RESEARCH ARTICLE OPEN ACCESS

Solid Waste Management (SWM): A Review

D.K. Chaturvedi, E. Guru Dayal Saran, Mayank Pratap Singh
Faculty of Engineering, Dayalbagh Educational Institute, Dayalbagh, Agra, Uttar Pradesh

ABSTRACT
The increasing pollution and depleting natural resources of material and energy is one of the biggest reasons behind the numerous ongoing studies on Solid Waste Management (SWM). To ensure the sustainability of SWM it becomes important to choose correct approach. Using optimal techniques depending on the location/area by considering important attributes of all elements of the system and understanding the complexity of the system can enhance the sustainability of SWM. This integration of correct approach and appropriate selection of methods can help in better management of waste. In this paper, a review of methods and different approaches to SWM is presented. This review helps to get an overview of progress of methods and change in approaches for sustainable SWM and encourages the future studies to focus on latest methodologies which are frameworks based on holistic view or systems thinking and using advanced methods like soft computing techniques.

KEYWORDS: Integrated approach, Integrated Solid Waste Management (ISWM), systems thinking, Holistic approach, Soft computing techniques

---

Date of Submission: 02-06-2021 Date of Acceptance: 15-06-2021

I. INTRODUCTION

Waste management includes collection, transport, handling, treatment, material and energy recovery and disposal of waste. The rapid growth in volume and complexity of waste due to modern economy is affecting ecosystems and human health. Decay of the organic proportion of solid waste causing about 5 per cent of global greenhouse gas emissions [1]. According to UN environment programme, total electronic waste generated by the world in 2019 is 53.60 million tonnes. [2]

India generated 277 million tons of solid waste in 2016 [3], 708,445 tonne of e-waste in 2017-18 and 771,215 tonne the next fiscal, the report estimated. In 2019-20, the figure increased by 32 per cent upto 1,014,961 tonnes. These figures considered the 21 types of electrical and electronic equipment which are listed in the E-Waste Management Rules, 2016.[4]

Fig. 1 E-wastage

Our earth has limited natural resources, so, their conservation is important. Through Waste management it is possible by minimization of resource and energy use and recovering secondary resources. In the last few decades waste managementhas become a critical issuemostly due to thewaste stream complexity and the steadily increasing volumes of waste generation.As there are increasing technologies to face waste management problems, there is a requirement of the decision-making by considering a significant number of usually conflicting criteria in order to come up with the optimal solution among different scenarios.[5]

Cervantes et al. proposed three attributes that make up sustainability (social, environmental, and economic attributes) and evaluated ISWM based on those attributes. SWM is generally inefficient because of a lack of proper administrative, infrastructure, and adequate resource utilization. The implementation process involves complicated operations with complex linkages that are impacted by both the quantities and qualities of waste within the system. This situation requires adequate analysis tools and systemic approaches that support decision making and provide a comprehensive representation that considers the interactions between the main elements of SWM and their evolution.

II. EXISTING METHODS IN SWM

Selected literatures were reviewed and extracted in order to study the methods used in SWM problems. These methods can be classified into two namely classical MCDM and Hybrid methods. The relevant journal papers, which used these methods are also discussed.

AHP, PROMETHEE, TOPSIS, ANP, VIKOR, ELECTRE, ISM are examples of classical MCDM methods which are better than other decision support frameworks like CBA, LCA, while soft computing techniques like fuzzy logic, genetic algorithm, neural networks are used to support MCDM or one or more classical methods are combined to form hybrid methods like AHP-Delphi method, fuzzy-AHP method etc.

a. Classical MCDM methods

Multiple Criteria Decision Making (MCDM) is a largely used discipline to solve complex decision problems involving more than one criterion. MCDM also is continuously growing in fields of Mathematics, Decision Sciences, Business, Management and Accounting, Medicine, Social Sciences, Environmental Science, Economics, Econometrics and Finance, etc. SWM is a complex domain involving the interaction of several dimensions; thus, its analysis and control impose continuous challenges for decision makers. In this context, multi-criteria decision-making models have become important and convenient supporting tools for SWM because they can handle problems involving multiple dimensions and conflicting criteria. MCDM is used in decision making environment like for selection of landfill location/strategy, assessment, and monitoring etc., Following are the examples of classical MCDM methods:

i. Analytical Hierarchical Process (AHP):

It is a decision-making method developed for prioritizing alternatives when multiple criteria must be considered and allows the decision maker to structure complex problems in the form of a hierarchy, or a set of integrated levels. The AHP is relatively simple to use and understand.

This method incorporates qualitative and quantitative criteria. AHP is an ideal method for ranking alternatives when multiple criteria and sub-criteria are present in the decision-making process.

The use of the AHP approach offers a number of benefits. One important advantage is its simplicity. AHP can also accommodate uncertainties and subjective information, and allows the application of experience, insight, and intuition in a logical manner. It is observed that AHP is being pre- dominantly used in the area of selection and evaluation.

AHP allows the researcher to work with criteria divided in several classes and levels. This method fits with SWM assessment requirements because criteria in this sector are often grouped in general classes, such as economy, environment, society, and regulations.

Another important characteristic of this method is that it provides an easy way to attribute weights from stakeholders' opinions by using a pairwise comparison procedure.

ii. Preference ranking organization method for enrichment evaluation (PROMETHEE):

PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) was developed by Brans and Vincke in 1985. It is a pairwise comparison-based outranking method which is used to solve MCDM problems. Different preference functions are used to convert the pairwise comparisons to uni-criterion preference degree. A multi-criteria preference degree is then calculated to compare the criteria to each other. Then we calculate leaving flow and entering flow, the difference of which being the net value that is the basis for determining the outranking of the alternatives by each other. This category has the second rank (after AHP, and if we do not count the other/hybrid methodologies – which is fair). It is interesting that most of the application of this method belong to the waste management category

iii. Interpretive Structural Modeling (ISM)

In the ISM, attributes are arranged into an extensive systematic model that considers both direct and indirect attributes. Fundamental graph theoretic approach is adopted to combine the theoretical, conceptual and computational advantages of addressing complex patterns of logical relations among the attributes to identify the influence, direction and order of a system's attributes. Field expert experiences and knowledge gained from practice are used to analyse the complex interrelationships among the proposed attributes and rearrange them into a hierarchical structure. The method tackles the problems of attribute dependence, linguistic preferences and hierarchical structure modelling by providing additional valuable information for determining strategic directions.

iv. Delphi Technique

Delphi is based on the principle that forecasts (or decisions) from a structured group of individuals are more accurate than those from unstructured groups.

The basic theory on which Delphi method is based is two-fold:

1. That with repeated measurement the range of responses will decrease and converge towards the mid-range of the distribution and
2. That the total group response will successfully move towards the true or correct answer.

v. Multi Criteria Analysis (MCA)

MCA is a technique used for decision making and solving complex problems. This tool is also useful for multi-criteria problems including analysis of quantitative and qualitative aspects. It is also used to overcome environmental impact related to e-waste management. Different methods are used to analyse the economic benefits by using defined products models, development and evaluation, formulation and construction of strategy chart in order to minimize the economic cost. This tool has been used, to select the feasible method for e-waste management in Spain.[6]

Limitations of Classical MCDM methods

Its evolution throughout the years is interesting; some limitations of the use of MCDM include:

1. It is sensitive to uncertainties. MCDM concerns the problems that need the views' point of decision makers facing multiple conflicting criteria. Unfortunately, human judgments' preferences are often unclear to express by exact numerical values. In classical MCDM problems, certainty is required to evaluate criteria weights and ratings by crisp values
2. In a complex decision-making context, the existence of issues such as interdependence of preferences and double counting presents another type of uncertainty in real-world case studies.

b. Hybrid Methods

Hybrid models are the combination of two or more individual techniques so as to address complexity. Therefore, they are also known as combined models. The idea behind using the hybrid models is to overcome the limitations of the individual models and to utilize the advantages of individual models, merge them together and provide a new hybrid model to achieve the purpose.

i. Integration of fuzzy logic

MCDM is supported by Integration of fuzzy logic due to the imprecision and vagueness of decisions. Indeed, according to the proponents of fuzzy logic, it is more natural to express judgments by fuzzy numbers instead of crisp values.

1. Fuzzy decision-making trial and evaluation laboratory (FDEMATEL):

The DEMATEL method is an effective tool for dealing with complex interrelationships among attributes. The FDEMATEL method is employed to examine the causal interrelationships among the attributes by reviewing the qualitative information in the linguistic descriptions provided by experts and generating a causal diagram of the proposed attributes. First, fuzzy set theory is used to quantify equivocal concepts related to subjective human judgments in an uncertain environment into crisp values, and then the DEMATEL technique is applied, which is designed to build and analyse the interrelationships between complex perspectives as well as to construct inter-correlations among aspects and criteria.

2. Hybrid ISM and DEMATEL model

Chuang et al.applied a hybrid ISM and DEMATEL model to address complex, multi-criteria decision-making problems. Tseng et al. used this technique to evaluate the causal interrelationship and hierarchical inter-relationships of attributes and identify the attribute critical for improvement. Waste management is a complex problem due to the nature of waste and the increasing restrictions on managerial capabilities. The results of this study indicate that the proposed methods are appropriate for assessing ISWM.

3. Hybrid FDM, ISM, and FDEMATEL

Study by Tsai FM et al.[7], was based on SBSC, and involves structuring hierarchical frameworks and interrelationships under uncertainty. The lack of studies has limited the development and implementation of the SBSC for providing sustainable strategic management. Only a few studies have assessed ISWM with regard to SBSC using qualitative information, and proper methods of implementing the framework remain an unsolved problem. The extremely limited and incomplete information makes it difficult to gain insight into the complex problem of ISWM. This study applies a hybrid method of FDM, ISM, and FDEMATEL to investigate the ISWM.

ii. Integration of Soft computing techniques

MCDM is supported by soft computing techniques such as neural networks and genetic algorithms. These methods are generally used for optimization problems

There are some studies like [8],[9]which uses Genetic Algorithm to develop hybrid models.

In the study done by Dehghanian& Mansour [9], Life cycle analysis (LCA) has been applied to investigate the environmental impact of different end-of-life (EOL) options. Analytical hierarchy process (AHP) has been utilized to calculate social impacts. Next in this research, a three-objective mathematical programming model has been developed to maximize economic and social benefits and minimize negative environmental impacts, simultaneously.

Multi-objective genetic algorithm (MOGA) was used to find the Pareto-optimal solutions to design a sustainable recovery network to manage waste. [8] used MOGA for WEEE, whereas Scrap tires have been considered for a case study by [9].

III. EXISTING APPROACHES TO SWM

Different methods for waste management are used based on different Approaches which are classified from the available literature as: 1) Stage Focused Approach/ Reductionist Approach, 2) Integrated Approach, 3) Systems Thinking Approach/ Holistic Approach

a. Stage Focused Approach/ Reductionist Approach

R. E. Marshall and K. Farahbakhsh[10] mentioned that the waste management system is a very complex system, it is reduced into parts and studied which is called reductionist approach. Most of the previous studies have focused only on some of the stages or elements of the waste management system but not taking the entire system into view. Isolated problem i.e., particular stage is chosen and only that is focused and its impact on multiple other systems like economy, environment, society, Technology, Political system, Healthcare system etc., is less focused. Not more than one dimension is considered in this approach in most of the studies. Rezaei in his study [11] mentioned that there are highest number of studies available on Recycling compared to other reverse logistics problems. Some are on the processing and recovery, waste-energy (WtE), Location and process optimization problems. Less number of studies are there on segregation and behaviour of people.

Following are some of the examples of Reductionist Approaches

- Strategy optimization approaches
- Process optimization approaches
- Location optimization approaches
- Selection of best strategies
- Selection of best recyclers

Extended Producer Responsibility (EPR)

“EPR is another approach used in industries for taking back products after use. This tool is based on polluter-pays principles. It has been adopted by advanced nations such as Switzerland, Japan, and the European Union (EU) and has gained popularity since then.”[6]

i. Life Cycle Assessment (LCA) approach

“This technique is used to develop and design electronic devices based on **environmental** requirements. The main objective of the Life Cycle Assessment (LCA) technique is to minimize e-waste related issues. LCA is an assessment method that holistically compiles all pertinent materials and energy consumptions as well as emissions that occur during the life cycle of a product or a service. The assessment quantifies the environmental impacts, including global warming potential (GWP) generated during the life cycle of a product or a service, for decision-making. The key to understand LCA is the life cycle concept over a specified time horizon of a product or a service, applied to a coupled natural system and the built environment, such as an SWM system, to generate risk-informed and forward-looking solutions. In system thinking, the boundaries defined for an LCA begin with natural resources entering a predefined system in dynamic ways. The holistic processes occurring in the life cycle include **extraction, manufacturing, use, and disposal**.” [12]

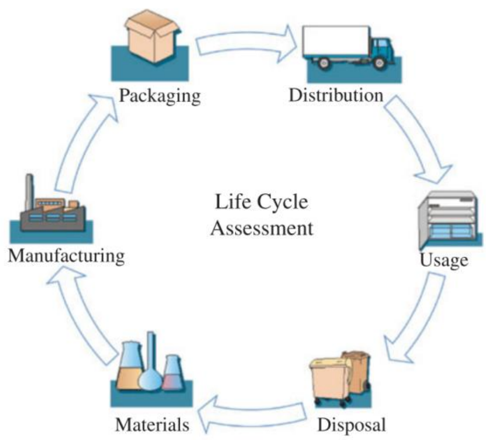

Fig. 2 life cycle of a product

Limitations of Reductionist Approach

These Approach can never achieve sustainability in practical terms, because there are many interrelations among the elements of WM system and different dimensions where there is an impact of these WM elements and interactions among these elements are not addressed by this approach.

b. Integrated Approach

This approach combines multiple dimensions and consider the integrated effect of all of them to achieve sustainability in waste management by having a trade-off or balance among these dimensions. Integrated SWM (ISWM) is an approach for preventing, recycling and managing solid waste in ways that most effectively protect human health and the environment. This encompasses the consideration of local facilities and their demands and conditions when selecting the most appropriate waste management activities that should be applied in specific contexts[7]. Multiple dimensions of sustainability are addressed. Like Social, environmental, economic, Technological, Political etc. Hybrid methods mentioned in Section 2.1.2 are used where methods like FDM, are used to take multiple attributes of major aspects for sustainability into consideration and to eliminate invalid criteria and methods like FDEMATEL to build causal interrelations among different attributes which are helpful to analyse the causes and effects of changes in one attribute on another. For instance, Marshall and Farahbakhsh[10] stated that the ISWM aims to establish an efficient SWM system by incorporating and integrating the interrelated processes along the entire waste management chain. By using methods like ISM hierarchical structures can be formed and critical criteria can be found. Reverse Logistics is also focused

i. Reverse Logistics Approach

Fig. 3 Reverse logistics

Reverse logistics is another effective area for products flows from point of consumption to its point of production or origin. Different types of processes have been applied to reverse logistics such as planning, controlling and implementing. Reverse logistics is used for the management of hazardous materials, logistics recycling, and waste disposal. It is also related to all logistics activities carried out in source of reduction, disposal, reuse and recycle of materials.[6]

Limitations of integrated Approach

Many 'ISWM' programs focused on individual components making up the system instead of the system as a whole. Likewise, different operating companies may control recycling, incineration, composting, and landfill operations.

Therefore, no one has control over the whole system, making it difficult to manage on a more holistic level. Consequentially, the bulk of the effort remains focused on lower level priorities such as recycling, which are important, but not sufficient [11].

c. Holistic Framework/Systems Thinking Approach

Holistic approach focuses on the thinking that all elements are parts of the same single system and each of them have effect on one another and should not be considered as separate entities. According to [10] In industrialized countries, SWM drivers are public health, environment, resource scarcity, climate change, and public awareness and participation. But in developing countries, urbanization, inequality, and economic growth; cultural and socio-economic aspects; policy, governance, and institutional issues; and international influences have complicated SWM. This has reduced the applicability of approaches that were successful in SWM for industrialized countries. There is a lack of literature available on this approach but there is single review done by [10]which demonstrates the importance of founding new SWM approaches for developing country contexts in post-normal science and complex, adaptive systems thinking.

Study [7] which is based on sustainable balanced scorecard (SBSC) approach stated to investigate how to structure hierarchical frameworks and interrelationships under uncertainty, which has yet to be explored in an ISWM context. sustainable balanced scorecard (SBSC) approach is an important tool for integrating sustainable attributes into a performance measurement process. Falle et al.

suggested that SBSC helps to secure and aid in the integration and coordination of various forms of expert knowledge when assessing sustainable performance.

J. Rezaei[11] and M. T. Islam et.al.[13] suggested frame-works of the complete waste management systems suitable to local areas and some authors like [14] have worked on holistic frameworks for urban SWM.

Here is the summary of publications of last 10 years in SWM in Table 2.2

Table III.1: Summary of 10 years publications in SWM

Authors	**Waste Type**	**Methodology**	**Approach/ Research Type**	**Dimension of Sustainability**	**Methods**	**Country/ Region**
Emily Hsu et al. (2019) [15]	E-Waste	This review focuses on recovery technologies for e-wastes	Review	_____	_______	Korea
Ikhlayel (2018) [16]	E-waste	to mitigate the environmental and economic burdens of e-waste by following the IWM concept	Integrated/ Theoretical	Environmental & Economic	LCA	Developing Countries
Muhammad et al. (2018) [6]	E-Waste	Comparisons of different methods	Review	Environmental	Qualitative	world
Tsai et al. (2019) [7]	Solid Waste	Explore ISWM hierarchical interrelationships	Performance assessment approach	Social, Environmental, Economical	FDM, ISM, FDEMATEL	Vietnam
Pratibha Rani et al. (2020) [17]	E-Waste	to evaluate the MCDM problems under the fuzzy atmosphere	divergence measure for fuzzy sets	Social, Environmental, Economical	Mixed	India
Kim (2013) [18]	E-Waste	Priorities of electrical & electronic Products for recycling	MCDM	Economic, Environmental	Delphi, AHP	Korea
Yue Yu (2000) [19]	E-Waste	Selection of Optimal Recycling Plan	MCDM	Economic, Environmental	AHP	USA
Taelman et al. (2018) [14]	Urban Municipal Waste	conceptual and comprehensive sustainability framework using Circular economy; lifecycle thinking	Holistic	Social, Environmental, Economical, technical, Political	Qualitative	European Countries
Ihsan Kaya (2012) [20]	E-Waste	To evaluate and to select the appropriate WEEE outsourcing firm based on Fuzzy MCDM	MCDM	Social, Environmental, Economical, technical, Quality	Fuzzy AHP	Turkey
S.Mahendran and ML.Mahadevan (2014) [21]	Plastic Waste	selection of best recycling process	MCDM	Social, Environmental , Economical	AHP	India

IV. CONCLUSION

Various waste management methods and approaches are discussed in this work. From the study it is found that a variety of works have been done by many authors for different Stages of waste management. It is made clear that hybrid methods are better than classical methods and advanced soft computing techniques can be used to improve the optimality. It is found from the study that Holistic/systems approach is the latest approach which is better than previous other approaches but also at the same time complex in nature. But only this kind of approach can achieve true sustainability because of its nature of considering system as a whole and true system modelling can get best results. The authors intention is that the validation of this framework is desirable by applying it to any real-life case study.

REFERENCES

[1] UNEP, "Solid waste management | UNEP - UN Environment Programme," *United Nations Environment Programme*, 2020. https://www.unenvironment.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management.

[2] "World Environment Situation Room." https://wesr.unep.org/downloader (accessed Mar. 18, 2021).

[3] "In 30 years, India tipped to double the amount of waste it generates - Times of India." https://timesofindia.indiatimes.com/india/in-30-years-india-tipped-to-double-the-amount-of-waste-it-generates/articleshow/74454382.cms?from=mdr (accessed May 12, 2021).

[4] "India collected just 3% e-waste generated in 2018, 10% in 2019: CPCB report." https://www.downtoearth.org.in/news/waste/india-collected-just-3-e-waste-generated-in-2018-10-in-2019-cpcb-report-75072 (accessed May 12, 2021).

[5] C. Achillas, N. Moussiopoulos, A. Karagiannidis, G. Banias, and G. Perkoulidis, "The use of multi-criteria decision analysis to tackle waste management problems: A literature review," *Waste Manag. Res.*, vol. 31, no. 2, pp. 115–129, 2013, doi: 10.1177/0734242X12470203.

[6] A. Muhammad, M. Z. S. M. Hussein, H. S. Jaafar, and S. Nasir, "Sustainable Electronic Waste (E-Waste) Management Using Enabling Strategies and Techniques: A Literature Review," *Adv. Transp. Logist. Res.*, vol. 1, pp. 242–254, 2018.

[7] F. M. Tsai, T. D. Bui, M. L. Tseng, K. J. Wu, and A. S. Chiu, "A performance assessment approach for integrated solid waste management using a sustainable balanced scorecard approach," *J. Clean. Prod.*, vol. 251, p. 119740, 2020, doi: 10.1016/j.jclepro.2019.119740.

[8] A. Aalirezaei and S. Shokouhyar, "Designing a sustainable recovery network for waste from electrical and electronic equipment using a genetic algorithm," *Int. J. Environ. Sustain. Dev.*, vol. 16, no. 1, p. 60, 2017, doi: 10.1504/ijesd.2017.10001371.

[9] F. Dehghanian and S. Mansour, "Designing sustainable recovery network of end-of-life products using genetic algorithm," *Resour. Conserv. Recycl.*, vol. 53, no. 10, pp. 559–570, 2009, doi: 10.1016/j.resconrec.2009.04.007.

[10] R. E. Marshall and K. Farahbakhsh, "Systems approaches to integrated solid waste management in developing countries," *Waste Manag.*, vol. 33, no. 4, pp. 988–1003, 2013, doi: 10.1016/j.wasman.2012.12.023.

[11] J. Rezaei, "A systematic review of multi-criteria decision-making applications in reverse logistics," *Transp. Res. Procedia*, vol. 10, no. July, pp. 766–776, 2015, doi: 10.1016/j.trpro.2015.09.030.

[12] N.-B. Chang and A. Pires, "Life Cycle Assessment and Solid Waste Management," in *Sustainable Solid Waste Management*, John Wiley & Sons, Inc., 2015, pp. 323–386.

[13] M. T. Islam and N. Huda, "Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review," *Resour. Conserv. Recycl.*, vol. 137, no. November 2017, pp. 48–75, 2018, doi: 10.1016/j.resconrec.2018.05.026.

[14] S. E. Taelman, D. Tonini, A. Wandl, and J. Dewulf, "A Holistic sustainability framework for waste management in European Cities: Concept development," *Sustain.*, vol. 10, no. 7, 2018, doi: 10.3390/su10072184.

[15] E. Hsu, K. Barmak, A. C. West, and A.-H. A. Park, "Advancements in the treatment and processing of electronic waste with sustainability: a review of metal extraction and recovery technologies," *Green Chem.*, vol. 21, no. 5, pp. 919–936, 2019.

[16] M. Ikhlayel, "An integrated approach to establish e-waste management systems for

developing countries," *J. Clean. Prod.*, vol. 170, pp. 119–130, 2018, doi: 10.1016/j.jclepro.2017.09.137.

[17] P. Rani, K. Govindan, A. R. Mishra, A. Mardani, M. Alrasheedi, and D. S. Hooda, "Unified fuzzy divergence measures with multi-criteria decision making problems for sustainable planning of an E-Waste recycling job selection," *Symmetry (Basel).*, vol. 12, no. 1, 2020, doi: 10.3390/sym12010090.

[18] M. Kim, Y. C. Jang, and S. Lee, "Application of Delphi-AHP methods to select the priorities of WEEE for recycling in a waste management decision-making tool," *J. Environ. Manage.*, vol. 128, pp. 941–948, 2013, doi: 10.1016/j.jenvman.2013.06.049.

[19] Y. Yu, K. Jin, H. C. Zhang, F. F. Ling, and D. Barnes, "A Decision-Making Model for Materials Management of End-of-Life Electronic Products," *J. Manuf. Syst.*, vol. 20, no. 6, pp. 94–105, 2001, doi: 10.1016/s0278-6125(02)80060-7.

[20] I. Kaya, "Evaluation of outsourcing alternatives under fuzzy environment for waste management," *Resour. Conserv. Recycl.*, vol. 60, pp. 107–118, 2012, doi: 10.1016/j.resconrec.2011.12.006.

[21] S.Mahendran and ML.Mahadevan, "Prioritization of Plastic Recycling Process Using Analytical Hierarchy Process," *Int. Colloq. Mater. Manuf. Metrol. ICMMM 2014 August 8-9, 2014, IIT Madras, Chennai, India*, no. August, pp. 1–5, 2014.

[22]. D.K.Chaturvedi, Soft ComputingTechniques,Springer, 2005.

[23]. D.K. Chaturvedi, Modelling andSimulation of Systems using Matlab and Simulink, CRCPress, 2010.