Study of Application of Operations Research in Waste Management in Urban Areas

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Abstract— Operations Research (OR) is the application of scientific & mathematical techniques to study &analyse problems involving complex systems. It enables more effective decisions and more productive systems based on robust data, the fuller consideration of available options, and careful prognosis of outcomes and estimates of risk. It is considered a kit of scientific and programmable rules which provides the managementa"quantitativebasis"fordecisionsconcerningthe operation under its regulation.

An additional characteristic is that ORfrequentlyattemptstofindabestsolution(referredtoasanoptimalsolution)fortheproblem under consideration, rather than simplyimprovingthestatusquo,thegoalistoidentifyabestpossiblecourseofaction. Solidwastemanagementisaconvolutedtask,absorbinga huge amount of resources and having amajorenvironmental impact.Itisoneofthecontemporarysociety'smostrelevant issue.Computerizedsystemsbasedonoperationsresearch techniques can aid decision makers to achieveremarkablecostsavings as well as to improve waste reclamation.Theobjectiveofthispaperistopresentanupdatedsurveyofthemostapplicable operations research literature onsolidwastemanagement, mainly stressing on strategic andtacticalissues.In addition develop and supply analytic supportforoptimal time, costing, pricing, or logistics networks forevaluation and/or implementation.

Key Words

Operations Research, Waste Management, Waste Flow Management, Solid Waste

[1]   INTRODUCTION

The Municipal Solid Waste (MSW) is defined by the United States Environmental Protection Agency (U.S. EPA) to include waste from residential, multifamily, commercial,and institutional(e.g.,schools,governmentoffices)sources.This definition excludes many materials that are frequently disposed with MSW in land- fills, including combustion ash, water and wastewater treatment residuals, construction and demolition waste, and non-hazardous industrial process waste. Modern life-style with its emphasis on consumption and disposal has brought in its wake the acute problem of Solid Waste Management across the globe. The problem is aggravated due to pressure on land space on our planet. The large and increasing amount of solid waste generated each year in both industrialized and developing countries, along withthepublicconcernforenvironmentalpreservation,is making solid waste management one of modern society's most relevant issues.

Each year in the European Union around 3 billion tonnes of waste is generated, and some 90 million is hazardous .In 2014, the total waste generated in the European union by all economic activities and households amounted to 2503 million tonnes, this was the highest amount recorded for the European union during the period 2004-2014 . The last U.S. EPA document on MSW generation in the U.S.A. reports a production of about 250 million tonnes of waste in 2009,and about 85 million tonnes of recycled and composted material, leading to approximately 34% of recycling rate. As per the report (May 2000) of Ministry of Urban Development , Government of India that 1,00,000 MT of Municipal Solid Waste was generated daily in the country. During the year 2004-05, Central Pollution Control Board through National Environmental Engineering Research Institute, Nagpur conducted survey in 59 cities (35 Metro cities and 24 State Capitals) and estimated 39,031 Tons per day MSW generation in these 59cities/towns.

India suffers from inefficient and insufficient waste infrastructure and also from increasing rates of solid waste generation per capita. Issues of service quality and waste quantity need to be handled hand in hand. Besides the infrastructure and technologies, we must address the issue fromasystemicperspective.Thusinreferencetothiscontext there is a need of an integrated Solid waste management system to address this issue. Computerized systems based on operations research techniques can help decision makers to achieve remarkable cost savings as well as to improve waste managementsystem.

StudyingaSWMsystemfromanoperationsresearchpointof view implies modelling it through a multi-channel supply chain in which the following processes take place: waste generation in regional districts; waste collection in transfer stations; waste separation performed at the sources or in separation plants; waste treatment through incinerators, waste-to energy plants, reclamation plants, or composite plants; waste disposal by land filling or landspreading

[2] OPERATIONSRESEARCH

Operations research (OR) is an analytical method of problem-solving and decision-making that is useful in the managementoforganizations.Itisadisciplinethatdealswith the use of advanced analytical methods to help make better decisions

Features of Operation Research 1.Decision-making

Each industrial organisation faces multifacet issues to identify the most suitable answer to their problems. OR aims to assist the executives to get the best solution with theemployment of OR techniques. It also guides the decision maker to improve his creative and judicious capabilities, analyseandunderstandtheproblemsituationleadingtobetter control, better co-ordination, better systems and finallybetter decisions.

ScientificApproach

OR applies scientific ways, techniques and tools for the aim of research analysis and to solve complex problems, using this approach there is no place for guess work and therefore there is no personal bias of the choice maker.

Inter-disciplinary TeamApproach

Basically the economic issues are of complicated nature and thus need a team effort to handle it. This team consists of scientist/mathematician and technocrats who conjointly use the OR tools to get a best possible solution of the matter. They try to analyse the cause and effect relationshipbetween varied parameters of the matter and evaluates the result of assorted variousmethods

SystemApproach

The aim of the system approach is to trace for everyproposal and all possible and indirect effects on all sub-system on a system and to judge each action in terms of effects for the system as an entire thing. The interrelation and interaction of every sub-system is handled with the assistance of mathematical/analytical models of OR to get acceptable answer.

Use ofComputers

The models of OR require heap of computation and thus, the employment of computers becomes necessary. With the employment of computers it's attainable to handle complicated issues requiring great amount of calculations.

[3]   APPLICATIONS OF OPERATIONSRESEARCH

Operations Research applies scientific method to the management of orderly systems in business, industry, government and other businesses or projects etc.Applications of OR in these and other areas deal with decisions involved in planning the potent allocation ofscarce resources - such as material, skilled workers, machines, moneyandtime-toachievestatedgoalsandobjectivesunder conditions of dubiety and over a span of time. Efficient allocation of resources may involve establishing policies, designingprocesses,orrelocatingassets.ORanalystsresolve such management decision problems with an array of mathematical methodologies.To do this, OR professionals first define the system in mathematical form. Rather than using trial and error on the system itself, they then form an algebraic or computational model of the system and then manipulate or solve the model, using computers, to come up with the best decisions. Often motivated by new decision problems, OR researchers work to enhance and elaborate the applicablemethodologies.

AsOperationsResearchprofessionalsattempttoconstructmodelsthataccuratelydisplayandfore castrelationships,they mayusestatisticalanalysis.Thesystemmaybecharacterized by uncertainty and risk and so require use of probability analysis. Finding an efficient allocation of resources may employ optimization techniques that can deal with large numbers of interrelated variables and constraints. For many complex systems, the implications of a particular resource allocation strategy may be understood only by building acomputer simulation of the system and testing an array of strategies against it. Evaluating allocation strategies often needs an understanding of accounting and managerial finance.

[4]   SOLID WASTEMANAGEMENT

Solid waste management involves a number of strategic, tactical and operational decisions, such as the selection of Solid waste treatment technologies, the location of treatment sites and landfills, the future capacity expansion strategies of the sites, waste flow allocation to processing facilities and landfills,serviceterritorypartitioningintodistricts,collection days selection for each district and for each waste type, fleet composition determination, and routing and scheduling of collection vehicles. Given that dealing with each of these aspects

leads to solving several combinatorial optimization problems, computerized systems based on Operations Research techniques. This can help decision makers to achieve remarkable cost savings.

Most of the models in the literature aim at helping the decision maker towards the choice of the best strategy, selected among a set of options. Such methods evaluate all the suitable alternatives at every stage of the decision process. In some cases, the goal of the model is easy (e.g., optimize waste collection routes for vehicles), while in others it is more complex (e.g., evaluate alternative waste management strategies). However, because Solid waste management also involves institutional, social, financial, economic, technical, and environmental factors, no model described in the literature is able to capture all differentaspectstobeconsidered.Ontheotherhand,general models have so many variables and constraints that solving them through general-purpose solvers can be very hard and timeconsuming.Ingeneral,theliteratureisstillscatteredand disorganized.

Given that a survey of all Operations Research modelsinthisareawouldrequireaverylongarticle,thefocus of this paper is to concentrate on some of the most important methodological contributions and the most significant applications originating from the application of Operation Researchtechniquestostrategicandtacticalproblemsarising in Solid waste management, as well as to indicate future research directions. Consequently, designing or re-designing a regional Solid Waste Management system is a strategic decision having long termeffects. The main features to take into account are:

Time: Decisions related to building a new facility or closing an existing one affect a long-term planning horizon.

Network structure: A multi-echelon logistic network is needed to model all the strategic decisions.

Commodities: The cost of transporting and disposing waste depends mostly on the category of waste such as municipal refuse, industrial waste, farm refuse, demolition and construction debris, etc.. Moreover, each waste type can be processed in a finite number of ways .For example inert refuse cannot be composted.

Facility cumulative capacity: Landfills have an overall cumulative capacity for waste disposal, which progressively reduces as long as refuse are stored.

Economies of scale: The operating cost of a facility is a concavefunctionofitsactivitylevelbecauseofeconomiesof scale that may beachieved.Transshipment with waste transformation: Once a waste type is processed in a

facility, its own characteristics change, forexample its volume reduces. This peculiar feature can be modeled through a network flow with gains.

Objectives: Decision makers often pursue conflicting goals, such as to locate facilities as close as possible to sources to minimizetransportationcosts,andtolocatefacilitiesasfaras possible from urban centers. In addition, SWM often gives rise to socio-political issues that are difficult tomodel.

[5]   APPLICATIONSOFOPERATIONSRESEARCHIN WASTE MANAGEMENT

(A)   Fleet and crewcomposition

A   large   percentage   of   total   solid   waste   management   cost relatedtowastecollectionabout75%isduetotheequipment   and   the   workforce.   Therefore, optimizing such aspects could result in significant cost savings. However, regardless of its importance, the problem of optimizing the fleet composition and the crew assignment has not been much studied in the literature with respect to solid waste management. A non-linear model for calculating manpower requirements for refuse collection is used . This model is used for matching work shifts to curbside refuse demand so as to minimize weekly missed collections, subject to union regulations and manpower and truck constraints.   The   algorithm   used   for   solvingthenon-linearmodelisamodificationofthegradient method, in which constraints are handled in the objective function by means of penalty terms. The linear programs techniques are used for   the   assignment   of   sanitation   crews   to shiftsanddaysoftheweekonasingledistrictbasis.Thegoal is to balance payroll cost and missed refuse collection, while satisfyingconstraintsduetoavailableequipmentandpolicies for granting rest days. The models are solved by means of standard linear programming routines, and extensions of the model to planning for several districts simultaneously are pointedout.

(B)   Districting

The purpose of the districting (or zoning) phase is to determine collection districts. The districts must be such that the aggregate of solid waste loads within each district does not exceed the holding capacity of the vehicles that will perform the operations. A districting heuristic based on the constructionofanauxiliarygraph,calledcyclenodegraph,in which

nodes represent trips and edges represent feasibletrips aggregations is used . The approach is based on the partition of an Eulerian graph into cycles using a "checkerboard pattern". This partition is characterized by a large number of smallcycleswhereeveryedgeofthegraphbelongstoexactly one of them. Such cycles are then used to determine the districts.

(C)   Waste flowallocation

When waste generation is deterministic, the waste flow allocation problem is usually solved as a part of the more general strategic planning models.We can combine a genetic algorithm with simulation to solve the problem of municipal waste flow allocation under uncertainty. In particular, each candidate solution of the population set, which contains uncertain elements such as the quantity of waste generatedat eachdistrict,issimulatedtobeevaluated.Then,basedonthe results of the simulation phase, the genetic algorithm allows the system to evolve toward better solutions, generating a new set of candidates to be evaluated again bysimulation.After termination, the algorithm provides, in addition to the best solution, a number of "good" solutions. In this way, the method could be used for policy comparisons purposes also.

(D)   RouteOptimization

We study the Waste Collection Vehicle Routing Problem with Time Window which is concerned with finding cost optimal routes for garbage trucks such that all garbage bins are emptied and the waste is driven to disposal sites while respecting customer time windows and making sure that drivers are given the breaks that the law requires. We forth putanadaptivelargeneighbourhoodtransportationalgorithm for solving the problem and illustrate the usefulness of Operations Research by showing that it can improve the objective. In a municipal solid waste management system, decreasing hauling costs, which consist of 85 % of total disposal expenditure, can be carried out by a route optimization. Thus, a huge amount of economic benefits is gettingfurnished.

Municipal solid waste collection (MSWC) has about 85%proportion of the total cost for solid waste management system. MSWC is the starting of the process of solid waste management which consists of generation, collection, transfer, treatment and final disposal. Integrated solid waste management involves a variety of programs and

facilities, and incorporates source reduction, reuse, recycling, composting, incineration and landfilling. Waste stream from a city to any destination is charged a unit hauls cost based on per-ton distance. However, waste stream of rejects from a processing facility to conversion or disposal facility is ignored, because it has no significant effect. Typical haul costs are in the range from 49 rs to 140 rs km/ton for collection vehicles, while transporting waste by transfer trailers reduces costs to 21 rs to 70 rs. km/ton.

The processes for planning, optimizing and controlling logistics and transport activities in urban areas are often referred to as "City Logistics". City logistics consists of forwardandreverselogisticsoperationsdealingwiththeflow of goods from the producers to the customers and the flow from the consumers to recycling or disposal facilities, respectively. Thus, the collection of waste is a central component in the logistic set-up of a big city. The waste collection problem consists of routing vehicles to collect customerswastewithingiventimewindowwhileminimizing travel cost. This problem is known as the Waste Collection VehicleRouting.

(E) CollectionPattern

Collection decisions mainly involve the choice of the collection days when the different operations must be executed. In particular, important decisions concern the maximum number of accumulation days (that is, the maximum number of days between two consecutive removals), and the service frequency (for instance, once or twiceaweek).Infact,ifsuchdecisionsarenottakenproperly (for instance, there are too many accumulation days, or the service frequency is not adequate) the risk is that the refuse removal is not uniform during the week and the trucks are fully exploited only in some peak days, while they are only partiallyfilledintheotherdays.Thiswouldleadtoincreased costs for the subsequent operational collection phase. Thus,a minimization of the service costs can be obtained through a minimization of the maximum quantity removed in a day (peakquantity).

Such problem involves a hierarchical decision process to determine: (1) the weekly collection frequency as well as the particular collection days in the week for each building (weekly collection schedule); (2) the number of runs per day and the buildings to be visited in each run; (3) the route in each run. The problem is modelled as a Periodic Vehicle Routing Problem, which is solved by means of a two-phase

algorithm.Inphase1,thebuildingstobeinsertedoneachday of the week are chosen, depending on their collection frequencies, ensuring that the maximum available driving time for the day is not exceeded. Phase 2 defines a set of routes for the assigned buildings, for each day of collection, minimizingbothtravelandcollectiontimes.Inbothphases,a Nearest Insertion Heuristic isused.

(F)   Problem with Time Windows(WCVRPTW)

AreallifeCasestudydoneearlierispresentedintheresearch below

In this study the waste management company JCT Inc. in North Ahmedabad is considered. Aside from the formulation of WCVRPTW given in this paper, three additional constraints are used.

1) a limit S on the number of customers to visit on each route,
2) a limit R on the total amount collected at customers for each route, which is a route capacity, andfinally
3) a lunch break of duration Starting in the interval.

Constraint 1) and 2) can easily be added to the model formulation, whereas the lunch break is slightly more complicated.Sincenospecificlunchlocationisrequired,one can assume that the lunch break is taken somewherebetween twostopsiandj.Thereisthusnoadditionaltravelcostforthe lunchbreak. The lunch break u can now be at three different positions (see figure): 1) after servicing node i, 2) between travellingfromnodeiandjor3)beforeservicingnodej.Note it is normally assumed that service cannot bediscontinued.
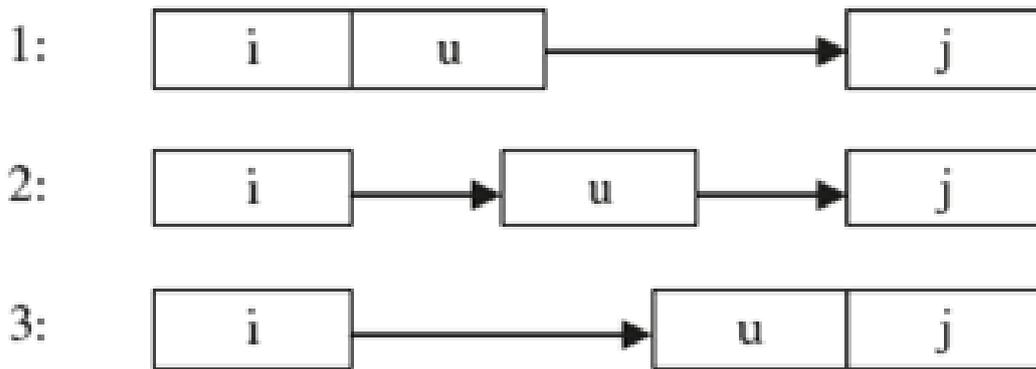
(Figure: Possible Lunch Positions)

Variable Identification Modeling

Suppose if we consider the problem in which number of producible of solid waste are "n" and respective cost of transport for these solid waste are c_{i_1}, c_{i_2}, c_{i_3}…….. c_{i_n} per unit area along with respective probabilities p_i . The decision variable x_j, element h_j and w_j denote collection area for vehicle "j" , the work time in labour hours and required water units for growing crop "j" at the unit area respectively.

As the collection area of each vehicle is limitedx_1+ x_2+ x_3+ x_4+……. x_n has to be less than or equal to "L" acres and we call it as "coverage constraint".

The total labour hours of working time is limited and thush_1x_1+ h_2x_2+ h_3x_3+ h_4x_4+…….+h_nx_n has to be less than or equal to a certain "H" and we call it as "labour constraint". Similarly, time is also another constraint of having "W" units and the total requirement must be adjusted within the limit, then equation w_1x_1+ w_2x_2+ w_3x_3+ w_4x_4+…….+ w_nx_n can be treated as "waste constraint".

Under these constraints and discrete crisp and fuzzy random cost coefficients, we want to find the decision variables x_j so as to maximize the profit(R).

Maximize R

Subject to $x_1 + x_2 + x_3 +$ …… $\leq X$(Coverage constraint)……………………(1)

$h_1x_1 + h_2x_2 + h_3x_3 +$ ….. $+ hX \leq$ (Labour constraint) …………………………. (2)

$w_1x_1 + w_2x_2 + w_3x_3 +$ …… $+ WX \leq$ (Waste constraint)……………………… (3)

$c_{11}x_1 + c_{12}x_2 + c_{13}x_3 + c_{14}x_4 + \ldots\ldots + c_{1n}x_n \geq R$……………...…………………..1.1.1

$c_{21}x_1 + c_{22}x_2 + c_{23}x_3 + c_{24}x_4 + \ldots\ldots + c_{2n}x_n \geq R$ ………………………….……… 1.1.2

$C_{31}x_1 + c_{32}x_2 + c_{33}x_3 + c_{34}x_4 + \ldots\ldots + c_{3n}x_n \geq R$ 1.1.3

$cm_1x_1 + cm_2x_2 + cm_3x_3 + cm_4x_4 + \ldots\ldots + common \geq R$ …………………….…..1.1.4

$x_1, x_2, x_3, x_4, \ldots\ldots x_n, R \geq 0$ ………………………..…………………….……1.1.5

5.1   Process of Solving LPP model by Using LINDO

Multi objective linear programming approach is given below

Step-1:   Solve each objective function with the same set of constraints provided in (1) separately.

Step-2:   Using the solution obtained in step1, find the corresponding value of all the objective functions for each of solution.

Step-3:   From step 2, obtain the lower and upper bounds hx and wx for each objective function and construct a table of Positive Ideal Solution (PIS).

Step-4:   Consider a linear and non-decreasing membership function

Step-5:   Transform multi objective linear programming into LPP as follows

Subject to $x_1 + x_2 + x_3 + \cdots \ldots x_n \leq x$ (Coverage constraint) …………   1.1.6

$h_1x_1 + h_2x_2 + h_3x_3 + \cdots \ldots . + h_nx_n \leq hx$ (Labour constraint) …………   1.1.7

$w_1x_1 + w_2x_2 + w_3x_3 + \cdots \ldots . + w_nx_n \leq wx$ (Waste constraint) ………..   1.1.8

Step-6:   Equation mentioned above can be solved easily using LINDO

Step-7:   Finally, the guaranteed expected return can be calculated as $zi\,(x)$

      $piki = 1$, where zix is the value of the it objective function at the

      values of decision variables obtained from the solution of equation.

[6]   CONCLUSION

Inthispaperresearcher has reviewedthemostimportantliteratureonthe use of OR methodologies to improve SWM. In solid waste management system, collection of solid waste is the most important process for total disposal costs. In order to minimize total solid waste disposal costs and increase the Profit of overall SWM. It is required to perform route optimization on present solid waste collection paths.

   An Integrated waste Management and Solution designs where:-

- End-to-end solutions tailored according to businesses and sector-specificneeds.
- Innovative design, founded on understanding current legislation and interpreting futuretrends.
- Processes that work in harmony along with the extensive logisticsflows.
- Careful selection and development of transportsolutions.
- Process flow analysis for optimum waste processing efficiency.
- Specialist equipment to maximize the value of recycled streams.

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