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Study of Operations Research in Waste Management

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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 management a "quantitative basis" for decisions concerning the operation under its regulation.**

An additional characteristic is that OR frequently attempts to find a best solution (referred to as an optimal solution) for the problem under consideration, rather than simply improving the status quo, the goal is to identify a best possible course of action.

Solid waste management is a convoluted task, absorbing a huge amount of resources and having a major environmental impact. It is one of the contemporary society's most relevant issue. Computerized systems based on operations research techniques can aid decision makers to achieve remarkable cost savings as well as to improve waste reclamation. The objective of this paper is to present an updated survey of the most applicable operations research literature on solid waste management, mainly stressing on strategic and tactical issues. In addition develop and supply analytic support for optimal time, costing, pricing, or logistics networks for evaluation and/or implementation.

Index Terms— **Operations Research, waste management.**

I. 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, government offices) 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 with the public concern for environmental preservation, is making solid waste management one of modern society's most relevant issues.

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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 59 cities/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 from a systemic perspective. Thus in reference to this context 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 management system.

Studying a SWM system from an operations research point of view implies modelling it through a multiechelon 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 land spreading

II. OPERATIONS RESEARCH

Operations research (OR) is an analytical method of problem-solving and decision-making that is useful in the management of organizations. It is a discipline that deals with 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 the employment of OR techniques. It also guides the decision maker to improve his creative and judicious capabilities, analyse and understand the problem situation leading to better control, better co-ordination, better systems and finally better decisions.

2.Scientific Approach

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.

3. Inter-disciplinary Team Approach

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 affect relationship between varied parameters of the matter and evaluates the result of assorted various methods

4.System Approach

The aim of the system approach is to trace for every proposal 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.

5.Use of Computers

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.

III. APPLICATIONS OF OPERATIONS RESEARCH

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 of scarce resources - such as material, skilled workers, machines, money and time - to achieve stated goals and objectives under conditions of dubiety and over a span of time. Efficient allocation of resources may involve establishing policies, designing processes, or relocating assets. OR analysts resolve 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 applicable methodologies.

As Operations Research professionals attempt to construct models that accurately display and forecast relationships, they may use statistical analysis. The system may be characterized 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 a computer simulation of the system and testing an array of strategies against it. Evaluating allocation strategies often needs an understanding of accounting and managerial finance.

IV. SOLID WASTE MANAGEMENT

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, service territory partitioning into districts, 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 different aspects to be considered. On the other hand, general models have so many variables and constraints that solving them through general-purpose solvers can be very hard and time consuming. In general, the literature is still scattered and disorganized. Given that a survey of all Operations Research models in this area would require a very long article, the focus 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 Research techniques to strategic and tactical problems arising 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 term effects.

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 concave function of its activity level because of economies of scale that may be achieved.

Transshipment with waste transformation: Once a waste type is processed in a facility, its own characteristics change ,for example 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 minimize transportation costs, and to locate facilities as far as possible from urban centers. In addition, SWM often gives rise to socio-political issues that are difficult to model.

V. APPLICATIONS OF OPERATIONS RESEARCH IN WASTE MANAGEMENT

A) Fleet and crew composition

A large percentage of total solid waste management cost related to waste collection about 75% is due to the equipment 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 solving the non-linear model is a modification of the gradient 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 shifts and days of the week on a single district basis. The goal is to balance payroll cost and missed refuse collection, while satisfying constraints due to available equipment and policies 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 pointed out.

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 construction of an auxiliary graph, called cyclenode graph, in which nodes represent trips and edges represent feasible trips 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 small cycles where every edge of the graph belongs to exactly one of them. Such cycles are then used to determine the districts.

C) Waste flow allocation

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 generated at each district, is simulated to be evaluated. Then, based on the 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 by simulation. 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) Route Optimization

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 put an adaptive large neighbourhood transportation algorithm 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 economical benefits is getting furnished.

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 0.07 to 0.21 US$ km/ton for collection vehicles, while transporting waste by transfer trailers reduces costs to 0.03 to 0.10 US$ 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 forward and reverse logistics operations dealing with the flow 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 customers waste within given time window while minimizing travel cost. This problem is known as the Waste Collection Vehicle Routing.

E) Collection Pattern

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 twice a week). In fact, if such decisions are not taken properly (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 partially filled in the other days. This would lead to increased 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 (peak quantity).

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. In phase 1, the buildings to be inserted on each day 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, minimizing both travel and collection times. In both phases, a Nearest Insertion Heuristic is used.

F) Problem with Time Windows (WCVRPTW)

A real life Case study done earlier is presented in the research below

In this study the waste management company Waste Management, Inc. in North America 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, and finally

3) a lunch break of duration S.starting in the interval.

Constraint 1) and 2) can easily be added to the model formulation, whereas the lunch break is slightly more complicated. Since no specific lunch location is required, one can assume that the lunch break is taken somewhere between two stops i and j. There is thus no additional travel cost for the lunchbreak. The lunch break u can now be at three different positions (see figure 2): 1) after servicing node i, 2) between travelling from node i and j or 3) before servicing node j. Note it is normally assumed that service cannot be discontinued.

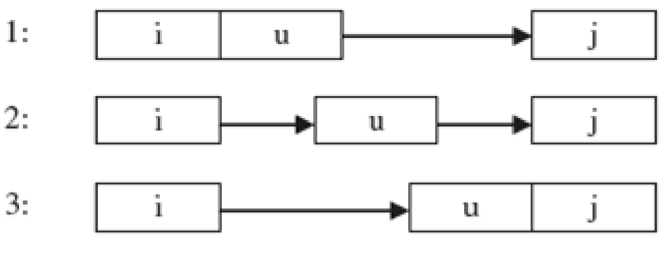

Fig. 2. Possible lunch positions

In order to model the lunch break two new variables are defined. A new binary variable y_{ijl} indicates whether lunch was taken between visiting node i and j by vehicle k. A continuous variable r_l gives the ratio of the driving done between previous and next stop when vehicle l take a lunch break.

$$\sum_{(i,j)\in A} y_{ijl} = 1 \qquad \forall l \in K \qquad (13)$$

$$y_{ijl} \le x_{ijl} \qquad \forall (i,j) \in A, l \in K \qquad (14)$$

$$w_{il} + s_i + y_{ijl}s^u + t_{ij} \le w_{jl} + (1 - x_{ijl})M \qquad \forall (i,j) \in A, l \in K \qquad (15)$$

$$a^u + s^u + t_{ij}(1 - r_l) \le w_{jl} + (1 - y_{ijl})M \qquad \forall (i,j) \in A, l \in K \qquad (16)$$

$$w_{il} + s_i + t_{ij}r_l \le b^u + (1 - y_{ijl})M \qquad \forall (i,j) \in A, l \in K \qquad (17)$$

$$\sum_{i\in V}\sum_{j\in V^c} x_{ijl} \le S \qquad \forall l \in K \qquad (18)$$

$$\sum_{i\in Vf} d_{il} \le R \qquad \forall l \in K \qquad (19)$$

$$0 \le r_l \le 1 \qquad \forall l \in K \qquad (20)$$

$$y_{ijl} \in \{0,1\} \qquad \forall i,j \in V, l \in K \qquad (21)$$

Each vehicle must take exactly one lunch break (13). Constraints (14) ensure that a lunch can only be between two nodes i and j if they are connected. The time window constraints (7) are modified to (15), which ensures that the lunch duration is taken into account. Constraints (16) and (17) ensure that the lunch break takes place within its time window. The number of customers serviced is limited in (18) and the route amount in (19). The ratio must be between zero and one (20). Finally the lunch variable must be binary (21).

In the implementation we have chosen to only allow lunch breaks directly after servicing a node. That is $r_l = 0$.

VI. LIMITATIONS AND BENEFITS

The limitations of the models are as follows:

There was time and financial constraint in carrying out the research.

Most of the informants were reluctant to participate in the research and had to be really convinced to answer.

Most of the respondents especially managers/heads of department claimed to be very busy and ignorant about the vocabulary that was used.

Implementation is a difficult task.

Limited knowledge while doing the research.

Factors that cannot be quantified can't be taken into account.

Complexities of human relations and behaviour has to be taken into account.

Benefits of this research are as follows:

Helps in reducing mismanagement, which is a key factor in environmental issues.
These models help engineers in integrated SWM.
It increases profitability of entire SWM process.
Helps in evaluation of risks and alternative decision.
Helps in maximum waste recovery.

VII. CONCLUSION

In this paper we reviewed the most important literature on the 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 minimise total solid waste disposal costs. It is required to perform route optimization on present solid waste collection paths.
What do we need?
An Integrated waste Management and Solution designs where:-

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

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