Title: Linear Programming Model of Solid Waste Disposal For the Metropolitan Service District (METRO), Dept. of Solid Waste, Portland, Oregon

Course:
Year: 1991
Author(s): T. Daim, E. Dorduncu, J. Goddard, G. Lee, S. MacDermant and M. Pervizpour

Report No: P91028

Abstract: This project uses a simplified model of the Metro solid waste system to show which disposal facility should receive garbage from specific areas of the Metro region in order to minimize the over all system cost.

LINEAR PROGRAMMING MODEL
OF
SOLID WASTE DISPOSAL
FOR
THE METROPOLITAN SERVICE DISTRICT
(METRO)

Dept. of Solid Waste
Portand, Oregon

T. Daim, E. Dorduncu, J. Goddard
G. Lee, S. MacDermant, M. Pervizpour

EMP-9128

LINEAR PROGRAMMING MODEL
of
SOLID WASTE DISPOSAL

for

THE METROPOLITAN SERVICE DISTRICT
(METRO)
Department of Solid Waste
Portland, Oregon

by

Tugrul Daim
Emre Dorduncu
Jim Goddard
Gordon Lee
Sean MacDermant
Mesut Pervizpour

submitted to

Dr. Dick Deckro
Professor of Engineering Management
Department of Engineering Mangement
PORTLAND STATE UNIVERSITY

in partial fulfillment of the requirements
for
EMGT 543 - Operations Research in Engineering Management

December 3, 1991

EXECUTIVE SUMMARY

The model is useful for two primary purposes: (1) finding the optimal policy for allocating waste from regions to stations, and (2) taking advantage of the existing model to make multiple runs. In the second purpose the model functions as a simulation tool that is valuable in assessing what-if scenarios. It is recommended that the model be revised and expanded to more closely represent the actual system.

When the results of all the runs were compared to actual figures, one discrepancy stood out clearly. The Forest Grove Transfer Station was the least desirable station for the model to choose. But in practice, it processes as many tons as it has capacity for, and has already approved an expansion.

Based upon current capacities and future optimal activity levels, it is the recommendation of the group that the METRO funded expansion of the Forest Grove Station facility be rejected as an option. If the proposed station at Wilsonville is built, no other expansion would be necessary. If not, an expansion of the METRO South Transfer Station is recommended to accommodate an additional 95596 tons per year.

All other stations can operate with existing capacities, except the Landfill, whose capacity will only slightly be exceeded (by 3448 tons if the Wilsonville Station is approved, by 23881 tons if not).

Looking at the map, it does not appear that Wilsonville is conveniently located. From the results of the unconstrained runs (SOFREE and XTRAFREE), however, its activity is greater than both the Landfill's and the Composter's. This is probably due to the fact that Wilsonville is accessible to I-5, and, in terms of travel time, is well located. If the model had been based upon distance rather than travel times, it would have come up with a different (and less realistic) solution.

Again it is recommended that the model be revised and expanded to more closely represent the actual system.

LINEAR PROGRAMMING MODEL
SOLID WASTE DISPOSAL
THE METROPOLITAN SERVICE DISTRICT
(METRO)
December 1, 1991

TABLE OF CONTENTS

INTRODUCTION

Solid waste is the term used to describe the garbage that is produced by the public and commercial businesses. A system for the collection, hauling and disposal of the solid waste insures that it is handled quickly and efficiently. METRO is the regional government for the Portland Metropolitan Area and has responsibility for the disposal of all solid waste generated within the area. This gives METRO the ability to direct the flow of waste from its point of generation to a specific disposal site. Metro currently uses a model that tries to predict where the garbage will be generated and disposed. This model attempts to take into account the political decisions made by governments about what waste should be directed to what facility. To date, there is no model that attempts to optimize the flow of garbage in the system.

This project uses a simplified model of the Metro solid waste system to show which disposal facility should receive garbage from specific areas of the Metro region in order to minimize the over all system cost. This would be a valuable tool to the solid waste decision makers for directing the flow of garbage to specific facilities (Peterson, 1991).

For the purposes of this project the solid waste system was simplified to include only the major disposal facilities in the region. These include: Central Transfer Station, Metro South Transfer Station, Riedel Composter, Hillsboro Landfill, and the Forest Grove Transfer Station (Watkins, 1991). The constraints for each of these facilities is based on administrative decisions to guarantee a minimum flow to a facility or by the maximum design capacity of the facility.

The waste generators are classified as either residential or commercial. Residential garbage is that generated by each person at their residence, and commercial garbage is that generated by the employees of each business in the metro region. The average amount of residential generated per capita and the commercial generation per employee are statistics obtained through METRO waste characterization studies (METRO Waste Characterization Study, 1989).

Residential garbage is collected by a rear packing truck that normally has a two person crew. The garbage is manually unloaded from trash cans into the back of the truck. On average, it takes 5.5 hours to fill the truck to its

5.0 ton capacity. Commercial garbage is collected in a truck that picks up and dumps a dumpster. This type of collection requires only one person to operate and takes fewer stops to fill the truck to its capacity. Each truck can carry 8.0 tons of commercial waste. The average commercial load collection time is 3.0 hours. (Phillips, 1991)

Average rates for operating the different trucks were obtained from Metro records and telephone interviews with truck owners. If a truck is half full at the end of a day it is held overnight until a full load can be obtained the following day. For the purposes of this project, the travel time to and from the truck garage and the collection routes were not included since there was no average information available. (Hodge, 1991)

The cost of disposal is set by METRO at all facilities except Hillsboro Landfill where Washington County approves the rates. The rates used in this project are accurate as of November 1991 and are not expected to change relative to each other in the near future.

The Metropolitan Service District (METRO) consists of 400 regions located throughout Multnomah, Washington, Clackamas and Clark counties. The size of individual regions varies and each region is divided up subjectively. The more heavily populated areas have smaller and more detailed regions, while the less populated areas have larger regions. The transportation engineers at METRO designed the regions so that each region is centered around a major thoroughfare.

METRO's goal is to minimize the cost of collecting, hauling, and disposing all the residential and commercial waste generated in each region. To do this, METRO tries to replicate the population's actual travel behavior. In the late 1970's METRO developed a Transportation Network which calculates the minimum time required to travel from the center of one region to the center of an adjacent region; the model considers minimum time of travel, not minimum distance. METRO considered the demographic center of each region, which is the center of activity for that region; a combination of employment center and population center (Peterson, 1991). Minimum times of travel between adjacent regions were obtained by averaging actual travel times taken by METRO staff (using 5 to 10 separate trials) during the PM peak hour which is considered to be 4:30 PM to 5:30 PM each weekday (Higgins, 1991). All these minimum travel times were entered into a computerized database.

From the Transportation Network, the minimum time of travel between any two regions within the system could be obtained. The present database was last updated in 1988, and will continue to be updated as population and employment areas change. (Higgins, 1991)

In order to make this project timely and useful to METRO, it was decided to modify the model with two changes that will be made to the solid waste system in the near future. The Forest Grove transfer station is currently in consideration for an expansion, so its new capacity was used as a constraint in run: CURRENT. The proposed station is another facility which will attract waste that would currently be sent to other facilities. It was added to the model for run: FUTRPROP.

LITERATURE SEARCH

The objective in locating public facilities is to be able to serve dispersed about the urban area by customers who are minimizing travel times or costs. Generally there are always constraints present like political pressures, zoning restrictions, site costs and physical restrictions. Another restriction is the number of the public facilities that are going to serve a given area. If only one single facility is present, and the cost of its service depends on the location of customers, then the optimum location is the one which minimizes the sum of location dependent costs for all customers. Most of the time this cost is either in terms of travel time or is a function of travel time (Helly, p. 133-153).

In the METRO model, the facilities also charge a constant rate ("tipping fee") that is not a function of travel time or distance.

The iterative approach can be applied considering the two-steps: 1) searching for the best facility location within each district, given the district boundaries, and 2) a search for the best district boundaries overall of the facility locations.

Still there is no reason that this approach will converge on an optimum solution. To simplify the iteration it is generally assumed that customer capacity (waste generation) is uniform in the region (for each type of waste) and that the cost of serving a customer is directly proportional to the distance between them and the transfer stations.

In the models Helly describes, none of the locations of the facilities are known. The objective of these models is to optimally locate the facilities. The problem for Metro is to minimize cost, given the exact locations of the stations.

The basic model, as described by Helly, tries to group the areas around each one of those facilities since the objective is to minimize travel-time. But considering the LP model for the waste transfer problem, it a few differences exist due to the nature of problem. Some of these differences can be listed as:

- given locations for each station
- minimization of total cost of the system instead of just travel-time
- having different capacities and guaranteed minimum flows at each station
- the high ratio of tipping fee to the traveling (hauling) fee (fixed to variable)

MODEL

The problem itself is not a difficult one to solve, even without the use of linear programming (Griffith, 1991). The decisions are just where to send the waste from each region. The costs associated with sending a ton of waste from a region to a station have three components: (1) collection costs, (2) hauling costs, and (3) disposal costs. Collection costs are constant, dependent only upon the amount of waste generated. Disposal costs are constant for each station, so they are independent of the region which generated the waste. If the stations were not constrained the decision would be simply to send the waste to the closest transfer station unless there is a cheaper disposal cost at a different station. If this is the case, the difference in hauling cost would have to be offset by the savings in disposal fees; otherwise the decision would still be the closest station. These calculations are quick and simple given the data available (see Appendix A - The Database).

Since the stations have limited capacities, and the Composter (Station 261) has a minimum guaranteed flow, the model must take them into account. METRO would like to plan for growth in area population and employment, and the accompanying increase in waste. The model should be relatively simple and easy to program in order to facilitate multiple runs (McGair, 1991). The model in general form is:

$$\text{MIN } Z = \sum_{i=1}^{400} \sum_{j=1}^{\#\text{ of stations}} (R_{ij}X_{ij} + C_{ij}Y_{ij}) \quad X_{ij}, Y_{ij} \text{ decision variables}$$

WHERE

X_{ij} = the amount of residential waste per year generated in region i to be hauled to station j

Y_{ij} = the amount of commercial waste per year generated in region i to be hauled to station j

R_{ij} = the cost to collect, haul, and dispose of a ton of residential waste from region i to station j

C_{ij} = the cost to collect, haul, and dispose of a ton of commercial waste from region i to station j

S.T.

$$\sum_{i=1}^{400} (X_{ij} + Y_{ij}) \leq L_j$$

$$\sum_{j=1}^{\#\text{ of stations}} (X_{ij}) = S_i$$

$$\sum_{j=1}^{\#\text{ of stations}} (Y_{ij}) = M_i$$

$$Y_{ij^*} \leq .5(M_i)$$

$$\sum (X_{ijt}) \geq P_{jt}$$

FOR

i	=	1 to 400
j	=	1 to the number of transfer stations
L_j	=	the maximum amount of waste (residential and commercial) that can be processed at station j in a year
S_i	=	the amount of residential waste generated in region i in a year
M_i	=	the amount of commercial waste generated in region i in a year
j^*	=	Hillsboro Landfill (Station 040)
$j^\dagger$	=	Riedel Composter (Station 261)
$P_{j^\dagger}$	=	the minimum amount of residential waste that is guaranteed to the Riedel Composter each year

$X_{ij} \geq 0$ for all i and j

$Y_{ij} \geq 0$ for all i and j

$Y_{ij^\dagger} = 0$ for all i , $j^\dagger$ signifies the Riedel Composter

SOLUTION

The base model was optimized using the data in Appendix A. A full report of the output is included in Appendix B. This run models the current system. The total cost of the policy is \$102,083,745, with an average cost per ton of \$107.57. The Hillsboro Landfill (Station 040) is the disposal station of choice. It is the only station receiving full capacity. This is not surprising given that it offers the lowest disposal fee per ton at \$52.60. All other stations charge \$68.00. The only other constraints that are binding in this solution are the Landfill constraints which limit the intake of any region's commercial waste to half of the waste generated and the guaranteed flow to the Composter. The Landfill commercial waste constraints are binding for select regions only (see Sensitivity Analysis Summary, Commercial Waste Table in Appendix B).

SENSITIVITY ANALYSIS

The marginal values (shadow prices) for the Landfill commercial waste constraints vary from $.03 to $4.34 for the regions that are at the limit. For each additional ton allowed sent to the landfill the cost savings is from $.03 to $4.34 depending on the region given the allowance. The marginal value on the guaranteed flow to the Composter is negative, ($.79). Since this constraint is a "greater than" constraint, the value's significance is not as obvious. For each additional ton per year guaranteed to the Composter, there is an associated cost increase of $.79. Conversely, if the guarantee is relaxed by a ton, the cost savings is $.79. (Kelso, 1991)

The capacity constraint on the Landfill has associated with it a marginal price of $13.52 per ton of additional capacity. However, there are costs associated with the Landfill that have not been captured by the model. Environmental concerns, health hazards, political concerns, and public perceptions all present disincentives to expanding the Landfill's capacity. The model does not see these very real costs. If METRO could quantify these costs, they could be included in the model.

EXTENSIONS

The model discussed so far is based on 1987 population and employment figures. The capacity of the Forest Grove Transfer Station (Station 368) is 325 tons per day, as it is actually. However METRO has already approved an expansion of the facility to a capacity of 520 tons per day. In the second run, referred to as run: CURRENT, the new capacity is used.

CURRENT

The total cost of the policy for run CURRENT is $102,083,745, with an average cost per ton of $107.57. These costs are identical to those of the initial run BASE (see Appendix B - Full Report Run: BASE, and Appendix D - Output for Run: CURRENT). In fact the entire solution is identical. This was to be expected from the BASE solution sensitivity analysis. Since Forest Grove should not have been run at capacity in the first place, METRO is adding units of a resource that has slack for the optimal policy.

FUTURE

The next run seeks to answer whether the current capacities are sufficient for the future. The only difference between runs CURRENT and FUTURE is that FUTURE uses projected population and employment figures for the year 2010 to calculate the amount of waste generated (see Appendix A). The total cost of the optimal policy is $141,575,556, with an average cost per ton of $107.21.

There are similar marginal values for the Landfill commercial waste constraints as with the previous runs (see Appendix E - Output Run: FUTURE). In this case they vary from $.03 to $1.80. The marginal value on the guaranteed flow to the Composter is negative, ($.12). The Landfill again has a marginal price associated with it. For this run it is even higher, $15.99 per ton of additional capacity.

A new capacity limit has also been reached, that of Metro South Transfer Station (Station 158). The shadow price for an additional ton of capacity is $.83. This run provided for Forest Grove capacity of 520 tons per day and there was slack. A second look also reveals that the activity level, 48,035 tons per year, is also less than the original capacity of 84,500 tons per year (325 tons/day = 84,500 tons/year). Perhaps METRO should look into expanding Metro South for the future rather than Forest Grove.

PROPOSED STATION

Metro is considering the addition of a new transfer station in Wilsonville. A new run FUTRPROP was made using the 2010 data. The capacity of the proposed station was estimated to be 800 tons per day.

The total cost of the optimal policy is $141,223,137, with an average cost per ton of $106.94. Again there are the marginal values for the Landfill commercial waste constraints and for the guaranteed flow to the Composter (see Appendix F - Output Run: FUTRPROP). The Landfill shadow prices vary from $.00 (rounded) to $2.31. The marginal value on the guaranteed flow to the Composter is negative, ($.45).

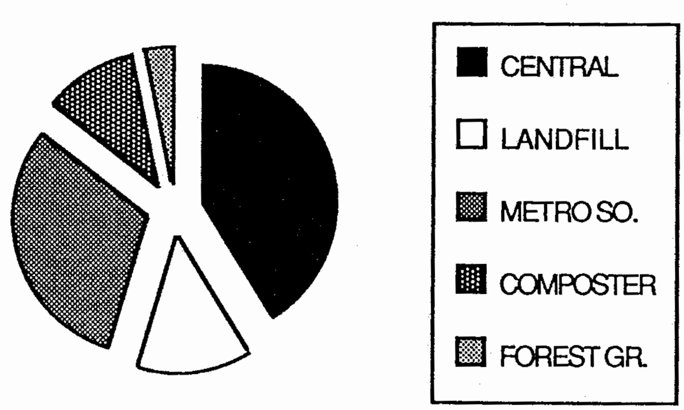
EQUAL TIPFEES

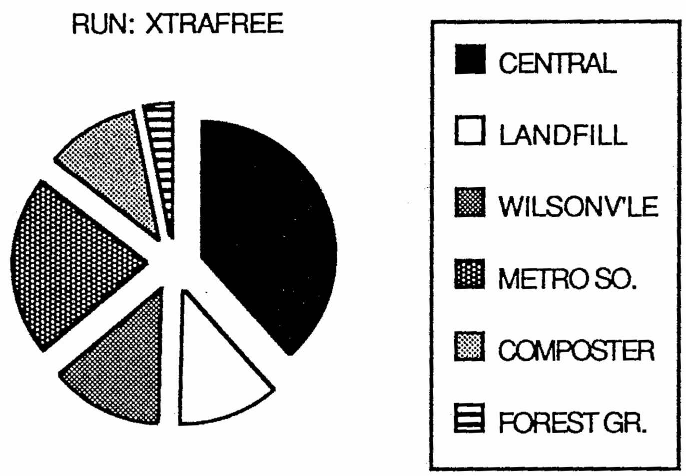
In all the runs thus far, the disposal cost per ton (tipfee) at the Landfill has been $52.60. All other stations charge $68.00. In planning for the future it would be beneficial to METRO to know the desirability of the geographic locations of each station. By running each station without capacity requirements or guarantees and with all tipfees equal, the model will allocate the waste from each region to the station that "it wants to go to." Since the objective is to minimize cost, the model will not choose to send to the Landfill unless it is the most cost effective location. The Landfill will still only accept up to 50% of any region's commercial waste.

Run SOFREE does not include the proposed Wilsonville Station. Run XTRAFREE does. The percentage of the total waste received by each station for each run is as follows:

	SOFREE	XTRAFREE
Central Transfer	41.3 %	38.6 %
Hillsboro Landfill	13.6 %	12.1 %
Wilsonville Transfer	N/A	13.5 %
Metro South Transfer	30.9 %	21.7 %
Riedel Composter	10.8 %	10.8 %
Forest Grove Transfer	3.5 %	3.4 %

RUN: SOFREE





DISCUSSION

FOREST GROVE

When the results of all the runs were compared to actual figures, one discrepancy stood out clearly. The Forest Grove Transfer Station was the least desirable station for the model to choose. But in practice, it processes as many tons as it has capacity for, and has already approved an expansion.

After bringing this to METRO's attention, we learned that the Forest Grove station is privately owned, and that trucks owned by the same company are mandated to tip at Forest Grove. This is not something the model was aware of, but it provides a good example of how the model is interested only in the total objective of the system.

The owner of the Forest Grove Station has it clearly in his best interest to require his trucks to tip at his station. From METRO's perspective this practice is counterproductive. The added cost to the station owner is passed on to METRO in the fees that the owner charges.

It is important to point out that the optimum for the system is not equal to the sum of the local optimums at each station. It is possible to optimize local systems, given the optimal solution of the total system (METRO).

TRAVEL TIMES

Looking at the map, it would not appear that Wilsonville is conveniently located. From the results of the unconstrained runs (SOFREE and XTRAFREE), its activity is greater than both the Landfill's and the Composter's. This is probably due to the fact that Wilsonville is accessible to I-5, and in terms of travel time is well located. If the model had been based upon distance rather than travel times, it would have come up with a different (and less realistic) solution.

WASTE GENERATION

The model is based on waste amounts calculated from population and employment figures. Obviously, reducing the amount of waste will reduce the cost of the system. Most of the runs have average cost per ton figures of about $107. Reducing the waste by a ton would result in a savings of this amount. But it is possible to get average costs per ton by region and type of waste (residential or commercial). METRO could attempt to limit waste generation in targeted high cost regions through incentives.

CONCLUSIONS

The model is useful for two primary purposes: (1) finding the optimal policy for allocating waste from regions to stations, and (2) taking advantage of the model to make multiple runs. In the second purpose the model functions as a simulation tool that is valuable in assessing what-if scenarios. It is recommended that the model be revised and expanded to more closely represent the actual system.

Based upon current capacities and future optimal activity levels, it is the recommendation of the group that the METRO funded expansion of the Forest Grove Station be reevaluated. The capacities and activity levels for these runs are:

	BASE CAPACITY	SOFREE ACTIVITY	XTRAFREE ACTIVITY
CENTRAL	650000	545448	509648
LANDFILL	156000	179881	159448
WILSONV'LE	208000	N/A	177876
METRO SO.	312000	407596	286030
COMPOSTER	5200000	142114	142114
FOREST GR.	84500	45564	45489

From these results, the expansion of the Forest Grove facility should be rejected. If the proposed station at Wilsonville is built, no other expansion would be necessary. If not, an expansion of the METRO South Transfer Station is recommended to accommodate an additional 95596 tons per year.

All other stations can operate with existing capacities, except the Landfill, whose capacity will only slightly be exceeded (by 3448 tons if the Wilsonville Station is approved, by 23881 tons if not).

Again it is recommended that the model be revised and expanded to more closely represent the actual system.