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Design of job assignment and routing policies in service logistics

Hizmet lojistiğinde iş atama ve rotalama politikaları tasarımı

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Absract

In this study, we consider to improve efficiency of an after-sales technical service in home appliances industry. The efficiency measure is the total time spent in a day to serve customer requests. Hence, the objective is to minimize total working hours spent in a day in the after-sales services. We first analyze the system to identify causes of delays in job completion. Upon findings of our analysis we choose to focus on job assignment and job sequencing to improve efficiency. We propose a mixed integer programming model for the assignment of technicians to jobs and sequencing of jobs for each technician to minimize total time spent in a day. Through this model we solve the problem with expected job durations. We present a numerical study to illustrate the proposed solution procedure.

Keywords: Job assignment, Job routing/sequencing, Mathematical modelling, Mixed integer programming.

Öz

Bu çalışmada, ev aletleri endüstrisinde satış sonrası teknik servisin verimliliğini arttırmayı ele almaktayız. Verimlilik ölçütü, müşteri taleplerini karşılamak üzere harcanan toplam süredir. Böylece, amaç satış sonrası teknik hizmetlerinde harcanan toplam çalışma saatinin en küçüklenmesidir. Öncelikle, işlerin tamamlanmasındaki gecikmenin nedenlerini belirtmek üzere sistemi analiz ettik. Analiz bulgularımız neticesinde verimliliği arttırmak üzere iş atama ve iş sıralamaya odaklanmayı seçtik. Teknisyenleri işlere atayan ve her teknisyen için bir günde harcanan toplam zamanı en aza indirgeyecek şekilde rota belirleyen karışık bir tamsayı programlama modeli önerilmiştir. Bu model ile, iş sürelerinin beklenen değeri için problemi çözmekteyiz. Önerdiğimiz çözüm yöntemini gösterecek bir sayısal çalışma da sunmaktayız.

Anahtar Kelimeler: İş atama, İş rotalama/sıralama, Matematiksel modelleme, Karışık tamsayılı programlama.

1 Introduction

Our focus in this study is the management of after-sales technical services of a company operating in durable consumer goods sector. The company produces and sells variety of home appliances such as white goods (refrigerator, washing machine, dishwasher, etc.), electronic devices (television, notebook etc.), heating and cooling systems (air conditioner, boiler etc.), small house appliances (iron, kitchenware etc.). After-sales services are provided through their authorized technical services (ATS). An ATS employs technicians that are expert at least in one of the product segments.

An ATS is responsible for shipment of products from the retailer store to the location of the customer, installation of the products, training and informing the user, repair, maintenance, and replacement (when repair is not possible). They also provide, upon request, physical and infrastructural survey for suitability of a product for a certain location prior to purchase. Furthermore, an ATS sells supplementary warranty in addition to the manufacturer's warranty.

Providing a satisfactory after-sales service requires a well-planned business operation. In a well-planned business day of the technical service: the right amount of jobs is assigned to right technicians, the technicians are equipped properly (right spare parts in right amounts), the most time-efficient job sequencing is done and the most time-efficient route is taken between each visit locations, overtimes are minimized and delays in job completions are reduced.

Next, we explain the current process flow implemented in an ATS which is to be improved. There are three ways for a customer to access the technical service: (i) by calling the central call-center, (ii) by calling the local technical service, (iii) by walk-in visit to a technical service. When a customer calls the call center, the representative first asks questions to identify whether the call is for a malfunction or for an installation. If the request is for a malfunction, the representative attempts to diagnose and solve the problem online by applying First Line Support (FLS) process. FLS is an algorithmic process where the representative asks some questions to the customer and based on the answers, the representative instructs the customer to fix the problem by herself. If the problem can be solved via FLS process, no other operation is required. Otherwise, the representative directs the customer call to a proper ATS, regarding product type and the customer's place of residence, notifies the ATS to call the customer. If the customer's request is an installation, the representative promptly assigns this customer call to a proper ATS and notifies the ATS to call the customer. Either when the customer directly calls the ATS or the customer prefers to walk in to the ATS, identical procedures are followed: equipment type, a short description of the problem, the address information are recorded. Based on the collected information ATS plans a visit to the customer's site.

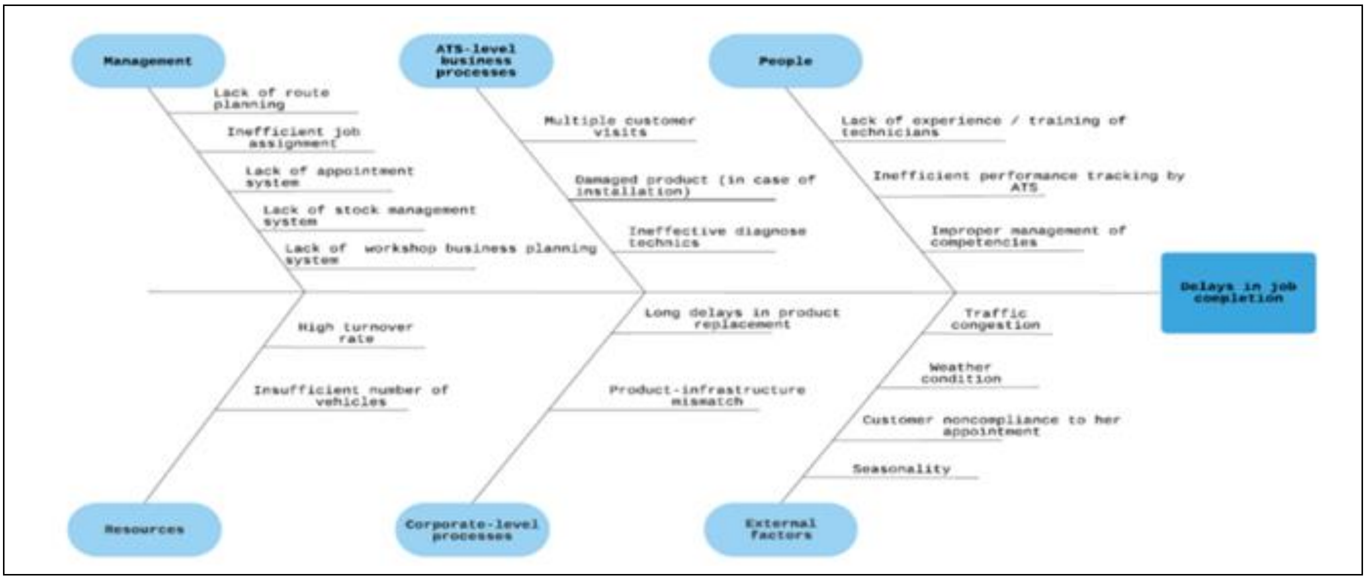

Figure 1: A fishbone representation of causes of delays in job completion.

Before visiting the customer's site, the technician calls the customer for her availability for the visit. The technician visits the customer only if the customer is available. Upon arrival, for malfunctions, the technician first diagnoses the problem. The technician attempts to fix the problem in his first visit. Fixing may require replacement of parts. When the required spare parts are in his mobile stock, the technician repairs the machine and the repair order is closed. However, if he does not have the spare parts in the mobile stock, he checks the availability of that spare part at the ATS's inventory. If the necessary spare parts are available in stock at the ATS, the technician directs the customer to ATS to schedule a new appointment. In case of stockout, the technician informs the ATS to place an order for that spare part and directs the customer to ATS to schedule a new appointment. If the problem cannot be fixed on site, the machine is picked from the site and sent to the workshop.

When the service type is installation, they start installation process as soon as they arrive at the customer's site.

When the customer is not available the technician attempts to reschedule the visit to a new time frame in the same day when the customer declares to be available. In this case, the technician includes that job again into the job list of that shift, reroute the jobs and proceeds with the next customer on the list. When the rescheduling is not possible, he directs the customer to ATS's call center for a new appointment. At the end of the day, technicians return to the ATS and report completion status of job orders.

We visited the ATS to observe the daily operations, business processes and to collect data. We summarize our analysis and findings in a fishbone diagram (see Figure 1). The fishbone diagram specifically depicts and categorizes the causes of delays in job completions.

We categorize causes of delays into six main groups:

<u>1. Management:</u>

1.a. Lack of route planning: Technicians are responsible for the route planning and sequencing of their assigned jobs, and it is done through intuition.

1.b. Inefficient job assignment: Based on their competencies each technician has a responsibility area, and jobs from that area are assigned to the responsible technician based on the competency requirement. Experience or capacity is not considered in assignment.

1.c. Lack of appointment system: ATS intends to make an appointment for their customers based on customer availability. Although the company desires to give an appointment to the customers in 2-hour time slots, they cannot succeed this. The appointment time slots are as 'before noon' and 'after noon', which increases the possibility of not finding the customers at their place, which in return may cause delays in job completions.

1.d. Lack of stock management system: Although there is an excess amount of spare part stock at the ATS they are mostly slow-moving items. For more frequently demanded spare parts they usually are out of stock and they order it from the company when needed. The delivery time of such orders is one or two days, which causes delays in job completion.

1.e. Lack of workshop business planning system: ATS has a single repair shop. The repair shop is mostly overloaded because of disorganization, lack of employee etc.

<u>2. ATS-level business processes:</u>

2.a. Multiple customer visits: The aim of the ATS is to resolve a problem in a single visit. However, often technicians need to visit a customer multiple times due to shortage of spare parts or mismatch of technician expertise with the problem type.

2.b. Damaged product (in case of installation): When a product to be installed is damaged installation cannot be completed. Another visit is required when the product is replaced.

2.c. Ineffective diagnose technics: FLS system cannot be carried out with all customers due to communication problems. Therefore, technicians visit the customer without a prior information, which increases the likelihood of delays.

<u>3. People:</u>

3.a. Lack of experience/training of technicians: Experience and expertise of technicians affects the duration of problem solving.

3.b. Inefficient performance tracking by ATS: The only performance evaluation of the technicians is through a survey of the customers in which customers assess the technician on scale from 0 to 9.

3.c. Improper management of competencies: Technician competencies (diversity and count) do not comply with the demand.

<u>4. Resources:</u>

4.a. High turnover rate: Statistics indicate that experienced technicians tend to quit their jobs to work independently.

4.b. Insufficient number of vehicles: Vehicles used by the technicians to visit the customers do not have backups and may be out of usage due to repair and maintenance.

<u>5. Corporate-level processes:</u>

5.a. Long delays in product replacement: For the end-of-life products, the replacement procedures are very long due to approval procedures.

5.b. Product-infrastructure mismatch: Customer may purchase products which are not compatible with the infrastructure or dimension of their sites. In this case, installation of the products cannot be completed, and the product must be replaced which requires another visit to the customer.

<u>6. External factors:</u>

6.a. Traffic congestion: Traffic congestion affects the transportation time. In case of the technician is late for an appointment due to traffic, the job may be delayed or rescheduled for another day.

6.b. Weather condition: Weather conditions (especially the snow) and natural disasters caused by weather conditions (such as flood) may delay job completions.

6.c. Customer noncompliance to her appointment: When the customer is not available on her site at the scheduled visit time, the job is delayed and may be rescheduled for another day.

6.d. Seasonality: Special dates/events may lead to an increase in demand, which in turn may cause delays in job completions. Sales campaigns, wedding season or Feast of Sacrifice are examples of peak periods.

In this study, we focus on 'management' and 'people' categories.

The contribution of this study is to identify the main causes of delays in job completions at an ATS and to reduce delays in job completion by considering causes identified in management and people, as explained above. Specifically, we provided an optimization model to minimize total time and overtime in a day by deciding on job sequencing and assignment. The rest of this paper is organized as follows: Problem definition and related studies in literature are given in Section 2. The proposed mathematical model is described in Section 3. Experimental study is in Section 4.

2 Problem definition

We start by elaborating our observations in 'management' and 'people' categories, which we will incorporate in our model. Jobs are assigned to technician teams without careful consideration of capacities and locations. Often, during the day, technicians are assigned additional jobs with no consideration of their current locations, but only based on their competencies. Technicians have the liberty to accept or not to accept an additional job assignment during a day. Although it is the responsibility of representatives to plan appointments for the customers and to assign jobs to the technician teams, the technicians sometimes overrides the representatives by communicating with the customers by themselves. Technicians have the responsibility of scheduling and routing of their assigned jobs. It is not rare that technicians ignore factors such as distance, predicted job duration, availability of the necessary tool ware and spare parts stock etc. Such managerial shortcomings play major role in delays in job completions hence, reduce number of jobs completed in a day.

The problem under consideration is a variant of technician routing and scheduling problem. Analogous to the problem herein, the problem faced by maintenance or infrastructure providers are discussed in [1]. They state that the maintenance providers usually try to accomplish a given number of jobs requiring a set of competencies in a working day. The objective of the study is to minimize the sum of total technician routing and outsourcing cost with the help of adaptive large neighborhood search algorithm. Service routing problem of mandatory and optional customers has been studied in [2] when travel times and service times are stochastic. They employ a two-stage approach where the first stage is planning, and the second stage is execution. In [3] technician routing and scheduling problem with multiple time windows and stock control for spare parts for each technician has been studied. The problem is solved by tabu search and adaptive memory methodology. [4] investigates the technician and task scheduling problem by considering outsourcing and precedence constraints. A two-phase constructive heuristic is proposed where teams are constructed in the first phase and tasks are assigned in the second phase. Additionally, an adaptive large neighborhood search heuristic is proposed for the same problem. In [5], authors propose a model for the technician routing and scheduling problem subject to workforce heterogeneity and experience-based learning of technicians. The duration of a service time depends on the technician's experience. The objective is to minimize the makespan in a day.

Constructive heuristics and a genetic algorithm-based meta-heuristic for the field technician scheduling problem to maximize the total priority value of daily service tasks have been proposed in [6]. [7] considers service technician and task scheduling problem with experimental learning and stochastic tasks. An approximate dynamic programming algorithm is developed to minimize the sum of expected daily service durations for a multi-period planning horizon. In [8], authors construct a mixed integer linear programming model for the technician routing and scheduling problem. The objective is to maximize the profit. They consider the availability of spare and special parts, time windows and postponement of tasks.

[9] proposes a metaheuristic to solve technician routing and scheduling problem. The proposed approach is composed of three components: a constructive heuristic, a parallel adaptive large neighborhood search, a post-optimization mechanism. [10] analyzes field technician scheduling problem for telecommunication sector and proposes a greedy heuristic, a local search algorithm, and a greedy randomized adaptive search procedure to solve the problem. All these studies are

beneficial in terms of technician routing, time windows and related issues.

[11] suggests a mixed integer programming model and a branch-and-price algorithm to solve the technician routing and scheduling problem. Technicians have diversified competencies. The technicians are assigned to teams. Teams are assigned to jobs. Routes of teams are determined. [12] studies a team forming, job assignment and routing problem where employees have various skills and experience levels. Three objective functions are to be minimized: sum of job completion times, longest working time between all teams, total employee working time. An optimization model is proposed.

We refer the reader to [13] for a taxonomy for renewable resource-constrained routing and scheduling, including technicians' problems.

Under the light of our observations and the literature, the objective of this study is to minimize the total working hour spent in a day while covering all the jobs assigned through a mathematical model which creates optimal route plan for each technician and optimal job assignment which is consistent with the appointment time of the customer, technicians' competencies, customer location, job durations and appointed time intervals.

3 Mathematical model

We propose our mathematical model to solve the aforementioned problem. The assumptions, sets, parameters, decision variables and the model are presented below:

Assumptions:

- ATS1 is considered as the initial node for each technician in a day and accepted as the first job.
- ATS2 is considered as the final node for each technician in a day and accepted as the last job.
- Since ATS1 and ATS2 are physically the same places, the distance between them is 0.
- When a technician is not assigned to any job in a day, he starts the day at ATS1, covers the virtual route from ATS1 to ATS2 and finishes the day at ATS2.
- Job requests arriving during the day are not attended in the same day.
- There are no time schedules for biological needs, such as lunch break.
- A regular working day is planned to be 10 hours (600 minutes), but overtime is allowed.
- Each job requires only one competency.
- A technician may have more than one competency.
- Competency required for a job can be identified before assigning to a technician.

Set for jobs:

I = {ATS1,1,2,…,m,ATS2}, $i \in I$

Set for technicians:

J = {1,2,3,…,n}, $j \in J$

Set for jobs (identical with I):

K = {ATS1,1,2,…,m,ATS2}, $k \in K$

Set for competencies:

Y = {1,2,3,…,l}, $y \in Y$

Subsets:

I' = {ATS1,1,…,m}

I'' = {1,…,m,ATS2}

I''' = {1,…,m}

K' = {ATS1,1,…,m}

K'' = {1,…,m,ATS2}

K''' = {1,…,m}

Parameters:

$$H_{i,y} = \begin{cases} 1, \text{if job } i \text{ requires competency } y \\ 0, \text{otherwise} \end{cases}$$

$$C_{j,y} = \begin{cases} 1, \text{if technician } j \text{ has competency } y \\ 0, \text{otherwise} \end{cases}$$

D_i = The duration for completing job i

$T_{i,k}$ = The travelling time from job i to job k

S = The regular working hours in a day

E_i = The earliest time at which job i could be started

L_i = The latest time at which job i could be started (Note that $L_i = E_i + \alpha$, where α is the length of the time window allocated for a customer)

p = Penalty coefficient (in case of overtime)

w = Penalty coefficient for postponing a job (in case of incomplete jobs in a day)

Decision Variables:

$$X_{i,j} = \begin{cases} 1, \text{if technician } j \text{ is assigned to job } i \\ 0, \text{otherwise} \end{cases}$$

$$B_{i,k,j} = \begin{cases} 1, \text{if technician } j \text{ covers the route from node } i \text{ to node } k \\ 0, \text{otherwise} \end{cases}$$

V_j = The amount of overtime that technician j works

$F_{i,j}$ = The starting time of job i by technician j

$$R_i = \begin{cases} 1, \text{if job } i \text{ is postponed to the next day} \\ 0, \text{otherwise} \end{cases}$$

$N_{i,j}$ = The finishing time of job i by technician j

$WT_{i,k,j}$ = The waiting time between job i and job k by technician j

The Model:

$$\begin{aligned} \min z = & \sum_{j=1}^{n} \sum_{i=ATS1}^{m} \sum_{k=1}^{ATS2} B_{i,k,j} T_{i,k} \\ & + \sum_{j=1}^{n} \sum_{i=ATS1}^{ATS2} D_i X_{i,j} \\ & + \sum_{i=ATS1}^{ATS2} \sum_{k=ATS1}^{ATS2} \sum_{j=1}^{n} WT_{i,k,j} \\ & + \sum_{j=1}^{n} V_j p + \sum_{i=1}^{m} R_i w \end{aligned} \tag{1}$$

subject to;

Assignment constraints:

$$\sum_{i=ATS1}^{ATS2} X_{i,j} \geq 2; \forall j \quad (2)$$

$$X_{i,j} - \sum_{y=1}^{l} C_{j,y} H_{i,y} \leq 0; \forall j, \forall i \in I''' \quad (3)$$

$$\sum_{j=1}^{n} X_{i,j} + R_i = 1; \forall i \in I''' \quad (4)$$

$$X_{ATS1,j} = 1; \forall j \quad (5)$$

$$X_{ATS2,j} = 1; \forall j \quad (6)$$

Routing constraints:

$$\sum_{k=1}^{ATS2} B_{ATS1,k,j} = 1; \forall j \quad (7)$$

$$\sum_{i=1}^{ATS2} B_{i,ATS1,j} = 0; \forall j \quad (8)$$

$$\sum_{i=ATS1}^{m} B_{i,ATS2,j} = 1; \forall j \quad (9)$$

$$\sum_{k=ATS11}^{m} B_{ATS2,k,j} = 0; \forall j \quad (10)$$

$$\sum_{i=ATS1}^{m} B_{i,k,j} - \sum_{i=1}^{ATS2} B_{k,i,j} = 0; \forall j, \forall k \in K'''(i \neq k) \quad (11)$$

Assignment-Routing constraints:

$$\sum_{i=1}^{ATS2} B_{k,i,j} - X_{k,j} = 0; \forall j, \forall k \in K'''(i \neq k) \quad (12)$$

$$B_{k,i,j} + B_{i,k,j} \leq 1; \forall j, \forall i \in I', \forall k \in K'' \quad (13)$$

$$\sum_{i=ATS1}^{m} B_{i,k,j} - X_{k,j} = 0; \forall j, \forall k \in K'''(i \neq k) \quad (14)$$

$$X_{i,j} + B_{ATS1,ATS2,j} \leq 1; \forall j, \forall i \in I''' \quad (15)$$

Overtime constraints:

$$V_j - N_{ATS2,j} + S \geq 0; \forall j \quad (16)$$

Appointment constraints:

$$F_{i,j} - E_i X_{i,j} \geq 0; \forall j, \forall i \in I''' \quad (17)$$

$$F_{i,j} - L_i X_{i,j} \leq 0; \forall j, \forall i \in I''' \quad (18)$$

$$F_{ATS1,j} = 0; \forall j \quad (19)$$

Arriving-Leaving-Waiting constraints:

$$F_{i,j} + D_i X_{i,j} + T_{i,k} - M(1 - B_{i,k,j}) - F_{k,j} \leq 0; \forall i, \forall k, \forall j \quad (20)$$

$$N_{i,j} - F_{i,j} + D_i X_{i,j} = 0; \forall i, \forall k, \forall j \quad (21)$$

$$F_{k,j} - N_{i,j} - B_{i,k,j} T_{i,k} - M(1 - B_{i,k,j}) - WT_{i,k,j} \leq 0; \forall i, \forall k, \forall j, (i \neq k) \quad (22)$$

Sign restrictions:

$$V_j \geq 0; \forall j \quad (23)$$

$$F_{i,j}; N_{i,j} \geq 0; \forall i, \forall j \quad (24)$$

$$WT_{i,k,j} \geq 0; \forall i, \forall k, \forall j \quad (25)$$

$$R_i \in \{0,1\}; \forall i \quad (26)$$

$$X_{i,j} \in \{0,1\}; \forall i, \forall j \quad (27)$$

$$B_{i,k,j} \in \{0,1\}; \forall i, \forall k, \forall j \quad (28)$$

In the objective function (1), total time spent in a day and the penalties due to overtime working and postponing jobs from the present day's list to the job list of the next day are to be minimized. Total time of the completed jobs includes three components: transportation time, time on the job and idle time for technicians (due to appointment windows).

Jobs must be assigned to technicians. While constraint (2) assigns at least 2 jobs to each technician, constraint (5) and constraint (6) ensure that those 2 jobs are ATS1 and ATS2 (starting and ending nodes for all job sequences). Constraint (3) ensures that the technician to be assigned to a job has the required competency *y*. Constraint (4) guarantees that every job will be in the job list of a technician or will be postponed to the next day.

Constraints (7), (8), (9) and (10) are to make sure that every job schedule starts with ATS1 and ends with ATS2. The constraint (11) is a flow balance constraint to make sure that a technician j who takes the route from node i to node k must take another route from node k to any other node, except node i.

Constraints (12), (13), and (14) are to associate job sequencing with job assignments. Such that, (12) assigns technician j to job k if technician j is assigned to the route from node k to node i. Likewise, constraint (14) assigns technician j to job k if technician j is assigned to the route from node i to node k. Constraint (13) serves the purpose of eliminating backward movement of each technician. Constraint (15) ensures that if there is a technician j assigned for a job i, that technician j cannot be assigned to the route from ATS1 to ATS2 directly.

We want to minimize overtime hours in a day for which we have constraints (16) and (23). Through these constraints, it is ensured that overtime related decision variable (Vj) is set to be 0 for a technician j if the total time the technician j spends in a day is less than or equal to the daily regular working time; else, (Vj) gets the value by subtracting the daily regular working time from the total time the technician j spends in a day.

Constraints (17) and (18) guarantee that every job will be attended in the allocated time window. Constraint (19) is to set that each technician starts his tour in ATS1 at time zero. Constraint (20) sets up the relation between starting times of consecutive jobs. Constraint (21) defines the finishing time of job i assigned to technician j by adding up the duration of job i to starting time of job i. Waiting time for a technician j before he starts job k is calculated by summing up the finishing time of previous job i and the travelling time between job i and job k and subtracting the value from starting time of the job k if waiting time occurs by constraint (22). The remaining constraints are for sign restrictions.

4 Experimental study

In order both to illustrate and validate the above model we use two sets of experiments. We use CPLEX solver in GAMS software for solving the experiments. We design various business scenarios by changing some of the parameters which may represent tactical level management decisions. We observe solution sensitivity to those parameters. The tactical level managerial decisions we consider are (i) the number of technicians to be employed, (ii) the competency distribution of technicians, and (iii) the length of time window to serve the customers.

5 Experimental Set #1

In this experimental set we assume that there are 20 jobs and 3 technicians, i.e. m=20, n=3. All technicians are available to work 600 minutes in a day in regular time, S=600. Earliest start time of each job I (E_i), duration for completing each job i (D_i), competency requirement for the jobs ($H_{i,y}$), transit time among each job location pair ($T_{i,k}$) are depicted in Tables 1.a - 1.d. Note that transit times in Table 1d are symmetric.

The cardinality of sets and subsets of the experimental setting are as follows: $|I| = 22, |J| = 3, |K| = 3, |Y| = 9, |I'| = 21, |I''| = 21, |I'''| = 20, |K'| = 21, |K''| = 21, |K'''| = 20$. Hence, the model has 4,310 constraints with 1,540 binary and 1,521 non-negative continuous decision variables.

We generate four different scenarios by varying the length of the appointment time windows, α, and competency distribution of technicians, $C_{j,y}$. Appointment time windows for the customers is 120 minutes, α=120, in scenarios 1 and 3, and is 240 minutes, α=240, in scenarios 2 and 4. In scenarios 1 and 2 technicians have limited number of competencies (competencies are distributed randomly among them), whereas in scenarios 3 and 4, all technician have all the competencies (full competency). These scenario variants are summarized in Table 2.

Table 1a: Earliest start time of jobs (in minutes).

i	E_i	i	E_i	i	E_i	i	E_i
J1	60	J6	560	J11	180	J16	300
J2	120	J7	360	J12	120	J17	60
J3	180	J8	420	J13	60	J18	420
J4	120	J9	120	J14	240	J19	360
J5	240	J10	240	J15	180	J20	300

Table 1b: Duration for completing jobs (in minutes).

i	D_i	i	D_i	i	D_i	i	D_i
ATS1	60	J6	24	J12	17	J18	13
J1	18	J7	17	J13	12	J19	19
J2	18	J8	12	J14	18	J20	16
J3	15	J9	11	J15	15	ATS2	30
J4	19	J10	13	J16	17		
J5	39	J11	11	J17	19		

Table 1c: Competency requirement for jobs, $H_{i,y}$.

	1	2	3	4	5	6	7	8	9
J1		1							
J2				1					
J3			1						
J4		1							
J5								1	
J6									1
J7		1							
J8	1								
J9				1					
J10	1								
J11			1						
J12		1							
J13	1								
J14	1								
J15		1							
J16			1						
J17	1								
J18	1								
J19	1								
J20	1								

Table 1d: Transit time among each job location pair, $T_{i,k}$.

	ATS1	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J17	J18	J19	J20	ATS2
ATS1	0.0	4.7	3.5	3.0	5.0	4.6	1.3	0.4	3.9	4.5	1.5	3.2	3.6	4.8	5.4	1.4	4.0	0.9	0.1	3.2	1.5	0.0
J1		0.0	2.2	1.8	2.9	1.1	3.8	5.0	2.8	0.2	5.5	3.3	1.4	0.9	2.8	3.4	3.6	5.0	4.7	1.6	3.3	4.7
J2			0.0	1.3	1.6	1.4	2.3	3.7	0.8	2.0	3.8	1.1	2.3	1.7	1.9	2.1	1.5	3.4	3.5	2.1	2.7	3.5
J3				0.0	2.8	1.7	2.1	3.3	2.0	1.5	3.7	2.0	1.2	1.8	2.9	1.7	2.7	3.2	3.0	0.9	1.7	3.0
J4					0.0	1.8	3.7	5.2	1.2	2.9	5.0	1.9	3.6	2.1	0.5	3.7	1.4	4.8	5.0	3.5	4.3	5.0
J5						0.0	3.5	4.9	1.9	1.1	5.1	2.5	2.0	0.3	1.7	3.2	2.6	4.7	4.6	2.1	3.4	4.6
J6							0.0	1.5	2.6	3.6	1.7	1.9	3.0	3.7	4.1	0.5	2.7	1.2	1.3	2.6	1.5	1.3
J7								0.0	4.0	4.8	1.2	3.3	3.9	5.0	5.5	1.6	4.1	0.7	0.3	3.6	1.9	0.4
J8									0.0	2.7	3.9	0.8	3.0	2.2	1.5	2.6	0.8	3.6	3.9	2.9	3.3	3.9
J9										0.0	5.3	3.1	1.2	0.9	2.7	3.2	3.4	4.7	4.5	1.4	3.0	4.5
J10											0.0	3.1	4.6	5.4	5.4	2.1	3.7	0.6	1.4	4.3	2.8	1.5
J11												0.0	3.1	2.7	2.4	2.0	0.9	2.9	3.2	2.9	2.8	3.2
J12													0.0	2.0	3.6	2.5	3.8	4.0	3.6	0.4	2.0	3.6
J13														0.0	1.9	3.4	2.9	4.9	4.8	2.1	3.5	4.8
J14															0.0	4.0	1.9	5.2	5.4	3.6	4.5	5.4
J15																0.0	2.8	1.6	1.4	2.2	1.0	1.4
J16																	0.0	3.6	4.0	3.6	3.7	4.0
J17																		0.0	0.8	3.7	2.2	0.9
J18																			0.0	3.3	1.6	0.1
J19																				0.0	1.7	3.2
J20																					0.0	1.5
ATS2																						0.0

Table 2: Scenario variations in experimental set #1.

Scenarios	Competency distribution of technicians	α
S1	Random (Limited)	120 min.
S2	Random (Limited)	240 min.
S3	Full	120 min.
S4	Full	240 min.

We compare each scenario in terms of 'Number of jobs completed', 'Time spent by technicians', 'Overtime of technicians', 'Idle time of technicians', 'Objective function value', and 'Total man-hour spent' in Table 3.

Solution to the scenarios indicate that all jobs are completed in a single business day. In Scenarios 1 and 2, all technicians have certain workload as completed jobs, however in Scenarios 3 and 4 all jobs are completed by only one of the technicians. This is due to the competency distribution of technicians. If technicians acquire all the competencies single technician would suffice under this setting. Two of the technicians spend 90 minutes for ATS chores but they are not assigned any jobs. One counterintuitive observation is that when the appointment time window for the customers is shorter, overtime is required to complete jobs and also idle time (waiting time between customer visits) of the technicians increases. This is due to the fact that when the time window is shorter the number of appointments in the same window must be less, which, in turn, reduces the flexibility of the technicians. Having shorter appointment time windows increases customer satisfaction but obviously decreases the efficiency of the technicians. Note that in Table 3, objective function value incorporates both the total man-hour spend by the technicians and penalties for overtime and job postponement. The model herein generates the optimal sequencing and allocation of jobs when the parameters in Tables 1.a-1.d are given. However, the model we provide may be useful for tactical level decision making through scenario analysis as illustrated.

6 Experimental Set #2

For our second experimental set the number of jobs is 111, m=111, the number of technicians is 13, n=13, and appointment time window for the customers is 24 hours, α=1440. Our construct has three scenarios. The competency level of technicians is the differentiating input in these scenarios. We run the model for the identical jobs and the different competency levels for technicians. We expect to detect the effect of competency level on the objective function and total man-hour spent. In Scenario 1, technicians have competencies which they currently have in the considered ATS. In Scenario 2, each technician has all competencies. In Scenario 3, each technician has 2 competencies. However, we apply a condition that any technician cannot have such 2 competencies that are mostly demanded in a day. We come up with a result that such a competency distribution plan has no significant effect on the objective function value. It is just worth to indicate that the best-case scenario is the one in which each technician has all competencies. The detailed results are shown in Table 4.

Table 3: Outputs of experimental set #1.

	Total (Tech1, Tech2, Tech3)			
Outputs	S1	S2	S3	S4
Number of jobs completed	20(10,5,5)	20(10,5,5)	20(0,0,20)	20(20,0,0)
Time spent by technicians	1,358(600,351,407)	1,193(555,291,347)	780(90,90,600)	748(568, 90,90)
Overtime of technicians	15(15,0,0)	0	15(0,0,15)	0
Idle time of technicians	698(335, 145,217)	516(269, 89,157)	145(0,0, 145)	101(101,0,0)
Objective function	1,680	1,194	1,102	748
Total man-hour spent	1,373	1,194	795	748

Table 4: Outputs of experimental set #2.

Scenario	Output	Technician													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	Total
S1	Number of jobs completed	0	1	0	0	33	0	32	7	4	32	0	0	2	111
	Time spent by technician	90	136	90	90	600	90	597	324	394	595	90	90	194	3381
	Overtime of technician	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Objective function	3381													
	Total man-hour spent	3381													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	Total
S2	Number of jobs completed	0	0	21	26	20	0	0	0	0	0	22	22	0	111
	Time spent by technician	90	90	421	563	518	90	90	90	90	90	571	562	90	3355
	Overtime of technician	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Objective function	3355													
	Total man-hour spent	3355													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	Total
S3	Number of jobs completed	18	6	30	0	0	5	0	7	13	0	0	29	3	111
	Time spent by technician	428	181	588	90	90	211	90	391	361	90	90	600	193	3404
	Overtime of technician	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Objective function	3404													
	Total man-hour spent	3404													

5 Conclusion

By the help of this study, ATSs would serve customers with an optimal route planning and job assignment system which results in decreasing delays in job completion. This improvement in the service would increase the customer satisfaction and the customers would become more loyal to the brand. They would opt more products of the brand and they would need more after sales services from the ATSs. ATSs would keep providing better service with a proper planning provided by the proposed model.

Regarding managerial insights, the managers can observe the trade-off between different competency levels by the help of the proposed solution method. New technicians may be employed based on the analysis and training can be arranged accordingly. The managers can evaluate different scenarios and decide on the investment necessary for training technicians. They can also analyze the effect of different time slot for appointments on customers.

In terms of future research directions, a dynamic programming algorithm can be developed. The proposed solution approach solves the problem at the beginning of each day in a static manner based on predicted durations. However, actual and

predicted durations can be different. An algorithm to update the solution based on the actual realizations of job completion times would be more realistic. Then, the technicians would be able to change their planned customer visit route if necessary.
Another study could be developing a dashboard type of user interface which would make the company to use the proposed solution methodology easier. The company would use that decision support system platform by only introducing the number and type of jobs, the number and competencies of technicians in the ATS and customer related data and obtain the outputs in a daily fashion.

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