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Title

AN OPTIMIZATION ROUTING MODEL FOR COLLECTING INFECTIOUS MEDICAL WASTE

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Abstract:

Most small to medium–sized clinics and hospitals in Indore do not have on-site treatment facilities for their medicals and infectious wastes and must rely on outside agencies for its collection and treatment. In this paper the problem of optimally planning and scheduling the collection of medical wastes from a disperse group of facilities is formulated as a PVRP. Special attention is given to the requirement that waste pickup be made on at least a weekly basis. Optimization model consist of two phase: first phase solves a standard VRP to determine the set of individual routes for the collection vehicles by SFCOP (space filling curve with optimal partitioning) approach. Whereas second phase assigns routes to particular days of the week by mixed-integer programming. Also an illustrative example demonstrates the effectiveness of the approach.

Introduction:

Infectious waste generated by medical institutions has not been collected and treated adequately in recent decades. For that reason, governmental and public concern has arisen over the insufficient collection and treatment system of infectious medical waste, which is generated daily in Indore city at an estimated 50 t (approx.). Although more than 10 large public hospitals have their own incinerators to handle the infectious waste, relatively few of them provide a treatment service for other hospitals. The total waste treated by incinerators inside these large hospitals account for approximately 60% of all infectious waste. Most medium-sized hospitals and a large number of geographically dispersed clinics do not have a treatment facility, thereby necessitating the need for a privatized waste management agency capable of providing treatment and collection services.

Two private agencies that adopt two different types of treatment methods recently have begun providing an island wide service for hospitals and clinics in Indore. One of the waste management agencies adopts the conventional incineration method, where a rotary kiln is used to treat infectious waste along with other industrial wastes. The incinerator is located in central Indore so that the service area is a comprehensive one. Because this treatment method was introduced earlier in Indore than the other method, approximately 25% of the infectious waste is collected and treated by the incineration process.

The other method, which was introduced recently in a technology transfer from Japan, uses an electric arc furnace (EAF) in the steel-making process to treat infectious waste. Infectious waste, including non combustible material such as needles, syringes, glass bottles, and combustible waste are stored in iron containers so that the loaded iron containers can be dropped directly into an EAF and melted along with other iron scrap in the steel-making process. Notably, all infectious waste is treated thoroughly because the melting point for iron is 1,560^{0}C. Combustible waste is incinerated rapidly and efficiently, whereas non combustible material such as glass is melted and becomes a portion of the slag floating above the liquid steel. Metal waste such as a steel needle would melt together with metal scrap and becomes part of the liquid steel and, eventually, is recovered as a part of the steel product.

For agencies that provide a treatment service for hospitals and clinics not in close proximity to each other, successful management does not depend on the treatment process because both the incineration and the EAF process have been proven successful for infectious waste treatment. Instead, system planning focuses on how to collect infectious waste from the geographically dispersed hospitals. Furthermore, local environmental regulations mandate the treatment of infectious medical waste on a daily basis if it is stored at room temperature. If stored at a temperature lower than 5^{0}C, such waste must be treated within a week. Under this regulation, the collection system must be well designed; the process must be completed within a week as well. Previous literature refers to this kind of problem as the periodic vehicle routing problem (PVRP).

Periodic vehicle routing problem (PVRP):

The PVRP, a generalization of the conventional VRP, attempts to design a set of daily routes for a given T-day period. In this study, T equals 6 days, including Sunday. The period vehicle routing problem (PVRP) is the problem of designing routes for delivery vehicles for all the days of a given T-day period where not all customers require delivery on every day in the period. Typically, if a customer requires $k\ (\leq T)$ visits during the period then these visits may only occur in one of a given number of allowable k-day delivery combinations. For example, if a customer requires two deliveries in a 5-day week then the allowable delivery combinations might be Monday/Wednesday, Tuesday/Thursday, Wednesday/Friday with no other combinations of delivery days being acceptable.

In general, the PVRP must be optimized while simultaneously considering vehicle routing and allowable day combination in the planning horizon.

Previous Work:

Early work on the PVRP was carried out by Beltrami and Bodin [1] in their study of hoist compactor routing. They considered two approaches to the problem:

(1) Developing routes which were then assigned to delivery days; and

(2) Assigning customers to delivery days and then routing each day separately.

Russell and Igo [10] proposed three approaches to the problem:

(1) Assigning customers to delivery days by a clustering algorithm where the clusters for each day were formed around customers with a single allowable delivery combination,

(2) An adaptation of the single-day vehicle routing heuristic MTOUR of Russell [9] which is based on the travelling salesman heuristic of Lin and Kernighan [7],

(3) An adaptation of the single-day vehicle routing heuristic of Clarke and Wright [3].

Christofides and Beasley [2] presented heuristic algorithms for the PVRP based upon an initial choice of customer delivery days to meet service level requirements followed by an interchange procedure to improve upon the choice of delivery days. Tan and Beasley [1984] extended the work by fisher and Jaikumer [1981] on VRP to solve the PVRP using a heuristic method where a mathematical programming method is adopted after determining the subgroups of customers. Russel and Gribbin [1991] proposed a multi-stage method to solve the problem where an interchange heuristic was suggested to reduce distribution cost after an initial solution was obtained using a generalized network model. Gauodio and Paletta [1992] recommended

Using a heuristic to minimize the fleet size as well as the travel mileage where the visiting frequency of each customer could be specified.

Outline for infectious waste collection:

This study proposes an approach to resolve the collection vehicle scheduling and routing problem for infectious waste management. Owing to environmental regulations, medical institutions that generate infectious waste must be visited weekly, accounting for why the PVRP must be considered. For those institutions generating a larger amount of infectious waste, more than a weekly visit is necessary to collect the waste. While considering the storage capacity of a refrigerator, collection time must be evenly arranged on a weekly basis. For instance, an institution with infectious waste equivalent to three truckloads may want the waste collected every other day, i.e., Monday-Wednesday-Friday or Tuesday-Thursday-Saturday, thereby minimizing the refrigerator's capacity. In general, a traveling salesman problem solves for a hauling route assuming there exists no vehicle capacity limit whereas a VRP considers vehicle capacity. A PVRP can be viewed as an optimization problem that includes VRP and the constraints of allowable day combination. Christofides and Beasley (1984) formulated the PVRP as a mathematical programming problem that includes standard mathematical programming formulation of VRP and the constraints that consider allowable day combinations for the customers that require multiple visits. However, because the numbers of variables and constraints increase dramatically as the number of customers increases, the PVRPs generally are solved by heuristic methods instead of mathematical programming methods.

In this study, we have recommended solving PVRP in two phases. Initially, we solve a standard VRP without considering the allowable day combination constraints. Second, a mixed integer programming method is employed to assign daily the obtained routes to balance primarily the daily workload. In the first phase, a relaxed problem of the original optimization problem is solved in which total travel is minimized and the constraints of allowable collection day combination for the institutions with multiple visits are relaxed temporally. Under this premise, any credible approach in previous literature that solves VRP can be adopted. Fig. 1 depicts the procedures of the proposed approach. The optimal routes obtained will be assigned to 6 working days in phase II considering the allowable day combinations for the customers. In the second phase, the routes obtained in phase I are assigned to 6 working days where the constraints that consider the allowable day combinations of the hospitals in each route are included. Two mixed-integer programming models are used to solve the route scheduling problem where the objectives are:

- To minimize the difference between the maximal and minimal daily travel
- To minimize the maximal daily travel.

The resulting maximal daily workload then is used to determine the number of hauling vehicles for the collection system. Theoretically, the fact that the approach neglects the constraint of allowable day combination when solving VRP in phase I may prevent us from finding a feasible solution for route assignment. However, in practice, a feasible solution frequently is found in phase II. The following two problem characteristics allow us to satisfy the allowable day combination in the mathematical programming models for each route obtained from phase I:

1. The clinics that demand a single visit on a weekly basis frequently outnumber those hospitals that require multiple visits. The number of constraints that consider allowable day combination is limited and are not as many as those in the general PVRP discussed in previous literature.

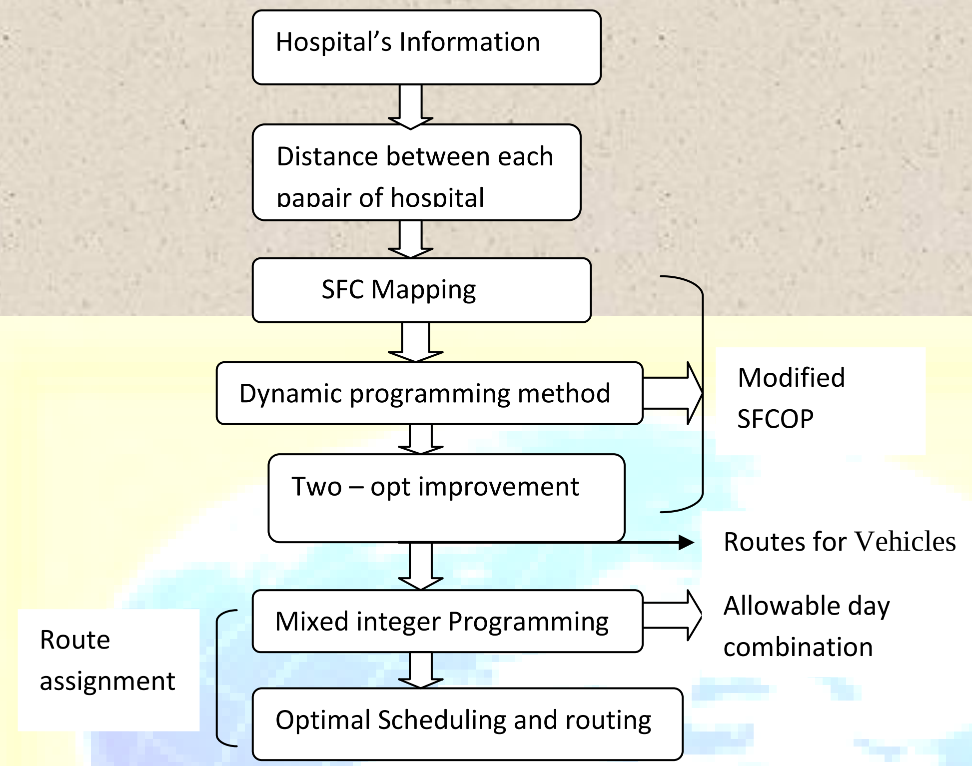

Fig: 1 Flowchart of Proposed Approach

2. For those hospitals requiring multiple visits, assume here that only one visit in a week may need to share the vehicle route with other hospitals while the remaining visits carry a full truckload of infectious waste. Because the collecting vehicle with a full truckload goes back and forth between depot and the hospital, the route does not include other hospitals. This also makes it simpler to write down constraints of allowable day combination in phase II. Because of the two problem characteristics, the proposed approach becomes attractive. The advantages of the proposed two-phase approach include the following:

1. In phase I, the VRP can be solved using analytic as well as heuristic methods depending on the computation capacity and the required level of solution quality. This study used the space filling curve with optimal partitioning (SFCOP) approach that was shown better than several conventional approaches in Bowerman et al. (1994).

2. In phase II, the routes are assigned to 6 working days using mixed-integer programming models. The assignment solutions are optimal because analytic approaches instead of heuristic methods are used.

The following two sections describe the procedure of the two phases, respectively.

VRP: Using SFCOP Method:

The VRP has received extensive interest, along with diverse applications made in recent decades. Bodin et al. (1983) and Laporte (1992) thoroughly reviewed the VRP. Here, we utilize the SFCOP method recently developed by Bowerman et al. (1994) to solve the VRP. Bowerman et al. demonstrated that their approach is better than several conventional approaches, e.g., Clarke and Wright procedure (1964), in terms of computational efficiency. The concept of the SFC is used to provide one-to-one mapping of a two-dimensional space onto a unit interval (from 0 to 1) and preserve the ‘‘nearness’’ of points in the space. The construction of the SFC is not unique.

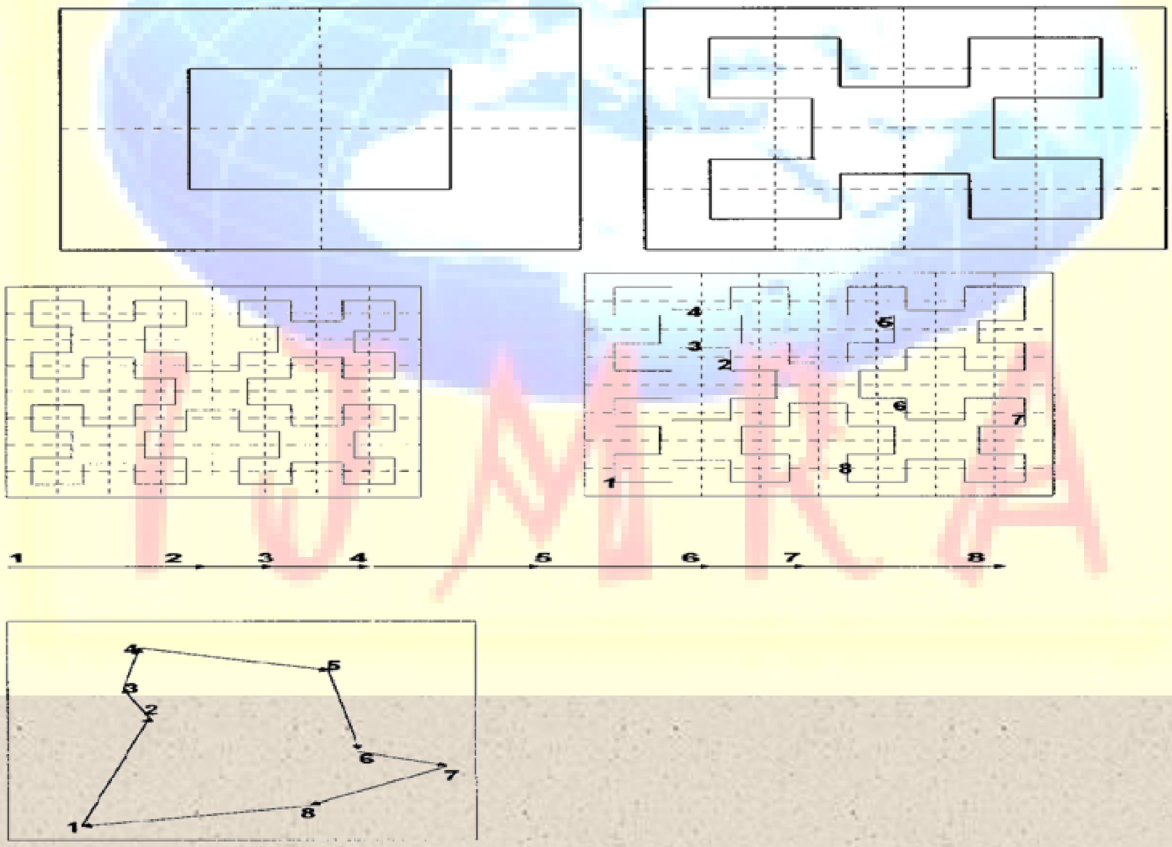

Fig: SFC Mapping

For example, Bartholdi and Platzman (1988) presented several typical SFCs. Bartholdi and Platzman (1988) also described that an SFC could be thought of as the limit of a sequence of recursive constructions whereby the square is subdivided into smaller squares, into which are copied scaled versions of the preceding constructions. Fig. 2 presents an illustrative example of SFCs where the solid line represents an SFC and the dashed lines depict the subdivision of the squares. As the squares get smaller, the SFC will "fill" the two-dimensional space. The customer points are visited in the order dictated by the SFC. A potential heuristic strategy for solving the VRP is first to map the problem from the plane to the unit interval with a SFC and then solve the transformed problem on the line. An example of this process is given in Fig. 3. It is important to emphasize that this SFC "line" is actually a closed curve, that is, the end points of the line are connected together as though the line is the perimeter of a circle. Another advantage of SFCs is that calculation of a given point's position on the curve is simple and fast. To calculate the position of *n* demand nodes on the unit interval, if the coordinates of a point are given to *k*-digit accuracy takes only O(*kn*) elementary operations with multiplication and division by a constant determined by the SFC.

Once the point sequence is determined, a dynamic programming model is solved for a VRP to attain the optimal breaking (partition) places to minimize the total travel distance without exceeding the vehicles' carrying capacity. The study extend the work of Bowerman et al. (1994) and include an additional constraint that the working time. The modification is made because the vehicle working time (8 hours) frequently is exceeded before the vehicle capacity is exceeded when the waste of many small clinics collected on a route. A constraint denoting working time is included in the dynamic programming formulation proposed by Bowerman et. al. (1994)

$$minimize \quad f_k(s_k, d_k) = e_{s_k} + f_{k-1}^*(s_{k-1}) \qquad (1)$$

Where $f_k^*(s_k) = min_{d_k} f_k(s_k, d_k)$.

Subject to

$$d_k \geq 0 \qquad (2)$$

$$l_k \leq \sum_{j=1}^{s_k} q_j \leq u_k \qquad (3)$$

$$\sum_{j=s_{k-1}+1}^{s_k} q_j \leq W \qquad (4)$$

$$\sum_{j=s_{k-1}}^{s_k} t_j + tt_{s_{k-1}+1,depot} + tt_{s_k,depot} \leq T \qquad (5)$$

where $S_0 = 0$; and $f_0^*(S_0) = 0$. The objective of this dynamic Programming problem is to minimize the cost (travel mileage) and find the location s_k at which the kth vehicle terminates its route to return to the depot at stage k.

Constraint in (2) allows only the formation of sensible routes.

Constraint in (3) ensures that the state is chosen so that the fulfilled demand is within feasible limits.

Constraints in (4) and (5) ensure that the vehicle capacity and working time are not exceeded.

The formulation basically is the same as the dynamic programming formulation suggested by Bowerman et al. (1994) except the constraint in (5) denoting the working time limit. In summary, the solution approach of the SFCOP approach for VRP consists of the following five steps:

Data Collection:

Collect the pertinent data of medical institutions, including the amount of infectious waste, location of depot, and the medical institutions as well as the capacity of collecting vehicles.

Formulation:

For medical institutions that require multiple weekly visits, infectious waste is divided into several piles, depending on the vehicle capacity. For instance, when the vehicle capacity is 2,000 kg, the amount of 5,000 kg waste can be divided into three piles: two full truckloads (2 x 2,000 kg) and one partial load (1,000 kg). In the following steps, we do not consider the routes of the two fully loaded vehicles because the routes go only between the hospital and depot. In other words, in the foregoing formulation the quantity q_j is equal to 1,000 kg. The two fully loaded vehicles won't be considered until the mixed-integer programming problem is solved in the next phase.

SFC Mapping:

Sequence the institutions by using an SFC (Bartholdi and Plazman 1982).

Vehicle routing:

Use dynamic programming to identify the optimal partition points and identify the groups of customers that should be visited on each route.

Use of Two-opt Procedure:

Finally, each resulting route of VRP can be improved using a two-opt procedure that examines all two-opt moves (Lin 1965). A two-opt move in general consists of breaking two edges and reconnecting the two resulting paths to obtain a new route. For example, there is a route going through four points in Fig. 3 in the sequence of P1-P2-P3-P4-P1. A two-opt move may break the edges P1-P4 and P2-P3 and connect P2-P4 and P1-P3 so that the new sequence becomes P1-P2-P4-P3-P1. The new route is taken if it is shorter than the old one.

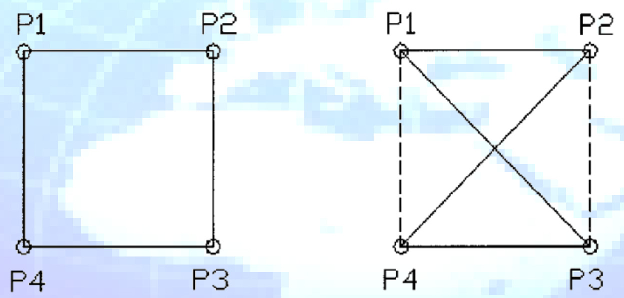

Fig: Example of Two – opt Procedure

Model Formulation:

This study proposes two mixed-integer programming models with two different objectives to assign the routes to 6 working days. The first model attempts to balance simultaneously the daily workload and minimize the collection fleet size by minimizing the difference between the maximal and minimal daily travel mileage. Meanwhile, the second model attempts to minimize the collection fleet size by simply minimizing the maximal daily travel mileage. A different route assignment can be obtained depending on which objective function is chosen. From a managerial perspective, the less the maximal daily travel implies a lower operation cost, whereas a balance of workload implies that the working time of the collection crew is reasonable. Two factors need to be considered in writing the model constraints of the allowable day combination for the medical institutions that require multiple visits. For instance, the allow-able day combination for a medical institution that requires three visits may either be of the following sequence: Monday-Wednesday-Friday or Tuesday-Thursday-Saturday. Further-more, when the hospital shares a route with other hospitals that require multiple visits, the **‘‘common’’** allowable day combination of the institutions must be identified to write down the model constraints. Restated, assume that two institutions are on the same route, one requires three visits, while the other one needs two visits. The allowable common day combinations for the route are determined in light of the fore-going day combination and the combination for the institutions that need two visits. If the allowable day combinations for the two-visit institution are Monday-Thursday, Monday-Friday, Tuesday-Friday, Tuesday-Saturday, and Wednesday-Saturday, the common (intersection) allowable day combination for the route then is either Monday-Friday or Tuesday-Saturday.

Model – I Minimize $P - Q$ (6)

Model – II Minimize P (7)

Subject to

$$P \geq \sum_{j=1}^{m} D_j Y_{jk} \quad k = 1, 2, \ldots, 6 \quad (8)$$

$$Q \leq \sum_{j=1}^{m} D_j Y_{jk} \quad k = 1, 2, \ldots, 6 \quad (9)$$

$$\sum_{k=1}^{6} Y_{jk} = 1 \quad j = 1,2,\cdots,m \quad (10)$$

$$\sum_{k\in U^v} Y_{ok} - \sum_{k\in U^v} Y_{pk} = 0 \ \forall\ pairs\ of\ routes: o\ and\ pthat\ visit\ v\ and\ \forall\ U^v, \forall\ v \quad (11)$$

$$\sum_{j\in W^v} Y_{jk} \leq 1 \quad k = 1,2,\cdots,6\ \ and\ \ \forall\ v \quad (12)$$

$$Y_{jk} = 0 \quad j = 1,2,\cdots,m; \quad k \in Z_j \quad (13)$$

$$Y_{jk} \in (0,1) \quad \forall\, j,k \quad (14)$$

In the objective functions, P and Q denote the maximal and minimal daily travel mileage. The expression in:

(6) The objective function of model *I*, which minimizes the difference of maximal and minimal daily travels

(7) The objective function of model II, which minimizes the maximal daily travel.

(8) & (9) denote that maximal and minimal travel mileages are obtained.

(10) Denotes that each route can be assigned only to 1 day.

(11) Ensures that only one of the allowable day combinations is selected for a medical

institution that requires multiple visits. For example, assuming two routes, o and p, pass the institution v that requires two visits while the allowable day combination is either Monday-Friday or Tuesday-Saturday. The corresponding constraints can be written as

$$Y_{o1} + Y_{o5} - Y_{p1} - Y_{p5} = 0$$
$$Y_{o2} + Y_{o6} - Y_{p2} - Y_{p6} = 0 \qquad (15)$$

The expression coupled with the constraint in (10) ensures that when route o is assigned to Monday, route p will be assigned to Friday. On the other hand, when route o is assigned to Tuesday, route p is assigned to Saturday.

(12) Ensures that each institution can be visited, at most, once a day.

(13) Ensures that only the allowable day combination can be selected for the route assignment.

In this study, the sets, U^{v}, W^{v}, and Z_j need to be identified for each route and hospital that requires multiple visits immediately after the VRP is solved in phase I. For example, when a hospital needs two weekly visits and the possible visiting times are Monday-Thursday or Tuesday-Friday, then the set $Z_j = \{1, 2, 4, 5\}$.

Illustrative Example: Infectious waste collection for hospitals in Indore city:

This section describes an illustrative collection vehicle routing and scheduling problem for infectious waste in Indore city. This example includes 40 hospitals, each having more than 50 beds. Currently, the 40 hospitals are customers of different agents and the routing and scheduling for the collecting vehicles are conducted manually. Table 1 displays the amount of infectious waste generated by these hospitals. Notably, even we find maximum no. of hospitals in Indore city, only five hospitals generate more than 2,000 kg/per week of infectious waste and require multiple visits in a week. This supports the use of the two-phase approach for resolving the problem. The phase I, the SFCOP method is employed to solve the VRP. The problem is solved following the five steps:

- Daily waste is assumed to be 0.6 kg. per bed [Hsieh(1994)]
- The vehicle carrying capacity is equal to 2,000kg.
- Three FORTRAN programs are written to facilitate the calculation, respectively, for

The phase II, the proposed mix-integer programming are solved to assign optimally the daily vehicle routes. The mix-integer programming problems are solved using commercial software LINGO.

Table: 1 Waste Generated by Hospitals in Indore

SL.No.	Name of Hospitals	No. of Beds	Amount of Waste(kg/week)
1	Amol Hospital	55	184.80
2	Anand Hospital	62	208.32
3	Ankur Hospital	101	339.36
4	Appollo Hospital	243	816.48
5	Arihant Hospital	225	756.00
6	Bhandari Hospital	881	2,960.16
7	Charak Hospital	346	1,169.28
8	CHL Hospital	1076	3,615.36
9	City Nursing Home	348	1,162.56
10	Curewell Hospital	474	1,592.64
11	Devi Hilda Hospital	112	376.43
12	Gokuldas Hospital	584	1,962.94
13	GovindRam Seksaria Hospital	64	216.65
14	Greater Kailash	866	2,904.86
15	Gurjar Hospital	570	1,825.30
16	K.D.Care Hospital	375	1,260.00
17	Khandelwal Hospital	58	194.88
18	Life Line Hospital	499	1,697.54
19	Maharaja Yeshwantrao Hospital	1757	5,903.53
20	Manish Hospital	132	442.76
21	Mayur Hospital	851	2,897.06
22	Medicare Hospital	375	1,123.45

23	Mother care Hospital	154	567.56
24	MTH Hospital	149	500.75
25	Murlidhar Kripa Hospital	57	198.52
26	Nahar Nursing home	570	1,867.73
27	Nobel Hospital	319	1,034.16
28	Pooja hospital	101	336.56
29	Recovery Hospital	500	1,564.85
30	Sanjeevani Nursing Home	154	537.44
31	Sarvodaya Nursing Home	139	654.86
32	Saurabh Children Hospital	151	539.64
33	Shrinath Hospital	204	678.65
34	Shubham Hospital	99	336.52
35	SNG Hospital	881	2,876.14
36	Sundaram Hospital	145	546.43
37	Suyash Hospital	474	1,453.75
38	Suyog Hospital	499	1,676.65
39	Unique Hospital	851	2,859.36
40	Vyas Children Hospital	100	337.32
	Total -	15601	52177.25

Table 2 displays the results of both model I and model II assuming that the capacity of a vehicle is 2,000 kg and the depot is located near the intersection of A.B Road & M.G Road i.e,Palasia Square, Indore. Among those results include routing, day assignment, and accumulative travel mileage of each route. Notably, the results of the two models are identical because the maximal daily travel (57.866 km) and the minimal daily travel (57.699 km) are extremely close. Although the models cannot solve for the number of trucks directly, it can be obtained by using the resulting daily workload. According to our results of daily workload in the last column of Table 2, only one vehicle is necessary for infectious waste collection in this example because the daily total working hours are all approximately 7– 9 h. This is assuming that the vehicle average speed is 20 km/ h and the loading process takes 30 min. On the other hand, the results of models I and II slightly differ if a larger vehicle capacity (e.g., 4,000 kg) is used. Tables 3 and 4 summarize the results of the two models assuming that the carrying capacity is 4,000 kg. For model I, the difference between the maximal and the minimal daily travel is smaller than that in the model II (Table 5). This finding suggests that the workload is assigned more evenly if we follow the results of model I. However, the maximal daily travel in the model II is less than that in model I, indicating that the maximal workload is reduced if we assign the routes following the results of model II. However, maximal daily travels of the two models only slightly differ, we recommend using the model I because the workloads are more even among 6 working days. Furthermore, the maximal daily travel is pretty close to the results using model II.

Conclusion:

This study presents a novel means of solving the scheduling and routing problem for infectious waste collection. Owing to the unique requirements for the infectious waste collection, the optimal system planning for the infectious waste collection involves a periodic VRP. Via the proposed method, the problem can be resolved in two phases. In phase I, the SFCOP is modified to solve the VRP owing to its simplicity and computational efficiency. In addition to vehicle capacity constraint, the constraint of working time in the dynamic programming model is included. In phase II, two mixed-integer programming models are proposed to assign optimally the vehicle routes to 6 working days. The proposed two-phase approach provides satisfactory solutions primarily because relatively few hospitals require multiple visits. The proposed method is advantageous in that in addition to achieving minimal total travel mileage in a week, both the difference of workload among 6 working days and the maximal daily workload can be minimized.

TABLE: 2 Routing Results (Model – I & II; Carrying Capacity, 2t)

DAY (1)	ROUTES (2)	NUMBER OF HOSPITALS(3)	DISTANCES(Km) (4)	TIME(h) (5)
Monday	1	1	10.54	1.5
	2	1	6.12	1.3
	3	2	23.48	2.6
	4	2	17.02	2.3
Subtotal	4	6	57.16	7.7
Tuesday	1	1	10.36	1.5
	2	1	7.04	1.4
	3	2	15.43	2.2
	4	1	9.56	1.2
	5	2	14.98	2.1
Subtotal	5	7	57.37	8.6
Wednesday	1	1	12.00	1.6
	2	2	15.2	2.2
	3	2	18.54	2.4
	4	1	10.90	1.5
Subtotal	4	6	57.26	7.7
Thrusday	1	1	10.56	1.5
	2	1	11.65	1.6
	3	2	14.49	2.0
	4	1	7.80	1.3
	5	1	12.75	1.8
Subtotal	5	6	57.25	8.2
Friday	1	2	15.72	2.2
	2	1	6.08	1.3
	3	2	13.55	1.7
	4	2	12.74	1.6
	5	1	9.23	1.4
Subtotal	5	8	57.32	8.2
Saturday	1	1	10.77	1.5
	2	2	17.05	2.3
	3	1	8.41	1.3
	4	3	21.08	2.5
Subtotal	4	7	57.31	7.6

Table: **3 Route Assignments from Model – I (Capacity, 4t)**

DAY (1)	ROUTES (2)	NUMBER OF HOSPITALS(3)	DISTANCES(Km) (4)	TIME(h) (5)
Monday	1	2	10.34	2.0
	2	3	16.27	2.8
	3	2	9.61	1.4
Subtotal	3	7	36.22	6.2
Tuesday	1	3	12.10	2.1
	2	1	6.08	1.3
	3	5	20.05	2.0
Subtotal	3	9	38.23	5.4
Wednesday	1	4	28.33	3.6
	2	2	11.20	1.6
Subtotal	2	6	39.53	5.2
Thrusday	1	4	20.02	3.5

	2	2	18.22	2.0
Subtotal	2	6	38.24	5.5
Friday	1	2	17.21	2.1
	2	3	20.01	2.5
Subtotal	2	5	37.22	4.6
Saturday	1	2	13.71	1.6
	2	3	16.04	1.8
	3	2	8.37	1.4
Subtotal	3	7	38.12	4.8

Table: 4 Route Assignments from Model - II (Capacity, 4t)

DAY (1)	ROUTES (2)	NUMBER OF HOSPITALS(3)	DISTANCES(Km) (4)	TIME(h) (5)
Monday	1	1	10.53	1.5
	2	2	12.06	2.0
	3	2	13.34	2.0
Subtotal	3	5	35.93	5.5
Tuesday	1	4	21.10	2.6
	2	2	15.23	2.2
Subtotal	2	6	36.33	4.8
Wednesday	1	3	13.01	2.0
	2	2	11.37	1.6
	3	3	14.24	2.1
Subtotal	3	8	38.62	5.7
Thrusday	1	4	20.14	3.5
	2	3	19.26	3.3
Subtotal	2	7	39.40	6.8
Friday	1	2	15.67	2.2
	2	3	21.41	3.7
Subtotal	2	5	37.08	5.9
Saturday	1	3	13.17	2.0
	2	5	20.12	3.5
	3	1	6.08	1.3
Subtotal	3	9	39.37	6.8

Table: 5Comparison of Results of two Models (Capacity, 4t)

MODEL (1)	MAX.DAILY TRAVEL(km) (2)	MIN.DAILY TRAVEL(km) (3)	MAX. – MIN. (km)
Model –I	39.53	36.22	3.31
Model – II	39.40	35.93	3.47

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NOTATION:

The following symbols are used in this paper:
P = Maximal Daily travel distance in week (km);
Q = Minimal Daily travel distance in week (km);
D_j = Travel distance of route j;

d_k= Number of locations in route k;
S_k = State k, also last location of route k;
$S_{k-1} = S_k - d_k$;
e_{sk} = Cost caused by setting break point at locationS_k;
$f_k(S_k, d_k)$ = Cost of terminating route k at location S_k, with servicing d_k locations;
j = index for each vehicle route obtained after solving standard VRP, j = 1, 2,..., m;
k = index for working days, k = 1, 2,..., 6;
l_k = Lower limit of accumulated load for stage k;
q_j = weekly demand (mass quantity) of location j;
t_j = Time including travel time from locations j -1 to j and loading time at location j;
$tt_{S_{k,depot}}$ = Travel time from location S_k to depot;
u_k = upper limit of accumulated load for stage k;
v = index for institution that requires multiple visits;
o,p = indices for pairs of routes that visit medical institution v;
T = Daily working time limit of vehicle;
W = vehicle capacity
U^v = One of allowable day combinations for institution v;
W^v= Set of routes visiting institution v;
Y_{ik} = 1 when route i is assigned to kth working day and 0 when route i is not assigned to kth working day;
Z_j = Set of indices representing all allowable days for jth route.