe have involved complex and multi-faceted trade-offs among a bundle of technological alternatives, economic strategies and regulatory frameworks.These changes have resulted in various environmental, economical, and health concerns. To tackle these concerns we need to introduce a set of new sub-system which is robust, flexible and efficient to handle solid waste up to date. Systemic thinking and its implementation is a brand new approach which can be implied in Solid waste management (SWM)to give better results. Issues related to solid waste management arise due to lack of waste segregation at source, low percentage of house-to-house collection, large number of open vats, low operational efficiencies of waste transport, low collection efficiency and an inefficient informal recycling system. Systems engineeringprinciples can be applied to these loop holes to construct an efficient system. This paper deals with introduction of systems engineering to solid waste management: its methodology, systemic models, systemic tools, approaches and a case study of Integrated Solid Waste Management System at Rochester Institute of Technology, New York. This paper will cover various systems models, tools which can be applied to the SWM model in RIT. Considering the results from case study done in RIT, system analysis models and tools can be applied to any SWM system in a synergetic way which would certainly provide opportunity to develop better SWM strategies leading to conformity with current standards and foster future perspectives for efficient waste management systems.

Keywords- Solid waste management (SWM), Systems engineering (SE), Systemic models, Systemic tools,Integrated solid waste management (ISWM), waste transport

1. Introduction and Background

"We cannot solve our problems with the same thinking we used when we created them." - *Albert Einstein*

Modern thinking is to be applied to the existing model to make it more resistant, robust and efficient. In case of Solid waste management (SWM) strategies are emerged to address the health, environmental, economic and land-use concerns associated with inefficient disposal of waste. These issues are ongoing concern for nations, municipal bodies, industries, corporations, individuals and the global community at large. The major reason behind complexity of SWM is the unmanaged excessive solid waste generated per day due to uncontrolled growth of urban population and industrialization. Therefore in the current situation the sustainable management of solid waste has become necessary to design, validate, plan, operate and integrate a spectrum of new and existing waste treatment system. As well as the spectrum of new and existing waste treatmenttechnologies and managerial strategies are expected to maintain the environmental quality at present so as to meet the sustainability goals in the future. Such a combinationof goals and evolution has led waste management agencies, industries and municipal bodies to meet common needs of waste management with greatest green potential. These agencies need to encourage recycling of materials out of waste streams, reuse material until it becomes pure waste, increase the use of renewable energy and maintain the natural ecosystem consisting of flora and fauna. To achieve such goals, all technical and non-technicalaspects of SWM system should beanalyzed as a whole anda holistic approach should be introduced to integrate the methodologies.

Solid waste problems are becoming acute due to lack of land filling sites available in and around the city. New sites which are accessible and technically suitable for landfills and waste incineration are difficult to manage due to public and political influence. In spite of these the wastes generated continues to increase despite of increase in recycling and reusing of useful waste. In past few years, various rules and regulations have been imposed by various countries in accordance to decrease waste produced and to increase awareness among people of recycling and reusing. However most of these efforts have been focused on hazardous waste only [1]. Therefore, several changes in techniques of handling waste management system in both technology and managerial are necessary to develop an efficient system. Transportation and handling of waste is the backbone of any SWM system. To ensure high efficiency in SWM, it is necessary to have a proper collection, segregation and decomposition of waste. The existing waste handling model for city is explained in Fig. 1. This existing model can also be upgraded through systemic models to eradicate wastage of time and decrease the cost of program.

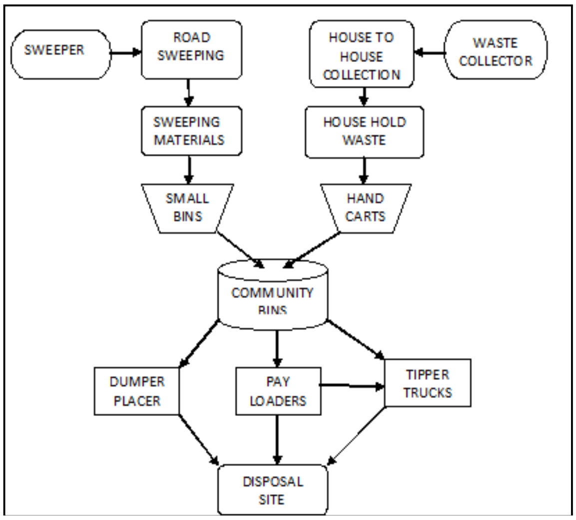


Fig. 1. Waste Handling model for a City

Systems engineering principles can be applied to handle solid waste through a wide spectrum of integrative and interdisciplinary methodologies. Combination of system engineering models and system assessment tools are employed to illuminate the challenges in SWM. A gamut of total five system engineering models and ninesystem assessment tools are used to tackle the existing loop holes[2]. System engineering models consists of Optimization models (OM), Forecasting models (FM), Simulation models (SM), Cost benefit analysis (CBA) and Integrated modeling systems (IMS). Whereas system assessment tools consists of Life cycle assessment (LCI) or Life cycle Inventory (LCI), Risk assessment (RA), Management Information systems (MIS), Decision support system (DSS), Expert system (ES), Material flow analysis (MFA), Environmental impact assessment (EIA), Scenario Development (SD), Strategic environmental assessment (SEA), Sustainable assessment (SA) and Socioeconomic assessment (SoEA).

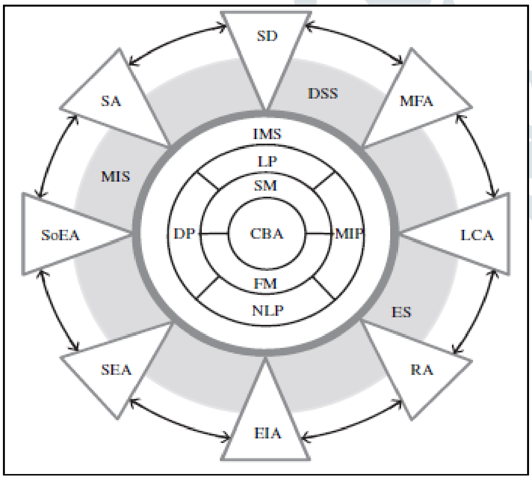


Fig. 2. The technology hub for SWM **[2]**

Fig. 2 illustrates the interrelationship between system models and tools through which fourteen technologies can be interconnected through such a hub. In the core part, the five systems engineering models are seen as the core technologies in which the costbenefitanalysis is used as a common platform in support of decisionmaking. Integrated modeling systems focuses ondifferent optimization models such as linear programming(LP), mixed-integer programming (MIP), non-linear programming(NLP), and dynamic programming (DP) models to address thesystem issues. It is seen that the SM and FM support theessential background in concert with CBA in the context ofsystems analysis. With such a focused structure, DSSs are re-build for separate applications. All of thesecore efforts are intensified by the remaining system assessmenttools described by the eight outer triangles. Connectionamong the eight triangles canalizes the information flows that inturn improve the contribution of the five systems models being formed through ES, DSS and MIS [2]. Overall,leads to a strong realization of the structure betweensystems engineering models and systems assessment tools fromwhich a systems analysis can be balanced for generatingenvironmentally benign, cost effective, ecologically sound, andsocially acceptable solutions.

Other than using systems model and tools we need to concentrate on the technical analysis of the problem so as to get a best possible solution. General properties of SWMsystem and MIMES model can be used for technical analysis of the system. MIMES/WASTE is developed from a general model for linked energy and material flows.The model has been created for the analysis of reducing pollutants and emissions resulting from wastes, options for recycling, technical options for processing solid waste and strategies for source separation.In the late 1960s models were focused on the subsystems of SWM's. Today, models have become more complex to be handled and managed. Recent approaches which are used in SWM are RRPLAN model and HARBINGER model [3]. RRPLAN serves to handle scheduling of area wise SWM. Harbinger model consists of eight sub-models. Six of them are input functions and two are for analyzing various variations of strategies. Harbinger models are non-time based models which are simulated number of times to compare and analyze optimization routines. An option that is not available in MIMES/WASTE is the detailed analysis ofthe transport system that is available in the transport network sub-model. This sub-model derivesthe shortest times through the road system for the waste collecting vehicles.The MIMES/WASTE model has been used in two pilot studies, one of the Goteborg, Sweden region (700,000 inhabitants), and one of the municipality boards (100,000 inhabitants) [3]. This proved models, tools and systems can be applied to the existing systems to upgrade the existing system to an optimized one. The following sections of this paper will describe the general modeling principles, models, tools and the methodologyand modes of application of systems engineering.

2. Systems Engineering Approach for SWM

"Systems engineering is a set of related components or sub-systems, which interact with each other to manage complex system." It consists of sub-systems which consist of group of interconnected and interactive components that perform an important task in a large system. Components consist of various parts which define its work. Solid Waste Management can be considered as a complex system. "Complex system consists of many autonomous but interrelated components or parts linked through dense interconnections." Solid waste management is a systemic control of generation, collection, storage, transport, source separation, processing, treatment, recovery and disposal of solid waste. Activities which are methodologies for decomposing the wastes are landfill, incineration, anaerobic digestion and composting. All these activities can be called as subsystem of the waste management system. Functioning of all these sub-systems is essential to ensure proper functioning of the system. The properties of a system are defined by the whole of sub-systems, their characteristic and their relationships. Therefore proper functioning of component is important so as to ensure proper functioning of subsystem. Other philosophies apart from synchronous working of sub-systems which are responsible for betterment of a system are explained below one by one-

1. Methodology

SWM is an open system that exchanges energy, material and information with itsenvironment, across the system boundaries. It is important to identify the boundaries concerning with the system which fits the defined problem and where possible, to study the interactionsbetween the system and its environment through a limited set of environmental factors [10].Fig. 3 indicates the most important factors in the environment of the Solid Waste Management System.With respect to boundaries chosen we can identify seven factors in the SWM system environment:

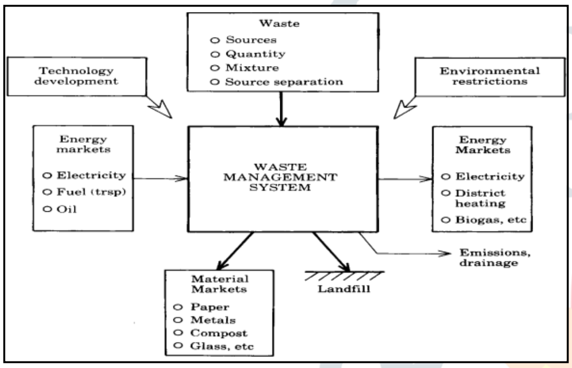


Fig. 3. The Environment of Waste Management System [3]

a. The quantity of waste and the degree of source separation.
b. The demand for recycled materials on the markets.
c. Availability of new sites for landfills.
d. Demand and wholesale prices for electricity and low temperature heat fordistrict heating.
e. The price and availability of auxiliary energy supply, e.g. oil, electricity, diesel etc.
f. Environmental restrictions, e.g. on emissions from incineration and on drainage from landfills.
g. Availability, cost and technical properties of new technologies.

The boundary of SWM, as described above, is not fixed, due to method or model limitations. Based on the nature of the problem, a wider or a narrower and a distinct system can be used for SWM system operated with the help of computer.

2. Model as a planning instrument

The MIMES/WASTE model is designed to find efficient solutions for the existing loop-holes in SWM system. The goal of the model is to facilitate future waste management systems which are cost efficient and environmentally feasible. These models can also be helpful in determining the consequences of the system due to alterations in the plan. Three steps incurred in planning based model design are- short-term planning, long-term planning and consequences analysis.

The differences between the modes of a model are shown below in Table 1. In long-term planning, system studies are performed by scenario analysis in order tohandle the uncertainties in the system environment. The result is we get a customized solution for the future SWAMS. These solutions are used to form a strategy for the development of the system. Examples of long-term planning problems that can be analyzed by the model are-

i. Introduction of new technology (e.g. bio-gas plants, composting plants)
ii. Introduction of emission fees and differentiated waste fees
iii. Strategies for source separation

Table 1: Model Modes

Model Modes	Modeling Techniques	Objective	Options
Long-term Planning	Optimization (LP/NLP)	Minimum system cost (variable and fixed cost)	Flows and process
Short-term Planning	Optimization (LP/NLP)	Minimum system cost (variable cost only)	None
Consequence Analysis	Simulation	NA	Flows and Processes

In short-term planning, the new investments option is excluded. Thismode includes how the waste streams of SWAMS should be utilized using existingtechnology in order to minimize costs. For example, at what price for recycled newsprintdoes burning become a cost efficient option? What fees should be used for constructionwaste, if the combustible fractions are separated at the construction sites?Consequence analysis consists of processes and flows which are fixed. These processes cannot be optimized unlike in long-term and short-term planning. This mode ensures if the assumptions made are feasible or not. And if these assumptions are found feasible what effect do they have on waste flow and emissions. This mode is generally used for validating a proposed plan in concern with technical, economic and environmental restrictions. This model can also be used for calculating the certain variables such as amount of nitrogen oxide emitted from the system etc.

3. The model

The systems approach to solid waste management, described in this paper, is built onthe modeling concept of MIMES. This model offers general concept for modeling of complex systems in context to materials and energy. This model identifies the methods of system identification, model formation, model representation, systems optimization and simulation. This model is general type of model which can be applied to various kinds of systems and their problems.

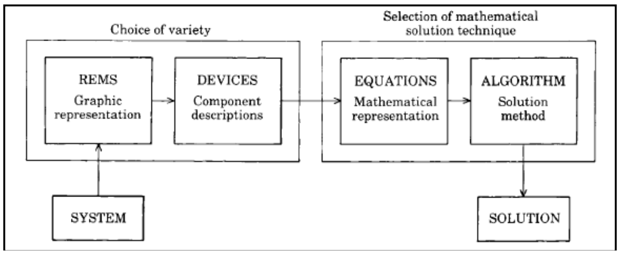


Fig. 4. General structure of the MIMES modeling concept [3]

MIMES/WASTE system can be divided into two parts. One is choice of variety and the other part is selection of mathematical solution technique. Choice of variety deals with representation of systems models. Its basic concern is how a system should be represented in model format. It identifies an efficient system boundary and then defines which all technologies and flows should be included and studied. It basically selects the valuable information from the system and describes that information in the form of model. The second part which is solution of mathematical solution technique is responsible for the entire problem concerning mathematical representation of the system.

3.1 System

The model is designed for systems of linked energy and material flows, of which the SWM system is an example. It is not limited to a specific system or technology because it consists of general framework for technology descriptions and flexible aggregation level for model units.

3.2 REMS

Reference energy and material systems diagrams are used for graphical representation of the system for handling complex systems in comprehensive systems. Graphic representation includes system boundaries and defines the scope and detail of the technical analysis of the system. REMS is an important tool for evaluating the model results together with the actors in the system.In energy systems engineering, network diagrams are used to show the flow of energy carriers from energy sources via energy conversion technologies to the final consumer.

3.3 Devices

Devices are the nodes in the network of energy and material flow. They are the subsystems for the handling the energy and material flow. MIMES offer a set of device options and flow optionsfor the devices, they define the possible flow paths, relationships between them and they also control these flows.

3.4 Equations

MIMES modeling concept consists of two types of equations, linear and non-linear. The REMS and device analysis provide the basis forselecting and specifying equations to obtain an algebraic representation of the system.The selection of equations can be generalized through the DEVEDprogram. The system of equations is solved by the algorithms.

3.5 Algorithm

For the mathematical optimization and simulation, MIMES uses two types of algorithms: non-linear programming(NLP) and linear programming (LP) algorithms. Sincesome systems may be described and modeled by purely linear equations, the option touse standard LP algorithms is available. From a mathematical point of view, linear equations are to be preferred. Advantages of using linear programming are that they can easily handle large equation systems and can solve them without taking much time. However non-linear equations are used for the applications in SWAMS.

4. Life Cycle Assessment

Life Cycle Assessment is model developed for analysis of material products from their cradle to grave. This is done by compiling an inventory of relevant inputs and outputs of a system, then evaluating the potential impacts of those input and outputs followed by interpreting the results in comparison with objectivesof the product [12]. LCA is responsible from stating the goal to the inventory analysis to the impact analysis and lastly improvement analysis. Every cycle works in the manner stated in the Fig. 5. Figure explains the life cycle of a system starting from defining goal to performing the improvement analysis.In the definition of LCA, 'Product' does not include just the product systems but it also includes the services that come along with the product. LCA is used world-wide to evaluate different strategies for integrated solid waste management and to evaluate treatment options for specific waste fractions. LCA model can be divided into five parts. The model can be explained, studied by applying concepts of upstream and downstream system boundaries, open loop recycling allocation, multi-input allocation, time and life cycle impact assessment [4].

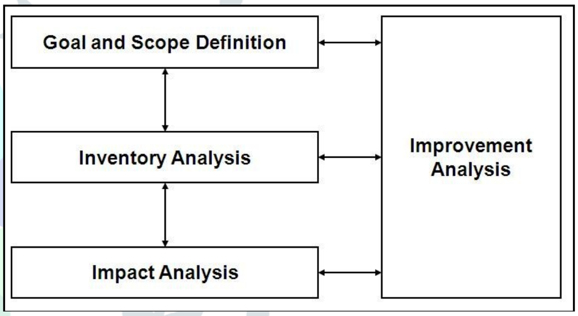


Fig. 5. Life Cycle of System

Upstream and downstream system boundaries examine the cradle and grave phase of the product. Open-loop recycling allocation deals with treatment of solid waste through various types of recycling procedures. They are also responsible for recycling energy and materials into other products. Multi-input allocation is the waste treatment process in which different materials and products are mixed. It is an application based allocation in which environmental interventions are considered for input of the materials. Time measures the span of emissions from landfills and land-filling done on a particular site. Life cycle impact assessment is the aspects of solid waste management systems that may require specific attention for the impact assessment element of a LCA. LCA model can be applied systemically for the management of solid waste management. The backbone of LCA systems are mentioned below-

4.1. Upstream and Downstream system boundaries

The main principle of LCA is that the system which is to be modeled should be modeled in such a manner that its inputs and outputs to the system should be monitored for the cradle to grave. In case of SWM systems inputs are the solid waste from households, industries, commercial complexes and etc. The waste generated from each source would be different thus these upstream boundaries are to be changed. Because if one of the system is compared to produce more or less waste than the others then the system inputs are no longer identical, and in principle the system boundary should be moved and upstream activities should be included, at least those parts which differ between different systems. This may in practice proves to be very difficult and therefore not done. In that case it should be noted that the impacts of the system which produces less waste is wrongly estimated in comparison with other. In case of downstream boundaries when materials and energy is recycled into new products similar error in the comparison is obtained. Generally in LCA waste after recycling aren't followed till it is completely decomposed. Therefore even if the waste is not identical but if it's providing similar comparable function then the LCA cycle should be carried out on the waste irrespective of the differences.

4.2. Open-loop recycling

Open loop recycling takes place when a product is recycled after its use into another product. The system boundary is not clear between the products. Therefore, this problem can be sorted out by recycling by allocating environmental interventions between recycled products and studying only one of them. Allocation in open loop recycling systems can be done in steps. First recycling, secondly production of primary material used in both recycled products and then disposal of materials used in both products. In order to avoid allocation problems, system boundaries can be expanded to include various sub-systems in the existing system. For example, in case of incineration the waste is treated with the help of heat and in case of land filling the solid waste is decomposed by letting the waste to bio-degrade by filling up the land or decomposing site. In incineration of energy can be produced by decomposing the waste thus it produces a secondary function. This secondary function can be added to another system such as land filing as an alternative heat source to achieve the function of treatment of solid waste. This way system can be expanded and made effective by proper allocation of function to sub-system. A drawback of using system expansion is that the models get complex. Models used in system expansion are based on critical assumptions concerning energy and material. When using system expansion, various functions are employed at the same time. Therefore it is not possible to study one particular product or function which can be a drawback of the expansion. But at the same time it is advantageous to the system since it reflects the real situation. Since management of available function gives us the best results therefore it can be claimed that the expansion gives the system a new outlook and makes it more complete and expanded when the boundaries are extended.

4.3. Multi-input processes

Processes in which multi input is given for a single output are known to be multi-input processes. In case of solid waste management of the system various approaches can be utilized in treating the solid waste generated from various sources. These approaches can be different terms but all have same motive of decomposing the waste. For example, Land-filling and incineration are two distinct processes. One involves with simply decomposing the waste by heating and other involves by filling up the land. Both the processes have one outcome that is decomposition through emissions. Therefore this multi-input processes can be deployed in case of LCA systems.

4.4. Landfills and time aspects

Time frame is the major difference which can be spotted between land-filling and other processes included in LCA. Emissions from the land fill can prevail for long time. In order to compare the emissions form land filling to other emissions during the life cycle, the potential emissions have to be integrated over a period of time. Time taken for emission by different substances in solid waste is different. For a biodegradable waste it would be 2-3 days but for heavy metals it would be around more than hundreds of years. Various theories and studies can be studied of experts to determine a particular time frame for a substance to release emissions. Another principle which has been discussed for defining the time period is to include the time period until the concentrations are lower than the acceptable or lower than background. Other than this availability tests can be performed to estimate the total leaching potential without temporal differentiation. When discussing the processes that may occur in a landfill, the exact kinetics is often difficult to predict. The kinetic depends upon the site characteristics such as climate and waste management practices that may differ and which will often be unknown in a specific LCA. Whereas the events and their sequences are better known and easier to track. It is therefore easier to define the time perspective in terms of the processes and the events rather than by years. Thus time aspects play an important role in analyzing the decomposition of substances in the LCA system.

4.5. Life cycle assessment of SWM systems

It is a part of LCA which is responsible for understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. In LCA, generally it is unknown that where and when all the emissions take place. This is one of the reason why LCA cannot predict impacts but is hindered to just analyzing potential impacts. When analyzing emission form landfills, this situation is enforced since the emission will occur in a future situation. The emission cannot be measured but only predicted. Due to which potential predictions are included in LCA rather thanactual values. This can make the impact assessment more difficult because there are increased problems modeling background concentrations and other aspects which may be of importance for the impact assessment. For example, valuation would be limited to effects within a time range, and then the specification of emissions after this time period would be unnecessary. Also, if the valuation placed a different importance on effects occurring at different times, the inventory analysis must indicate the time scale of emissions. The definition of LCA states that the analysis should include the complete life cycle irrespective of the total time taken to attain grave. This suggests that all emissions in solid waste management should be included regardless of when they occur and when they end.

5. System Analysis Techniques

Decision making is the sole backbone of an operation to be performed in a system. The decision maker should think critically and analytically to resolve a problem in a system. There are various systems engineering models which can be helped in decision making task of a system engineer. “Model-Based systems engineering can be defined as an approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle [13][14].” The decision making model can be basically divided into two: systems engineering models and system assessment tools [2].

5.1 Systems Engineering Models

Complexity in SWM system arises from various hindrances which resist the flow of system. This hindrance can be due to lack of technology, facilities and management in the system. To tackle the synergistic interfaces, systems engineering models can be helpful for promoting analysis based on cost-benefit analysis (CBA), optimization models (OM), simulation models (SM), forecasting models (FM) and integrated modeling systems (IMS).

a. Cost–benefit analysis (CBA) is a systemic approach to evaluate strengths and weaknesses of a decision. It is used in determining various alternatives for providing the best or optimized solution to achieve long term benefits or profits. CBA can be employed in for solid waste management so as to validate the cost effectiveness of project. Cost-benefit analysis can be used to assess positive and negative economic and physical effects independently. It is also used in optimizing models for system analysis. A well defined cost benefit models is used to translate environmental aspects of SWM systems into economic terms. However it is very difficult to deal with the integration of externalities in the system. Two main functions of CBA are- To determine if an investment/decision is sound (justification/feasibility) – verifying whether its benefits outweigh the costs, and by how much; and To provide a basis for comparing projects – which involves comparing the total expected cost of each option against its total expected benefits. Optimization models (OM) are used to identify the best solution among numerous alternatives.

b. Optimization consists of maximizing or minimizing a real function by systematically by choosing input values from within an allowed set and computing the value of the function. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. More generally, optimization includes finding "best available" values of some objective function given a defined domain (or input), including a variety of different types of objective functions and different types of domains.

c. Simulation models (SM) are used to trace the lengthy chains of continuous or discrete events based on cause and effect relations describing the operations in complex systems and helping investigate the dynamic behavior of the system.It is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. Simulation modeling can be used in solid waste management to design various parts such as incineration tumblers, disposal bins and etc. It is used to determine under what conditions and in which ways a part could fail and what loads it can withstand. Simulation modeling can also help predict fluid flow and heat transfer patterns in case of solid waste transportation through pipes and chambers.

d. Forecasting Model (FM) is a process of making predictions of the future based on past and present data analysis and trends. It is more of statistical model consisting of study of graphs and curves to study the pattern and predict the probable data. It involves statistical methods such as time series, cross-sectional or longitudinal data. Forecasting brings along two terms with it. One is risk and other is uncertainty. Generally forecasting model consist degrees of uncertainty in it. The most important concern regarding forecasting is that the data to be studied should be standardized and up to date. FM in solid waste management is used to characterize waste streams quantitatively and qualitatively and to construct a management information system to accumulate information over time.

e. Integrated modeling systems (IMS) are used to improve synergetic connections among different models, concatenating their total functionalities. IMS brings together discrete systems utilizing variety of techniques such as computer networking, enterprise application integration, business process management and manual programming. This technique can be used in channelizing solid waste management and creating a centralized model for monitoring tasks of subsystems and its components.

5.2 System Assessment tools

System assessment tools are majorly used for analyzing the performance characteristic of the system. They can be analyzed to note loop holes in the existing system and to make future systems efficient and robust. Tools which help decision makers towards such goals are called as system assessment tools. Management information system (MIS), Scenario development (SD), Material flow analysis (MFS), Life cycle assessment (LCA), Risk Assessment (RA), Environmental impact assessment (EIA), Strategic environmental assessment (SEA), Socio-economic assessment (SEA) and Sustainable assessment (SA).

a. Management information system (MIS) consists of different methods applied to exchange and manage information used in decision making. It basically focuses on to handling data and interpreting it in such a manner that an efficient and effective decision is made. This concept includes various subsystems such as transaction processing, transaction processing system, decision support system, expert system, or executive information system. It can be used in solid waste management to exchange the information between contractors which decompose the waste. This information can be used to manage the waste, such that recyclable waste is taken for recycling, bio-degradable wastes are taken to land filling sites where they are decomposed to get bio-degrade. These systems are also know as Decision support system (DSS) or Expert system (ES).

b. Scenario development (SD) is used to create hypothetical sequences of occurrences and events planned for the purpose of focusing attention on casual processes and decision points. This tool can be used for exploring the events that might occur and are associated with SWM on a temporary basis. Such events can be inside or outside the system. This tool can be used effectively used to approximate future lifestyle trends and waste composition patterns and strategies.

c. Material flow analysis (MFA) consists of a systematic assessment of the flows and stocks of materials within a system defined in space and time.It is basically an analytical method to quantify flows and stocks of materials or substances in a well-defined system. MFA is an important tool to study the bio-physical aspects of human activity on different spatial and temporal scales such as solid waste generated by humans and industries. MFA can be applied to SWM system by a single installation, for example, for tracking solid flow flows through a waste water or slurry flowing through municipal waste pipelines. When combined with an assessment of the costs associated with material flows this business-oriented application of MFA is called Material Flow Cost Accounting. MFA is an important tool to study the circular economy and to devise material flow management in case solid and industrial wastes.

d. Life cycle assessment (LCA) consists of a process to evaluate environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used, wastes and emission released to the environment, to assess the impact of those energy and material uses and releases and to identify and evaluate opportunities that lead to environmental improvements.

e. Risk assessment (RA) is used to relate environmental and human health risk to accidents quantitatively, through a statistical evaluation. It is used in determination of quantitative or qualitative estimate of risk related to a well-defined situation and a recognized threat (also called hazard). "Quantitative risk assessment requires calculations of two components of risk (R): the magnitude of the potential loss (L), and the probability (p) that the loss will occur. An acceptable risk is a risk that is understood and tolerated usually because the cost or difficulty of implementing an effective countermeasure for the associated vulnerability exceeds the expectation of loss." In all types of engineering of complex systems sophisticated risk assessments are often made within safety engineering and reliability engineering when it concerns threats to life, environment or machine functioning. Methods for assessment of risk may differ between industries and application whether it pertains to general financial decisions or environmental. Solid waste management decision can be dealt by using risk assessments. It includes the probable threats on the environmental pollution and public health. Landfills and incinerations and other methods have risks which are to be identified and ruled out by decision making.

f. Environmental impact assessment (EIA) is a procedure that aims to ensure that the decision-making process concerning activities that may have a significant influence on the environment. The purpose of the assessment is to ensure that decision makers consider the environmental impacts when deciding whether or not to proceed with a project. The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made. EIAs are unique in that they do not require adherence to a predetermined environmental outcome, but rather they require decision makers to account for environmental values in their decisions and to justify those decisions in light of detailed environmental studies and public comments on the potential environmental impacts. Application of environmental impact assessment in the field of solid waste management is necessary because SWM is concerned with decomposition of various hazardous substances and gases which directly affect the environment and ecosystem. Therefore assessment is to be carried out periodically to ensure that there no probable harmful impacts of waste decomposed on environment.

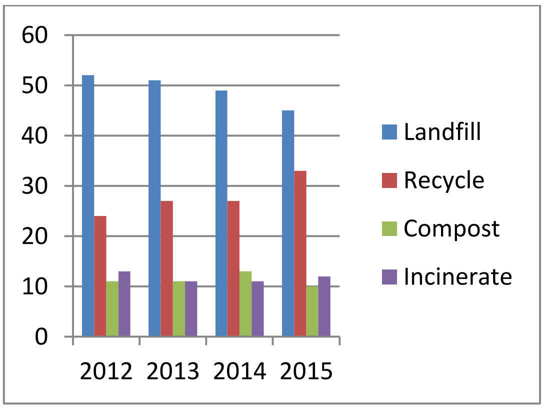
g. Strategic environmental assessment consists of a strategic action as a policy, a plan or a program. It is a systematic decision support process, which aims at ensuring that environmental and other sustainability aspects are considered effectively in policy, plan and program making. Effective SEA works within a framework to support more effective and efficient decision-making for sustainable development and improved governance by providing for a substantive focus regarding questions, issues and alternatives to be considered in policy, plan and program (PPP) making.SEA is an evidence-based instrument, aiming to add scientific rigor to PPP making, by using suitable assessment methods and techniques.

h. Sustainable assessment refers to the integration of different methodologies in such a way that obtaining an analysis, an evaluation or a planning that approaches several management aspects in which sustainability implications may be emphasized and illuminated.

3. Example of SWM at Rochester Institute of Technology

The pilot study for the SWM was carried out in Rochester Institute of Technology, Rochester (NY). The study was carried out in cooperation with Golisano Institute of Sustainability and Facilities Management Services, RIT. The main focus of study was to examine the various types of wastes generated from residence halls, café's, dining services, colleges, laboratories and offices and to suggest systemic models to the system and their effectiveness.

Rochester Institute of Technology is a privately owned doctoral university located in Rochester, New York. It was established in 1829 by Colonel Nathniel Rochester and associates. It aims at providing technical education to the aspiring students with latest technology and world-class facilities. The campus is spread over 1300 acres having nine full colleges, residence halls, dining services, indoor multi-purpose stadiums and administrative offices [5]. RIT generates over 2,500 tons of waste every year. Managing the waste at RIT is not less than a complex system. Due to 1300 acres spread of campus it is difficult for the facilities management services to collect the waste from each corner of the campus and to segregate it and then decompose it [7]. Various types of waste generated in RIT are single stream waste, trash, wood, Cardboard, paper, scrap metal, electronics, food composts, hazardous fluids from the laboratories, human wastes etc. Waste decomposition statistic for past four years is shown in graph1.It is seen that the amount of waste land-filled is almost 49% every year in respect to total waste decomposed. The land-filling is done in the area of Synameadows, Waterloo (NY). Recycled waste percentage has been increased in small percentages over the past year from 20 to 30%. Recycling of material is carried out in Material Recycling Facility (MRF) at Buffalo (NY).Compost and incinerate waste generated and decomposed remain in the range of 8-15%. Compost is taken to Noble Herst Energy where anaerobic digester helps in decomposing the food waste. The location of decomposition is around 40 miles away from Rochester [6].



Graph 1: Waste Decomposition Method for years 2012-2015

More and more efforts are to be made to increase the percent of recycled and reused waste. All the waste generated in RIT is needed to be tackled by applying systems engineering models so as to ensure proper and efficient management of wastes.

4. Systemic approach to SWM at RIT

There are various systemic models and tools which can be applied to the existing system. Appropriate selection of models, tools, decisions and implementations can improve the system through the concurrent engineering. The first approach in system thinking is to define a methodology. Defining the boundaries for the transfer of energy and material throughout the system makes it clear to understand and implement. Thus boundaries should be identified in case SWM at RIT. It should be identified from where the material (waste) is generated and where the energy can be recovered through this waste. A hierarchical model should be planned for managing the waste to ensure that there is less amount of threat put forward to the society by managing the waste. Therefore the waste management hierarchy which should be followed at RIT is mentioned in Fig. 6.It can be inferred from systems thinking that the best way to manage the waste is to avoid the circumstances that generate it. Therefore, primary aim of the system should be avoiding generation of the probable waste. Next in-line priority should be recycling followed by energy recovery. Treatment and disposal should be the least preferred way of managing waste because it is costly and affects the environment.

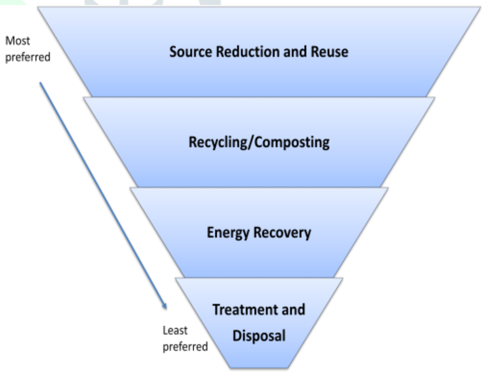


Fig. 6. Waste management hierarchy at RIT

MIMES/WASTE model can also be applied for SWM system in RIT. Designing a MIMES/WASTE model helps in finding new solutions for future waste management systems that are cost efficient and environmentally acceptable. This system is also used to analyze the consequences of specific changes that are suggested for the system. The model consists of periodic thinking. Therefore, in SWM at RIT long-term, short-term and consequence plans can be studied, designed and discussed by the authorities so as to avoid any future consequences of improper solid waste management. Examples of long-term plans can include introduction to new technology (e.g. Bio-gas plants, fuel cells etc). MIMES/WASTE model can also be used to find the most optimized model to obtain the best solution. Tools such as REMS (Reference Energy an Material Systems), devices, equations and algorithms can be applied by the experts to figure out the most suitable and most optimized SWM model for the RIT. Devices used in MIMES models in RIT can be used to find out possible flow paths of waste, relationships between those paths and control and moderation of flow. For example, a recycling sub-system (device) can be introduced in campus which can help to recycle the possible types of wastes such as paper, cardboards, and plastics. Equations and Algorithms are the mathematical approach to refine the system. Linear and non-linear equations can be designed and solved with the help of linear programming and non-linear programming to find the most suitable model at the RIT. LCA (Life Cycle Assessment) is an another tool which can be applied to SWM at RIT to study, manage, operate, decompose the life cycle of waste at RIT. Applying principles of LCA helps us to study a product right from its birth till it reaches its grave. It is important to study this cycle in detail so that every possible loop hole in the cycle can be eliminated. These loop holes can be identified with the help of upstream and downstream boundaries. For example if building A generates X amount of waste and Building B generates Y amount of waste where (X>Y). Applying same technology and approach to Building A as well as B will be not feasible. Therefore, there should be custom made model for each building in RIT so as to stop energy, technology, material, and money wastage. LCA also introduces to open-loop recycling model, advantages and disadvantages of system expansion, multi-input processes and etc. Therefore a customized model can be designed for the RIT SWM to ensure all the loop holes in the existing system are eradicated. System analysis techniques and their effects to the SWM in RIT are discussed in the results and discussion section.

5. Results and Discussions

We have discussed various system based models which can be applied to any system to upgrade it to more efficient, cost-effective, environmental friendly and feasible version of it. In this paper we have explained the complexity of the solid waste management model andneeds to implement systems thinking into the existing model. Improper solid waste management imposes a huge risk of spread of epidemics, loss of ecosystem, adverse affect on environment and sustainability. Therefore, introducing system based model in SWM would enhance the outlook of management strategies and would give better results. The study done on the existing SWM system at RIT suggests that there are a lot more opportunities available to enhance the system and to make it more efficient and environment friendly. We mentioned how these loop holes can be eradicated through the system just by the implication of systems thinking. Further we would like to propose various systems analysis techniques which can be applied to the SWM system at RIT to get a better result.

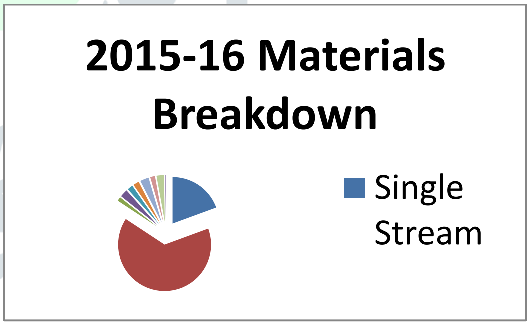
Table 2: Systems Engineering Model and Tool applied to SWM in RIT

Sr. no.	Systems engineering models and tools	Contribution to the SWM at RIT
1	Cost-benefit analysis	It would assess economic and optimization models for systems analysis. It would help RIT to reduce its cost in decomposition of waste by managing the waste wisely. Facilities Management Services and Accounting department should work in co-ordination with sustainability advisor to figure out the cheapest way to SWM
2	Optimization model	Managing waste through equations, algorithms would help RIT to optimize the existing model so as to get best solution for SMW among numerous alternatives and contractors. FMS can collaborate with industrial engineering graduates to solve transportation and linear programming problems to obtain the best model.
3	Simulation model	Simulation can be performed on existing components to trace the continuous or discrete events based on cause and effect relationship to investigate the dynamic behavior of the component. Ineffective or faulty components/models are to be changed as early as possible so as to avoid loss of waste (economic waste)
4	Fore-casting model	FCM can be deployed to study and characterize the various types of waste produced in RIT in quantitatively and qualitatively manner. They can be used to construct a management information system to accumulate all the information data related to statistics over a period of time
5	Integrated modeling systems	IMS models can be used improve inter-connections between various models and their functions to find a better solutions. This can be implemented in SWM to trace the dynamic information of waste generation and waste shipping. They can also be used for interconnecting patterns between optimal capacity expansions from waste to energy.
6	Management information system/ Decision support system/ Expert systems	Department of management information system can help the FMS in setting up of devices which would provide generating of information and storing it for future reference. It basically consists of various technologies used to manage the information and help board of members to for decision-making.
7	Scenario	FMS can take the help of civil

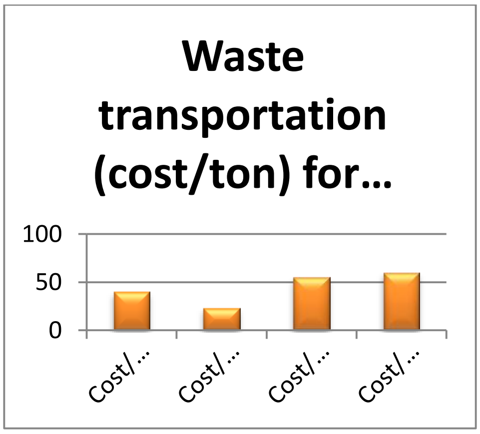
	Development	department as well as sustainability department to set up sequence of events to be constructed for the purpose of SWM through advancement in infrastructure and facilities on campus. This would include centralized dumping sites, separate recycling and land-filling bins as well as covered transmission of hazardous fluids, emissions, and gases.
8	Material Flow Analysis	MFA is responsible for systematic management of the flows and stocks of materials in managing solid waste being generated from all of the sources across the campus.
9	Life Cycle Assessment	LCA is a team which observes the system from start till end. Continuous monitoring and tracking by FMS will help them to study the system in detail and analyze future expansions and limitations.
10	Risk Assessment	Sustainability and health center should figure out the risk which can be endowed to the environment and to the human life in case of dysfunction of the SWM at RIT. Risk assessment also includes financial loss, infrastructural loss and other types of risk which should be analyzed before hand to eradicate any losses of resources.
11	Environmental Impact Assessment	FMS should carryout studies related to existing SWM and their probable environmental impacts. To achieve anything in long run, sustainability is much important. Therefore SWM should be such that it does not affects the environments as well as its components
12	Strategic Environmental Assessment	Decision and strategies should be formed in such a manner that those strategies should be environment friendly and should affect least to the environment. Therefore strategic planning and implementation of SWM is much important. It is important to shift the majority of the waste towards recycling and reusing rather than just decomposing it.
13	Socio-economic assessment	SEA'S are concepts which should also be taken care of while implementing an enhanced SWM plan. This concepts consists of computer-based practices that apply integrated market-based

		regulation requirements for SWM
14	Sustainable assessment	FMS department should refer to the integration of various pathways in such a way that obtaining an analysis, an evaluation or a planning should be in such a manner that implications related to sustainability are illuminated and considered while decision-making

Application of systems analysis techniques would be useful for decision making and managing the waste on campus. As mentioned earlier the main motive of the waste management system should be to lessen the amount of waste generated. Various washrooms on campus are equipped with hand dryers instead of napkins. This is to reduce the utilization of paper and waste caused by using the napkins. Food share is another program which can be maneuvered by the RIT dining services so as to avoid the wastage of surplus food prepared on daily basis. This food can be packed, preserved and transported to the homeless and needy people across the Rochester town. Goodbuy Goodbye is a sale event conducted by RIT every year at the start of the fall semester. This event encourages students to buy reused, recycled and refurbished stuff in fewer prices. This helps in reduction of waste in large quantity. More innovations like these are needed to cut down on landfills and increase recycling. Incinerations should be avoided and alternative ways of decomposition should be found out. Pie-chart (Graph 2)represents the material breakdown of waste generated on campus for the year 2015-16 [8].

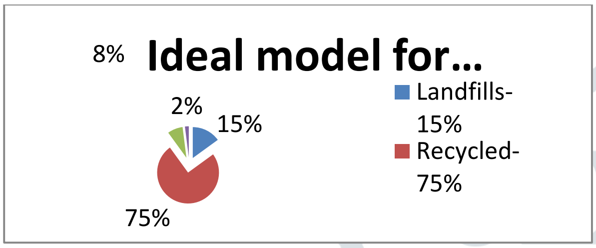


Graph 2: Material Breakdown for 2015-16 [8]



Graph 3: Waste transportation cost/ton for year 2015 in RIT [9]

According to the solid waste management audit carried out by the Golisano Institute of Sustainability in year 2015 we can say from Graph 3 that the transportation price for land-filling the waste per ton is more than the price required to take the recycling items to the recycling contractor. So our aim should be to recycle and reuse the waste as much as we can because it is the most efficient way of managing the waste. Thus by applying systems thinking we are making a great progress in increasing recycling and cutting down on land-filling. If we apply the systems thinking, its models and tools we can make the existing SWM system at RIT more efficient, more eco-friendly and much cost-effective. Pie-chart(Graph 4.) represents the ideal SWM model if the management of solid waste is done by applying systems engineering principles and its models.



Graph 4: Ideal Model of SWM at RIT

6. Conclusion

In today's world significant challenges are encountered while decomposing the solid waste through existing systems. Due to increase in population over the past decade it has become cumbersome to tackle and manage solid waste by using classical approach. There is continuous improvement neededin our system to accommodate the waste generated globally. Hence, a need for systems approach to SWM has been explicitly identified and inexplicitly recognized in this paper. It can be observed that there is a need to enhance existing system capabilities which can be effectively done by applying systems thinking and approach.

This paper dealt with various systemic models and analysis tools and their role in upgrading the SWM system. A study carried out in Rochester Institute of Technology suggests that if the systemic principles are applied to SWM system then it would make the system more economical, environmental friendly and sustainable. Systemic models can be effectively used to reduce the cost of management, improve the waste cycle, and to make the system sustainable enough to accommodate future expansions. Therefore, systems engineering models should be researched and applied to every complex solid waste management model across the globe which would definitely elevate us to new standards for our betterment and will help us to make a greener contribution towards a happier tomorrow.

7. Future Scope

Modern SWM systems should provide a possible route to minimize the waste generation and confirm the sustainability. Toachieve this goal, carrying out site-specific and process specificCBA, MFA, LCA, EIA, etc would be required. With these site-specificand process specific inputs, next-generation systems engineeringmodels would be able to reflect environmental impacts through anintegrated approach. It should lead to consider more options acrosswaste treatment technologies at all planning, construction, andoperational stages, and evaluate more policy instruments topromote waste prevention, reuse and recycling.To achieve these high-end decision analyses, systems engineeringmodels may be simultaneously and flexibly integrated withsystem assessment tools in the context of IMS or may be sequentiallyapplied in multiple stages so that the results from one modelor tool are the inputs needed for the next one. Given the new directives of waste management public participation and access in the assessment of waste management plans and waste prevention programs should increase. Apart from quantitative decision analyses should includemore stakeholders in the decision making process. With this trend,future CBA, LCA, MFA, EIA and SEA might become a multitude of essential models and/or tools that may become mandatory in handling complex systems.

8. Bibliography

1. [1]Marshall, Rachael E., and Khosrow Farahbakhsh. "Systems Approach to Integrated Solid Waste Management in Developing Countries." *Waste Management* 33 (2013): n. pag. Web. 21 Oct. 2016.
2. [2] Pires, Ana, Graca Martinho, and Ni-Bin Chang. "Solid Waste Management in Europian Countries: A Review of Systems Analysis Techniques." *Environmental Management* 92.4 (2011): 1033-050. Web. 25 Oct. 2016. <http://www.sciencedirect.com/science/article/pii/S0301479710004275>.
3. [3] Sundberg, J., P. Gipperth, and C. Wene. "A Systems Approach to Municipal Solid Waste Management: A Pilot Study of Goteborg." *Waste Management & Research*12.1 (1994): n. pag. Web. 31 Oct. 2016.
4. [4] Finnveden, Goran. "Methodological Aspects of Life Cycle Assessment of Integrated Solid Waste Management Systems." *Resource, Conversation and Recycling* 26.3-4 (1998): 173-87. Web. 27 Oct. 2016. <http://www.sciencedirect.com/science/article/pii/S0921344999000051>.
5. [5] "Information about RIT." *Introduction | Overview*. Rochester Institute of Technology, n.d. Web. 3 Nov. 2016. <http://www.rit.edu/about>.
6. [6] "Home | Golisano Institute for Sustainability | RIT." *Home | Golisano Institute for Sustainability | RIT*. N.p., n.d. Web. 4 Nov. 2016. <http://www.rit.edu/gis/>.
7. [7] "Facilities &Amp; Parking." *Facilities &Amp; Parking | Facilities &Amp; Parking*, www.rit.edu/fa/facilities/.
8. [8] Cardinnal, Ernid. "RIT Waste Material Audit 2015-16." N.p., n.d. Web. 12 Nov. 2016.

9. [9] Cardinal, Enrid. "Cost Audit for Waste Management Year 2015." *Cost Audit*. N.p., n.d. Web. 12 Nov. 2016.
10. [10] Eriksson, O., M. Reich, B. Frostell, A. Bjorklund, G. Assefa, J. Sundqvist, J. Granath, A. Baky, and L. Thyselius. "Muncipal Solid Waste Management from a Systems Perspective." *Journal of Cleaner Production* 13.3 (2005): 241-52. Web. 17 Nov. 2016. <http://www.sciencedirect.com/science/article/pii/S0921344999000051>.
11. [11]Bhattacharya, Bidyut, and Swapan Das. "A Holistic Approach for Integrated Solid Waste Management System of Kolkata Municipality Corporation Area." *Solid Waste Management* 7 (2011): 1999-2003. Web. 20 Nov. 2016. <http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F6029400%2F6035429%2F06035560.pdf&authDecision=-203>.
12. [12] McDougall, Forbes, and Joseph Hruska. “Report: the Use of Life Cycle Inventory Tools to Support an Integrated Approach to Solid Waste Management.” *Waste Management &Amp; Research*, vol. 18, 2000, pp. 590–594. wmr.sagepub.com/content/18/6/590.abstract.
13. [13] Alexander Kossiakoff, William N. Sweet, Samuel J. Seymour and Steven M. Biemer,“Systems Engineering Principles and Practice”, Second Edition
14. [14] Hart, Laura E. “Introduction to Model Based Systems Engineering.”