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THESIS

MONTEREY BAY AQUARIUM VOLUNTEER GUIDE SCHEDULING ANALYSIS

by

Philip S. Baxa

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Thesis Advisor:	Bard K. Mansager
Second Reader:	Carlos F. Borges

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13. ABSTRACT (maximum 200 words)

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No formal analysis has been previously completed to optimize guide scheduling based on existing constraints. Currently, the guide schedule is manually generated; however, last minute no-shows or drop-ins often prevent an optimal schedule from being generated. This thesis established target staffing levels for each shift based on requirements developed by the guide program managers.

Additionally, this thesis seeks to optimize the guides' scheduled rotation during their shift. While the guide program managers have done an excellent job using heuristic methods to develop nearly optimal schedules, they have not been able to incorporate methods that minimize the time that is lost by guides transiting from station to station. This thesis analyzed and developed guide schedules that minimize the time spent transiting between stations. The guide schedule was modeled as a multicommodity flow network and solved with linear programing.

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MONTEREY BAY AQUARIUM VOLUNTEER GUIDE SCHEDULING ANALYSIS

Philip S. Baxa
Lieutenant, United States Coast Guard
B.S. United States Coast Guard Academy, 2006

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December 2014

Author: Philip S. Baxa

Approved by: Bard K. Mansager
Thesis Advisor

Carlos F. Borges
Second Reader

Craig W. Rasmussen
Chair, Department of Applied Mathematics

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AV	wetlands/aviary
BRK	break
GAMS	General Algebraic Modeling System
GRT	greeter
KTP	kelp touch pool
MBA	Monterey Bay Aquarium
MMC	marine mammal cart
PYP	play your part
SFT	soft station
TD	tiny drifters
TP	touch pool
USCG	United States Coast Guard

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I. INTRODUCTION

A. THE MONTEREY BAY AQUARIUM

The Monterey Bay Aquarium (MBA) was founded in 1984 and hosts nearly two million visitors each year. The mission of the Monterey Bay Aquarium is to inspire conservation of the oceans. It does this through education outreach, exhibits, research and conservation, and by rehabilitating injured ocean wildlife. The Aquarium has a large and diverse staff that includes aquarists, scientific divers, administrators, and veterinarians. In addition to the paid staff, there are over one-thousand volunteers who are critical to Aquarium operations. Volunteers fill many roles that include Aquarium guides, information desk attendants, divers, and animal caregivers. Julie Packard, Executive Director of the Monterey Bay Aquarium, writes in the *MBA Volunteer Handbook*:

> The hundreds of volunteers who have contributed their time and talents to our institution over the years have been absolutely instrumental to our success. Whether sharing the secrets of kelp forest animals with a first-time visitor or assisting behind-the-scenes to maintain our exhibits, your work as a volunteer will directly contribute to our mission to inspire conservation of the oceans. (Monterey Bay Aquarium [MBA], 2009)

B. OVERVIEW OF THE MONTEREY BAY AQUARIUM GUIDE PROGRAM

The largest group of volunteers are the Aquarium guides. According to the *MBA Volunteer Handbook*, guides “interpret Aquarium exhibits and galleries for Aquarium guests” (MBA, 2009). The stations staffed by guides are divided into two types: soft and hard. Soft stations are not required to be staffed at any given time. Hard stations are required to be staffed the entire time the Aquarium is open to the public. A guide is assigned to a station for 30 minutes and then rotates to a different station. Some stations, such as the touch pools, are considerably more demanding and stressful than others.

I discussed the impact of touch pools on the guides with Pamela Byrnes, an Aquarium staff member who works alongside the guides to interpret the exhibits. She described the touch pools as the stations with the highest guest traffic. Guests are encouraged to visit these stations to see and touch many of the animals featured in the giant Aquarium habitats. These stations offer guides many opportunities for positive and meaningful guest interactions and demand the guides' utmost attention. The guides are responsible for ensuring the well-being of not only the guests but also the animals that the guests are handling. Further stressing the guides are the physical conditions at the station; the station requires the guides to put their hands into cold water that is about 15.5 degrees Celsius. The challenge is to assign guides to the touch pools enough times that they feel that they have a meaningful volunteer experience, but not so many times that they become burned-out by the station (P. Byrnes, personal communciation, April 5, 2014).

Each day is divided into volunteer shifts that are led by a shift captain. Weekdays are divided into three shifts, whereas weekends are divided into two shifts. The shifts last between three to four hours and each are staffed with 11 to 20+ guides. The shift captain uses their best-judgment to create a watch-schedule that equitably assigns guides to stations in the Aquarium. The shift captain has to meet several constraints that include hard station staffing requirements, special exhibit presentations, lunch-breaks, etc. Prior to the shift, the shift captain is told how many volunteers will be present; however, there is always a possibility of last minute no-shows or drop-ins to a shift. The shift captain uses the predicted supply of volunteers to generate the guide schedule. The guide program managers are paid staff who provide feedback to the shift captains ensuring that each shift meets station staffing priorities and are the primary contact for data pertaining to this project and the project's primary stakeholder.

C. CONTRIBUTION OF THESIS

The purpose of this thesis is to optimize guide scheduling. No formal analysis has been previously completed to optimize guide scheduling based on existing constraints. Currently, the shift captain manually generates the guide schedule using best-practices shared between shift captains. However, last minute no-shows or drop-ins often prevent the shift captain from generating an optimal schedule. This thesis will attempt to streamline the scheduling process and develop target staffing for each shift based on requirements developed by the guide program managers. This thesis will further analyze the resiliency of the shifts to changes in staffing levels caused by no-shows or drop-ins.

While the guide program managers have done an excellent job using heuristic methods to develop nearly optimal schedules, they have not been able to incorporate methods that minimize the time spent by guides transiting from station to station. The transit times between stations vary due to distance, the number of guests in the Aquarium, and whether a guest stops a guide to ask him or her a question. Guides value being relieved on time at a station, particularly if it is a high stress station. The guest experience suffers when guides are fatigued, are constantly checking their watch, or get visibly frustrated with their relief if they feel the relief was not there in a timely manner. Minimizing the transit times therefore increases the likelihood that the guides are going to be relieved on time and improves the guest experience. This thesis will seek to develop guide schedules that minimize the time spent transiting between stations.

In the next chapter, we will examine how this scheduling scenario can be modeled as a network and solved using linear programing.

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II. PROBLEM FORMULATION

A. OVERVIEW OF NETWORK DESIGN AND LINEAR PROGRAMMING TECHNIQUES APPROPRIATE FOR THIS PROBLEM

A network is composed of nodes and edges, and is a useful way of modeling many real world problems. According to Winston, "an [edge] consists of an ordered pair of [nodes] and represent a possible direction of motion that may occur between [nodes]" (2004, p. 413). For example, a city map could be represented as a network. Nodes might represent locations on the map and edges between nodes would represent streets connecting the different locations. There are many types of network problems that include finding the shortest path or multicommodity flows. This thesis shall use multicommodity minimum cost flow to model guide scheduling. According to Ahuja, Magnanti, and Orlin, "We wish to determine a least cost shipment of a commodity through a network in order to satisfy demands at certain nodes from available supplies at other nodes" (1993, p. 4).

Ahuja et al. (1993) continues by describing the basic elements of a minimum cost flow model which is summarized as follows: Let $G = (N, E)$ be a directed network defined by a set N of n nodes and as a set E of m directed edges. Each edge has an associated cost (c_{ij}) that indicates the cost per unit flow on that edge. Each edge has a lower bound (l_{ij}) and upper bound (u_{ij}) indicated the minimum and maximum flow across the edge. Each node i that is an element of N has an integer $b(i)$ representing its supply or demand. If $b(i)$ is positive it is a supply node; if $b(i)$ is negative it is a demand node, if $b(i) = 0$, flow does not stop at that node and simply moves through. The decision variables are arc flows, and flow between nodes i and j is represented as y_{ij}. The general minimum cost flow model can be written in standard form as a linear program as shown in Figure 1.

$$\text{Minimize:} \quad \sum_{(i,j)\in Edges} y_{ij} c_{ij} \tag{1}$$

Subject to:

$$\sum_{\{j\,(i,j)\in Edges\}} y_{ij} - \sum_{\{j:(j,i)\in Edges\}} y_{ji} = b(i) \quad \forall i \in Nodes \tag{2}$$

$$l_{ij} \le y_{ij} \le u_{ij} \quad \forall (i,j) \in Edges \tag{3}$$

$$y_{ij} \in Z^{+} \quad \forall (i,j) \in Edges \tag{4}$$

Figure 1. Minimum cost flow network linear equations.

Equation 1 is the objective function that minimizes the total flow over the network. Equation 2 is the network flow constraint where the total flow into a node minus the total flow out of the node is equal to the demand at that node. Equation 3 is the lower and upper bound constraints on the flow over the edges in the network. Equation 4 limits the flow to non-negative integers.

The minimum cost flow model however, is not robust enough to for this scenario. The minimum cost flow model only succeeds at tracking a single commodity. A multicommodity flow model is therefore appropriate for this scenario. According to Ahuja el al.:

> Multicommodity flow problems arise when several commodities use the same underlying network. The commodities may either be differentiated by their physical characteristics or simply by their origin-destination pairs. Different commodities have different origins and destinations, and commodities have separate mass balance constraints at each node. However, the sharing of the common arc capacities binds the different commodities together. In fact, the essential issue addressed by the multicommodity flow problem is that allocation of the capacity of each arc to the individual commodities in a way that minimized overall flow costs. (Ahuja el al., 1993, p. 8)

The model for the guide scenario will need to be able to track the movements of individual guides through the system. The set of *K* commodities, each representing a guide, are added to the original minimum cost flow model and the original formulation changes to the linear program in Figure 2 to accommodate the tracking of multiple commodities.

$$\text{Minimize:} \quad \sum_{k} \sum_{(i,j)\in Edges} y_{ij}^{(k)} c_{ij}^{(k)} \qquad (1)$$

Subject to:

$$\sum_{\{j:(i,j)\in Edges\}} y_{ij}^{(k)} - \sum_{\{j\,(j,i)\in Edges\}} y_{ji}^{(k)} = b^{(k)} \quad \forall k, \quad \forall i \in Nodes \qquad (2)$$

$$l_{ij} \le \sum_{k} y_{ij}^{(k)} \le u_{ij} \quad \forall (i,j) \in Edges \qquad (3)$$

$$y_{ij}^{(k)} \in \mathrm{Z}^{+} \qquad \forall k, \forall (i,j) \in Edges \qquad (4)$$

Figure 2. Multicommodity flow network linear equations.

Equation 1 is the objective function that minimizes the total flow of each commodity over the network. Equation 2 is the network flow constraint where the total flow of a particular commodity into a node minus the total flow of a particular commodity out of the node is equal to the demand of that particular commodity at that node. Equation 3 is the lower and upper bound constraints on the flow of the sum of all commodities over the edges in the network. Equation 4 limits the flow of each commodity to non-negative integers.

There are several algorithms that can solve the minimum cost flow model. Since this is a linear program, the simplex method is good candidate. Branches and bounds will be added to the algorithm to accommodate the integer constraint.

The software selected for this project is the General Algebraic Modeling System (GAMS) (GAMS Development Corp, 2014). GAMS is a free software package that allows for robust linear programing with repeatable results.

B. MODEL THE VOLUNTEER GUIDE SHIFT AS A NETWORK

The Monterey Bay Aquarium has 33 stations that are staffed by guides. The first 11 stations listed in Table 1 are hard stations, the remaining stations are soft stations (MBA, 2014b).

Table 1. List of all guide stations.

1	touch pool 1	17	open sea
2	touch pool 2	18	monterey bay habitats
3	kelp touch pool 1	19	nature center (on busy days)
4	kelp touch pool 2	21	greeter2/play your part 2 (top of the escalator)
5	kelp touch pool 3	22	drifters galleries
6	tiny drifters (live plankton)	23	ocean travelers (puffins, plastics and deck)
7	wetlands/aviary 1	24	splash zone—rocky shore, coral reef kingdom
8	play your part	25	sandy seafloor
9	wetlands/aviary 2	26	octopus/deep reef
10	greeter (main entry)	27	coastal stream/waves and tides (rocky shore)
11	marine mammal cart	28	enchanted kelp forest
12	today on the bay 1	29	sea otter exhibit
13	kelp touch pool 4	30	boiler/ cannery row exhibit
14	touch pool 3	31	shale reef/wharf
15	tentacles	32	jellies experience
16	kelp forest	33	break

An initial starting point might be to call each station a node. It is helpful to overlay these nodes on a map of the Aquarium to get an idea of the relationship between the nodes. Figure 3 is a map of the Aquarium with all the guide stations appearing as red dots.

It initially makes sense to simply connect each node to every node except itself to indicate that a guide rotating from one station can move to any other station in the network. Since there are a total of 33 stations, each guide has 32 options. Applying this to each node, the network quickly balloons to 1,056 edges. Since time layering will need to be applied to the model to reflect the several rotations that take place during the shift, the model grows into something that is not very intuitive. This begs the question, how is it that shift captains have been able to do this intuitively?

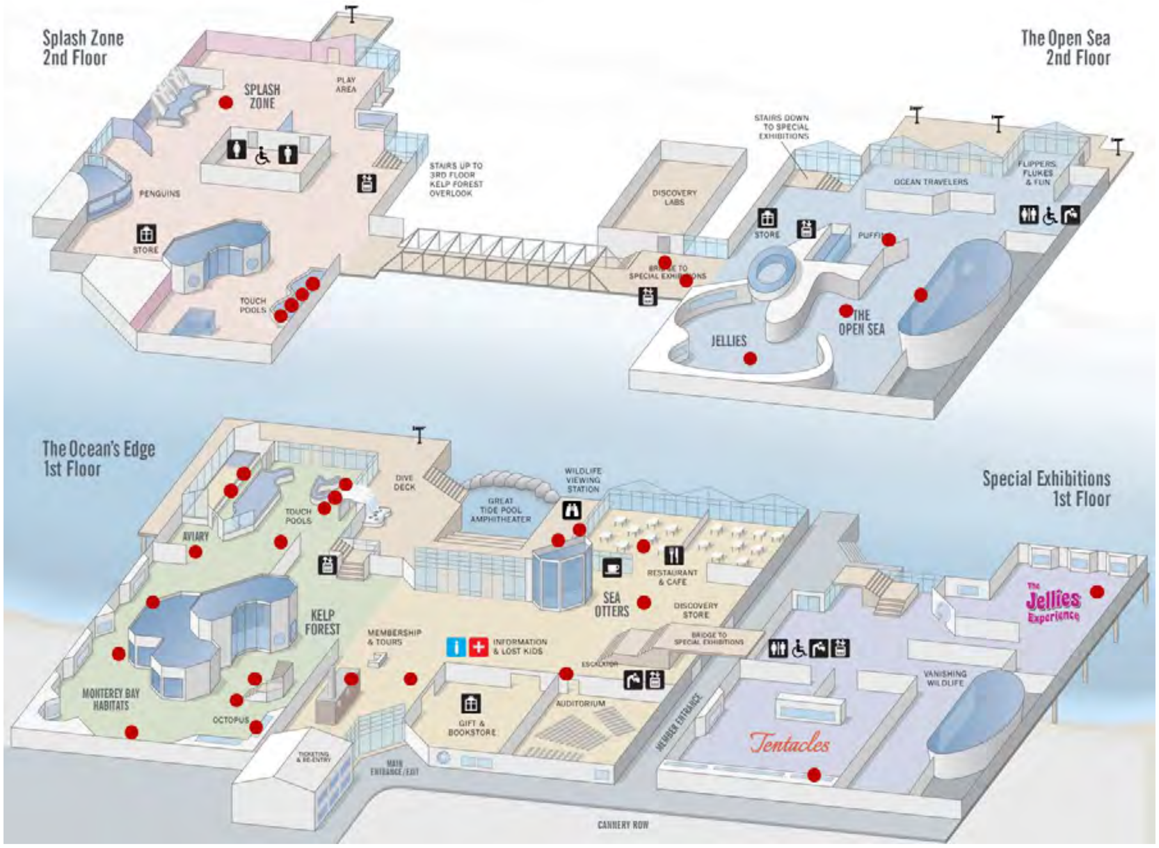

Figure 3. Map of the Monterey Bay Aquarium with dots representing the guide stations (after MBA, 2014a).

Closer examination reveals that the model can be simplified. Note that several of the nodes appear to be clustered together. For example, the four stations at the kelp touch pool can be combined into one kelp touch pool station. Also recall that soft stations are not required to be staffed. Thus all hard stations with multiplicity greater than one can be combined into a single node, and all the soft stations can be combined into a single node. Thus the graph of 33 nodes can be reduced to nine nodes as shown in Figure 4.

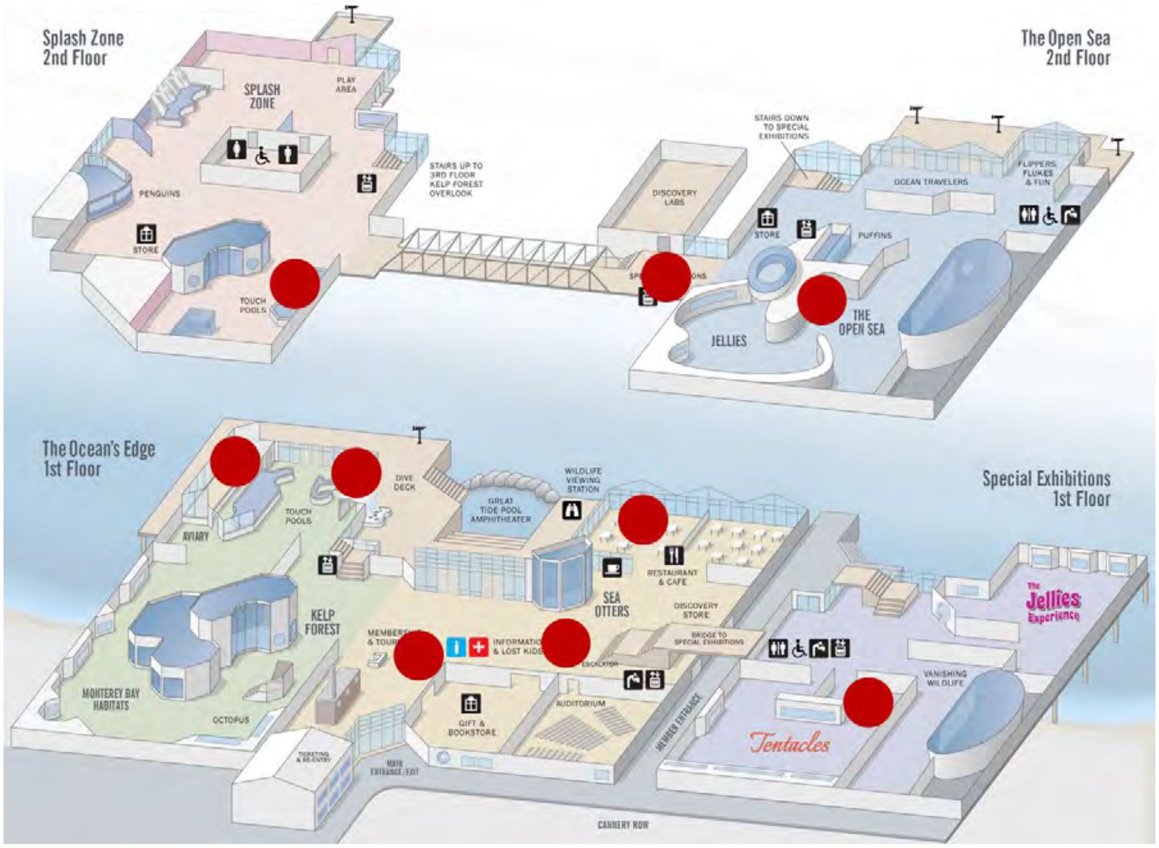

Figure 4. Map of the Monterey Bay Aquarium with groupings representing the guide stations (after MBA, 2014a).

Using our previous logic, the graph thatcan be created where every node is connected to every other node except itself now only has 72 edges, which is much more manageable. This reduction of the graph to just these critical elements will not hamper future analysis and still allows an examination of minimal staffing as well as developing schedules that minimize time spent transiting between stations. In addition to these elements, dummy nodes will be added to the model to track guide movements through the model.

The notion of a dummy node may sound silly, but in reality they add robustness to the model. There will be start and end nodes added as dummy nodes. There will be a dummy arc connecting the end node to the start node which will track the total number of guides that move through the network. The network will be divided into several levels, where each level will represent a 30-minute period in time with one being the first period two being the second and so on. Weekday models will have six levels and weekend models will have eight levels. Each level will have a series of nodes. Each hard and soft station will be node, and a break node will only be added to the weekend model. Table 2 lists the potential nodes in one level of the model.

Table 2. List of volunteer guide stations represented as nodes in a network.

Station Full Name	Node Abbreviation
touch pool	TP
kelp touch pool	KTP
tiny drifters	TD
wetlands/aviary	AV
play your part	PYP
greeter	GRT
marine mammal cart	MMC
soft	SFT
break	BRK

The model will drive flow using lower and upper bounds on the edges. Node splitting will create additional dummy nodes, and will add critical edges that will drive the flow. We split each node on each level into two nodes; call the first node by the node abbreviation and the second node the abbreviation-prime. Recall that there were several stations that required more than one guide to staff them. The requirement for multiple individuals at these stations will be managed with lower bounds. For example, in Table 3, the touch pool station needs a minimum of two individuals but up to three individuals can staff that station. Also note that edges between split hard stations with only a single individual will have a lower bound of one and an upper bound of one. The edges between soft stations and break nodes are non-negative but otherwise unrestricted.

Table 3. List of edges in one level of the network model.

Start Edge	End Edge	Lower/Upper Bound
TP	TPp	2/3
KTP	KTPp	3/4
TD	TDp	1/1
AV	AVp	2/2
PYP	PYPp	1/1
GRT	GRT p	1/1
MMC	MMCp	1/1
SFT	SFTp	0/∞
BRK	BRKp	0/∞

Each prime node, with the expectation of the SFTp node, in a level will connect to every non-prime node in the level above it with the exception of connecting to itself. The SFTp node will connect to every non-prime node in the level above it including itself. The bounds on these edges will be non-negative. This will force the guide to change stations between each level. An illustration of how the level one touch pool (1TP) will be connected to the level above is shown in Table 4.

Table 4. List of edges between touch pool in level one to all nodes it is connected to in level two.

Start Node	End Node	Lower/Upper Bound
1TPp	2KTP	0/∞
1TPp	2TD	0/∞
1TPp	2AV	0/∞
1TPp	2PYP	0/∞
1TPp	2GRT	0/∞
1TPp	2MMC	0/∞
1TPp	2SFT	0/∞

The cost values on the edges shall all initially be zero when building the model. To keep track of what station an individual guide is working at, we introduce the set K representing the guides. These guides will be the initial supply starting at the start node. To complete the network, we connect the start node to every non-prime node in the initial level and connect every prime node in the final level to the end node. For ease of display a model of the complete network with only two levels is shown in Figure 5. The full model will have six levels for weekdays and eight levels for weekends.

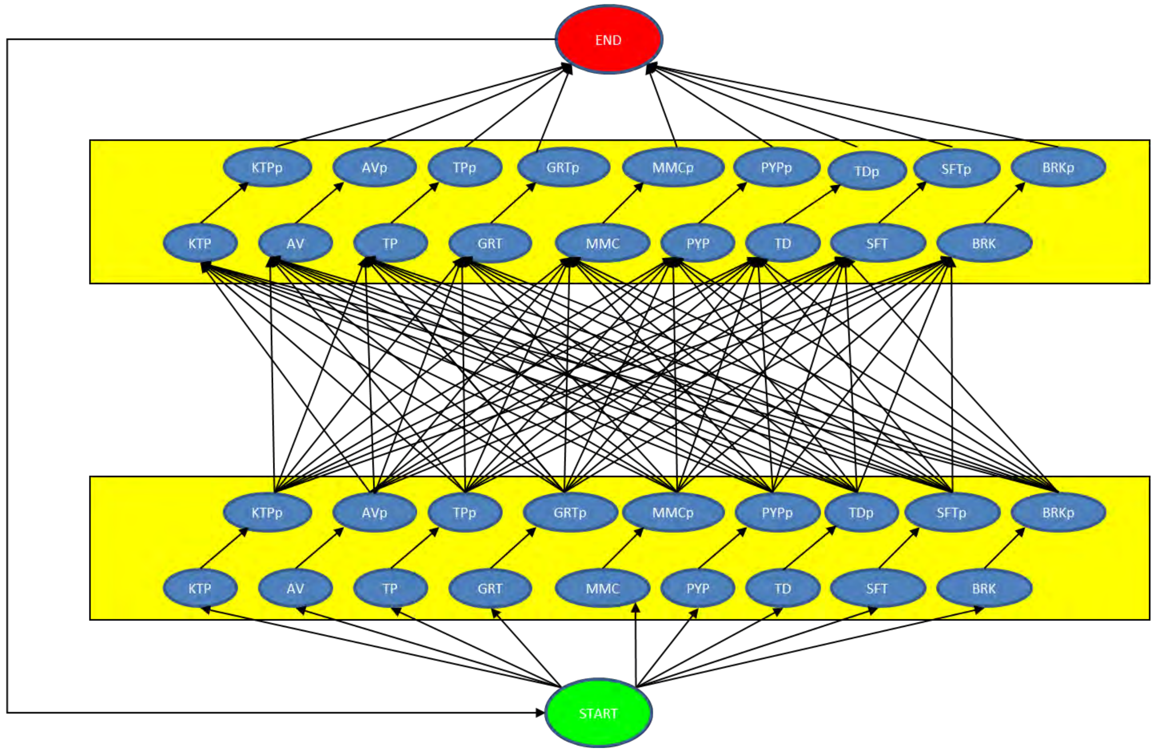

Figure 5. Complete network model with two time levels. When the model is implemented the weekday model will have six levels and the weekend model will have eight levels.

C. MINIMIZE THE NUMBER OF GUIDES REQUIRED ON A SHIFT

Having established the basic network, we will manipulate it to calculate the minimum staffing requirements to meet various scheduling constraints. The cost on the edge between the end and start nodes will be one, all other costs will be zero. This will track the total amount of flow through the system. We introduce a variable Δ, which will be an integer of the set [1, 4], which is the total number of touch pools that our guides can staff during a shift. The linear program for this model is shown in Figure 6.

$$\text{Minimize:} \quad \sum_{k} \sum_{(i,j)\in Edges} y_{end,start}^{(k)} \tag{1}$$

Subject to:

$$\sum_{\{j:(i,j)\in Edges\}} y_{ij}^{(k)} - \sum_{\{j\,(j,i)\in Edges\}} y_{ji}^{(k)} = b^{(k)} \quad \forall k, \quad \forall i \in Nodes \tag{2}$$

$$l_{ij} \le \sum_{k} y_{ij}^{(k)} \le u_{ij} \quad \forall (i,j) \in Edges \tag{3}$$

$$\sum y^{(k)}{}_{i,T} \le \Delta \quad \forall k,\ \forall T \in \{TP, KTP\} \tag{4}$$

$$\sum y^{(k)}{}_{i,TP} \le 2 \quad \forall k,\ \forall TP \tag{5}$$

$$\sum y^{(k)}{}_{i,KTP} \le 2 \quad \forall k,\ \forall KTP \tag{6}$$

$$\sum y^{(k)}{}_{i,TD} \le 2 \quad \forall k,\ \forall TD \tag{7}$$

$$\sum y^{(k)}{}_{i,AV} \le 2 \quad \forall k,\ \forall AV \tag{8}$$

$$\sum y^{(k)}{}_{i,PYP} \le 2 \quad \forall k,\ \forall PYP \tag{9}$$

$$\sum y^{(k)}{}_{i,GRT} \le 2 \quad \forall k,\ \forall GRT \tag{10}$$

$$\sum y^{(k)}{}_{i,MMC} \le 2 \quad \forall k,\ \forall MMC \tag{11}$$

$$\sum y^{(k)}{}_{i,BRK} = 1 \quad \forall k,\ \forall BRK \tag{12}$$

$$y_{ij}^{(k)} \in Z^{+} \quad \forall k,\ \forall (i,j) \in Edges \tag{13}$$

Figure 6. Minimize the number of guides required on shift linear equations.

Equation 1 is the objective function that minimizes the total number of guides required to meet all constraints for a shift by counting the number of guides that flow over the edge between nodes end and start in our network model. Equation 2 is the network flow constraint where the total flow of guides into a node minus the total flow of guides out of the node is equal to the guide demand at that node. Equation 3 is the lower and upper bound constraints on the flow of all guides over the edges in the network. Equation 4 limits the total number of touch pools and kelp touch pools a guide may visit to an integer variable Δ. Equations 5 through 11 force the guides to visit a variety of stations on their shift by limiting the total number of times a particular guide can visit a particular hard station to two. Equation 12 will only be used in the weekend model and forces each guide to be assigned a break during their shift. Equation 13 limits the flow of guides through the network to non-negative integers.

The program will run this optimization on both the weekend and weekday models for each Δ in GAMS and yield the minimum number of guides required based on the different touch pool constraints. These results shall be discussed in Chapter III.

D. MINIMIZE THE TIME GUIDES SPEND TRANSITING BETWEEN STATIONS

Using the results of the optimal staffing model, we will manipulate the original network model to determine the schedule that minimizes the total amount of time each guide spends transiting between stations. The new linear program will minimize the total time spent transiting by all the guides assigned to that shift. The cost on the edges between nodes will be the number of minutes it takes to transit from node *i* to node *j*. The cost on edges within a level, edges connecting to the soft and break nodes, and edges connecting to the start and finish nodes will all be zero. The edges with cost greater than one will be the remaining edges between levels. Recall that the original graph was reduced to nine nodes. The graph can be further reduced to seven nodes since we are not interested in minimizing the time transiting to and from the break or soft nodes. The graph with edges indicating adjacent stations and the time to transit between them is shown in Figure 7.

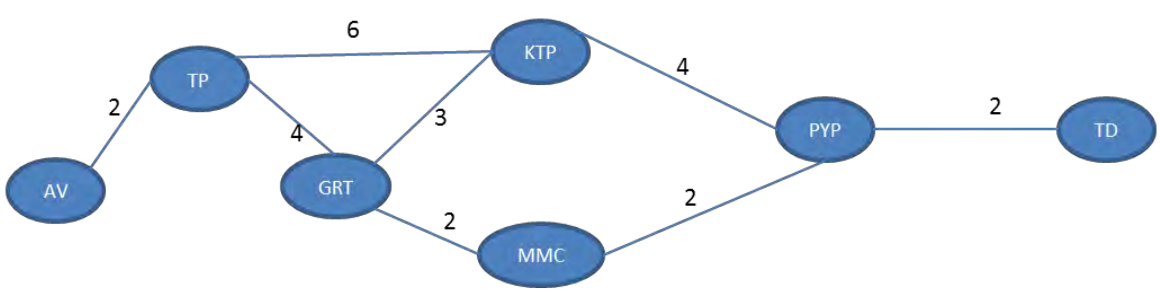

Figure 7. Network of hard stations with transit times in minutes.

The use of any shortest path algorithm, such as Dijkstra's algorithm, yields the minimum transit times between stations shown in Table 5.

Table 5. Transit times in minutes between stations.

	TP	KTP	TD	AV	PYP	GRT	MMC
TP	0	6	10	2	8	4	6
KTP	6	0	6	8	4	3	5
TD	10	6	0	12	2	6	4
AV	2	8	12	0	10	6	8
PYP	8	4	2	10	0	4	2
GRT	4	3	6	6	4	0	2
MMC	6	5	4	8	2	2	0

The linear program for this model is shown in Figure 8.

Minimize: $$\sum_{k}\sum_{(i,j)\in Edges} y_{ij}^{(k)} c_{ij}^{(k)} \quad (1)$$

Subject to:

$$\sum_{\{j:(i,j)\in Edges\}} y_{ij}^{(k)} - \sum_{\{j\,(j,i)\in Edges\}} y_{ji}^{(k)} = b^{(k)} \quad \forall k, \quad \forall i \in Nodes \quad (2)$$

$$l_{ij} \le \sum_{k} y_{ij}^{(k)} \le u_{ij} \quad \forall (i,j) \in Edges \quad (3)$$

$$\sum y^{(k)}_{i,T} \le \Delta \quad \forall k, \forall T \in \{TP, KTP\} \quad (4)$$

$$\sum y^{(k)}_{i,TP} \le 2 \quad \forall k, \forall TP \quad (5)$$

$$\sum y^{(k)}_{i,KTP} \le 2 \quad \forall k, \forall KTP \quad (6)$$

$$\sum y^{(k)}_{i,TD} \le 2 \quad \forall k, \forall TD \quad (7)$$

$$\sum y^{(k)}_{i,AV} \le 2 \quad \forall k, \forall AV \quad (8)$$

$$\sum y^{(k)}_{i,PYP} \le 2 \quad \forall k, \forall PYP \quad (9)$$

$$\sum y^{(k)}_{i,GRT} \le 2 \quad \forall k, \forall GRT \quad (10)$$

$$\sum y^{(k)}_{i,MMC} \le 2 \quad \forall k, \forall MMC \quad (11)$$

$$\sum y^{(k)}_{i,BRK} = 1 \quad \forall k, \forall BRK \quad (12)$$

$$y_{ij}^{(k)} \in Z^{+} \quad \forall k, \forall (i,j) \in Edges \quad (13)$$

Figure 8. Minimize guide total transit time linear equations.

Equation 1 is the objective function that minimizes the total transit time of all the guides on the shift. Equation 2 is the network flow constraint where the total flow of guides into a node minus the total flow of guides out of the node is equal to the guide demand at that node. Equation 3 is the lower and upper bound constraints on the flow of all guides over the edges in the network. Equation 4 limits the total number of touch pools and kelp touch pools a guide may visit to an integer variable Δ. Equations 5 through 11 force the guides to visit a variety of stations on their shift by limiting the total number of times a particular guide can visit a particular hard station to two. Equation 12 will only be used in the weekend model and forces each guide to be assigned a break during their shift. Equation 13 limits the flow of guides through the network to non-negative integers.

The program will run this optimization on both the weekend and weekday models for each Δ in GAMS. The results should be consistent with the minimum number of the guides required on a shift found in the previous model, and should yield an optimal sequence of stations for each individual assigned to the shift that minimizes the total time spent transiting the Aquarium by all the volunteers on the shift. These results shall be discussed in Chapter III.

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III. RESULTS OF ANALYSIS OF CURRENT SCHEDULING PRIORITIES

A. WEEKDAY MODEL

The weekday guide schedule covers a period of three hours which is divided into six 30-minute periods. The model is constrained by the maximum number of touch pools allowed per guide, the requirement for a variety of assignments, and the hard station minimum staffing requirement.

1. Minimum Staffing Requirements

The weekday guide shift was modeled as a directed network consisting of 98 nodes and 349 edges as described in Chapter II. The first formulation in GAMS was a coarse model designed to identify the minimum number of personnel required for a guide schedule consisting of six periods with no breaks required. The minimum staffing results are listed in Table 6.

Table 6. Weekday shift minimum staffing requirements.

Maximum touch pools allowed per guide	Minimum number of guides per shift
1	30
2	15
3	11
4	11

Each period requires a total of five people be assigned to the touch pools. Since there are six periods, a total of 30 touch pools stations need to be staffed on the shift. If there are 30 guides on the shift, they only have to visit a touch pool once. If there are 15 guides on the shift they have to visit a touch pool twice. In these cases, the minimum number of guides is driven by the touch pool constraint.

The minimum number of guides decreases to 11 when we relax the maximum number of touch pools per guide to three. The touch pool constraint has been relaxed to the point where the limiting constraint is now the minimum number of guides required to staff all hard stations during each period. Further relaxation of the touch pool constraint to four results in the same minimum staffing results as three touch pools since the constraint of 11 hard stations per period is limiting the minimum staffing requirements.

Since the weekday model is only six periods long and does not include the requirement for a break, the results match our intuition very well. While the model appears to yield results that do not go beyond basic arithmetic, it provides a useful model that was refined to minimize the total transit time for the guides on shift.

2. Minimize Volunteer Transit Time Between Stations

The model to minimize total transit time was adapted from the previous minimum staffing requirements model. Transit times were added to the arc data set and the objective function was updated as described in Chapter II to track the total transit time. The directed network of 98 nodes and 349 edges remained the same. Recall that since a soft station can be vacant with no penalty, transiting to and from a soft station is counted as zero transit time. The transit times based on the maximum touch pools required and the number of personnel who are available for the shift are listed in Table 7.

A minimum of 30 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is one. With 30 guides on shift the model yields a blend of assignments that alternates hard stations with soft stations resulting in zero transit time.

A minimum of 15 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is two. As the number of guides increases, while keeping a maximum of two touch pools per guide, the total transit time steadily decreases and reaches zero when 22 guides are on the shift. At this point the model yields a blend of assignments that alternates hard stations with soft stations resulting in zero transit time.

A minimum of 11 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is three. As the number of guides increases while keeping a maximum of three touch pools per guide, the total transit time steadily decreases and reaches zero when 22 guides are on the shift. At this point the model yields a blend of assignments that alternates hard stations with soft stations resulting in zero transit time. This is consistent with the two touch pool model that also achieved zero transit times with 22 guides on shift.

Table 7. Weekday minimize volunteer transit time results.

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
1	**30**	**0**
2	**15**	**81**
2	16	63
2	17	50
2	18	40
2	19	30
2	20	20
2	21	10
2	22	0
3	**11**	**202**
3	12	158
3	13	126
3	14	97
3	15	74
3	16	60
3	17	50
3	18	40
3	19	30
3	20	20
3	21	10
3	22	0
4	**11**	**201**
4	12	158
4	13	126
4	14	97
4	15	74
4	16	60
4	17	50

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
4	18	40
4	19	30
4	20	20
4	21	10
4	22	0

In the three touch pool model, when the number of guides available is 15 and 16, the total transit time is only one minute better than the two touch pool model. When the number of guides available is 17 or greater the total transit time is the same as the two touch pool model. The results of the four touch pool model are the same as the three touch pool model.

These results are consistent with the previous minimum staffing requirements model. Table 8 is a summary of the critical results based on all of the results of this model, giving more weight to minimizing touch pools over minimizing total transit time. Sample assignment schedules for each of the scenarios in Table 8 have been included in Appendix A.

My recommendation to the Aquarium is to recruit a minimum of 16 members for each weekday shift. The average transit time for 16 guides is less than four minutes. In the event of a single no-show this level of staffing is highly resilient since the average transit time for 15 guides increases by approximately one minute and the maximum number of touch pools per guide remains at two.

Table 8. Weekday model summary of critical results.

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
3	11	202
3	12	158
3	13	126
3	14	97
2	15	74
2	**16**	**60**

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
2	17	50
2	18	40
2	19	30
2	20	20
2	21	10
2	22	0

B. WEEKEND MODEL

The weekend guide schedule covers a period of four hours which is divided into eight 30-minute periods. The weekend model is similar to the weekday model because it is constrained by the maximum number of touch pools allowed per guide, the requirement for a variety of assignments, and the hard station minimum staffing requirement. The weekend model is different than the weekday model because it has an additional requirement; guides must have one break during the shift, and the break must occur after the first two periods but before the last two periods.

1. Minimum Staffing Requirements

The weekend guide shift was modeled as a directed network consisting of 138 nodes and 547 edges as described in Chapter II. The first formulation in GAMS was a coarse model designed to identify the minimum number of personnel required for a guide schedule consisting of eight periods. Break nodes were added to periods three, four, five, and six. A guide was required to visit a break node once during the course of the shift. The minimum staffing results are listed in Table 9.

Each period requires a total of five people be assigned to the touch pools. Since there are eight periods, a total of 40 touch pools stations need to be staffed on the shift. If there are 40 guides on the shift, they only have to visit a touch pool once. If there are 20 guides on the shift, they have to visit a touch pool twice. In these cases, the minimum number of guides is driven by the touch pool constraint and is consistent with our intuition.

Table 9. Weekend minimum staffing requirements

Maximum touch pools allowed per guide	Minimum number of guides per shift
1	40
2	20
3	15
4	15

The minimum number of guides decreases to 15 when we relax the maximum number of touch pools per guide to three. This is because the touch pool constraint has been relaxed to the point where the limiting constraint is now the requirement for the guide to have a break during the shift. This is inconsistent with the intuition we applied to the previous scenarios where the results were consistent with simple division. Further relaxation of the touch pool constraint to four results in the same minimum staffing results as three touch pools since the break constraint is the factor limiting the minimum staffing requirements.

Since the weekend model is eight periods long and includes the requirement for a break, the model results only match our intuition to a certain point. The model provides a useful starting point that was refined to minimize the total transit time for the guides on shift.

2. Minimize Volunteer Transit Time Between Stations

The model to minimize total transit time was adapted from the previous minimum staffing requirements model. Transit times were added to the arc data set and the objective function was updated as described in Chapter II to track the total transit time. The directed network of 138 nodes and 547 edges remained the same. Recall that since a soft station can be vacant with no penalty, transiting to and from a soft station is counted as zero transit time. Additionally, transiting to and from break is counted as zero transit time. The model yielded the transit times in Table 10 based on the maximum touch pools required and the number of personnel who are available for the shift.

Table 10. Weekend minimize volunteer transit time results.

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
1	**40**	**0**
2	**20**	**28**
2	21	14
2	22	0
3	**15**	**109**
3	16	86
3	17	70
3	18	56
3	19	42
3	20	28
3	21	14
3	22	0
4	**15**	**106**
4	16	86
4	17	70
4	18	56
4	19	42
4	20	28
4	21	14
4	22	0

A minimum of 40 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is one. With 40 guides on shift the model yields a blend of assignments that alternates hard stations with soft stations and breaks resulting in zero transit time.

A minimum of 20 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is two. As the number of guides increases while keeping a maximum of two touch pools per guide, the total transit time steadily decreases and reaches zero when 22 guides are on the shift. At this point the model yields a blend of assignments that alternates hard stations with soft stations and breaks resulting in zero transit time.

A minimum of 15 guides are required to be on shift to yield an initial feasible result when the maximum number of touch pools allowed per guide is three. As the number of guides increases while keeping a maximum of three touch pools per guide, the total transit time steadily decreases and reaches zero when 22 guides are on the shift. At this point the model yields a blend of assignments that alternates hard stations with soft stations and breaks resulting in zero transit time. It is also worth noting that when the number of guides available is 20 or greater the total transit time is the same as the two touch pool model.

The results of the four touch pool model are nearly the same as the three touch pool model. The four touch pool model is three minutes better with a minimum staffing of 15 guides, but is otherwise the same as the three touch pool model.

These results are consistent with the previous minimum staffing requirements model. Table 11 is a summary of the critical results based on all of the results of this model, giving more weight to minimizing touch pools over minimizing total transit time. Sample assignment schedules for each of the scenarios in Table 11 have been included in Appendix B.

Table 11. Weekend model summary of critical results.

Maximum touch pools allowed per guide	Number of guides available	Total transit time of all guides on the shift
3	15	109
3	16	86
3	17	70
3	18	56
3	19	42
2	20	28
2	**21**	**14**
2	22	0

My recommendation to the Aquarium is to recruit a minimum of 21 members for each weekend shift. The average transit time for 21 guides is less than one minute. In the event of a single no-show this level of staffing is highly resilient since the average transit time for 20 guides increases by approximately one minute and the maximum number of touch pools per guide remains at two.

Both the weekday and weekend scenarios accurately model current scheduling practices. These models are useful at establishing minimum staffing requirements that are consistent with current heuristic scheduling techniques. The models also propose schedules that are better than the heuristic techniques because they minimize the time spent transiting between stations. The next chapter will examine how modifications to the list of required hard stations changes the minimum staffing requirements and affects the optimal scheduling blend that minimizes the total transit time.

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IV. RESULTS OF ANALYSIS OF MODIFIED SCHEDULING PRIORITIES

A. WEEKDAY MODEL WITH GREET TREATED AS A SOFT STATION

The weekday guide shift model was modified by changing the greet station to a soft station. The greet station was selected because in addition to the volunteer guides, paid staff members currently greet visitors as they enter the Aquarium. The relaxation of the greet station therefore seemed like the most likely candidate to be changed to a soft station in the future.

1. Minimum Staffing Requirements

The minimum staffing results of the new model compared to the original model are listed in Table 12. The minimum number of guides is still driven by the touch pool constraint when one or two touch pools are allowed. When three or four touch pools are allowed the minimum number of guides is limited by the number of hard stations which has been reduced to 10.

Table 12. Weekday minimum staffing requirements with greet treated as a soft station.

Maximum touch pools allowed per guide	Original model minimum number of guides per shift	Δ	New model minimum number of guides per shift
1	30	0	30
2	15	0	15
3	11	-1	10
4	11	-1	10

2. Minimize Volunteer Transit Time Between Stations

The transit times of the new model compared to the original model are listed in Table 13.

Table 13. Weekday minimize volunteer transit time results with greet treated as a soft station.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
2	**15**	**81**	**-25**	**56**
2	16	63	-23	40
2	17	50	-20	30
2	18	40	-20	20
2	19	30	-20	10
2	20	20	-20	0
2	21	10	-10	0
2	22	0	0	0
3	10	Infeasible		217
3	**11**	**202**	**-36**	**166**
3	12	158	-30	128
3	13	126	-30	96
3	14	97	-27	70
3	15	74	-24	50
3	16	60	-20	40
3	17	50	-20	30
3	18	40	-20	20
3	19	30	-20	10
3	20	20	-20	0
3	21	10	-10	0
3	22	0	0	0
4	10	Infeasible		213
4	**11**	**201**	**-35**	**166**
4	12	158	-30	128
4	13	126	-30	96
4	14	97	-27	70
4	15	74	-24	50
4	16	60	-20	40
4	17	50	-20	30
4	18	40	-20	20
4	19	30	-20	10
4	20	20	-20	0
4	21	10	-10	0
4	22	0	0	0

While the minimum number of guides required when two touch pools are allowed per guide is still 15, the total transit time has been reduced from 81 minutes to 56 minutes. The dramatic difference in transit times continues as more guides are available until the total transit time is zero with only 20 guides on shift where in the original model, 22 guides were required for a transit time of zero.

As previously discussed, the minimum number of guides required when three or four touch pools are allowed per guide is 10, down from 11 in the original model. Similar to the two touch pool scenario in the new model, the transit times in the three and four touch pool scenarios in the new model are less than the original model. In the original model 11 guides with three or four touch pools allowed required 201 minutes of total transit time while in the new model they only require 166 minutes. The dramatic difference in transit times continues as more guides are available until the total transit time is zero with only 20 guides on shift, while in the original model 22 guides were required for a transit time of zero. Table 14 is a summary of the critical results based on all of the results of this model, giving more weight to minimizing touch pools over minimizing total transit time.

Table 14. Weekday model summary of critical results with greet treated as a soft station.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
3	10	Infeasible		217
3	11	202	-36	166
3	12	158	-30	128
3	13	126	-30	96
3	14	97	-27	70
2	15	81	-25	56
2	16	63	-23	40
2	17	50	-20	30
2	18	40	-20	20
2	19	30	-20	10
2	20	20	-20	0

B. WEEKEND MODEL WITH GREET TREATED AS A SOFT STATION

The weekend guide shift model was modified by changing the greet station to a soft station. The greet station was selected, for reasons stated previously, because in addition to the volunteer guides, paid staff members currently greet visitors as they enter the Aquarium.

1. Minimum Staffing Requirements

The minimum staffing results of the new model compared to the original model are listed in Table 15. The minimum number of guides is still driven by the touch pool constraint when one or two touch pools are allowed. When three or four touch pools are allowed the reduction from 15 to 14 guides is still limited by the break constraint.

Table 15. Weekend minimum staffing requirements with greet treated as a soft station.

Maximum touch pools allowed per guide	Original model minimum number of guides per shift	Δ	New model minimum number of guides per shift
1	40	0	40
2	20	0	20
3	15	-1	14
4	15	-1	14

2. Minimize Volunteer Transit Time Between Stations

The transit times of the new model compared to the original model are listed in Table 16. While the minimum number of guides required when two touch pools are allowed per guide is still 20; the total transit time has been reduced from 28 minutes to zero minutes, whereas in the original model 22 guides were required for a transit time of zero.

Table 16. Weekend minimize volunteer transit time results with greet treated as a soft station.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
2	**20**	**28**	**-28**	**0**
2	21	14	-14	0
2	22	0	0	0
3	14	Infeasible		111
3	**15**	**109**	**-33**	**76**
3	16	86	-24	62
3	17	70	-28	42
3	18	56	-28	28
3	19	42	-28	14
3	20	28	-28	0
3	21	14	-14	0
3	22	0	0	0
4	14	Infeasible		99
4	**15**	**106**	**-30**	**76**
4	16	86	-30	56
4	17	70	-28	42
4	18	56	-28	28
4	19	42	-28	14
4	20	28	-28	0
4	21	14	-14	0
4	22	0	0	0

As previously discussed, the minimum number of guides required when three or four touch pools per guide are allowed is 14, down from 15 in the original model. Similar to the two touch pool scenario in the new model, the transit times in the three and four touch pool scenarios in the new model are less than the original model. In the original model, 15 guides with three touch pools allowed per guide required 109 minutes of total transit time while the new model only requires 76 minutes. In the original model 15 guides with four touch pools allowed per guide required 106 minutes of total transit time while the new model only requires 76 minutes. The difference in transit times continues as more guides are available until the total transit time is zero with only 20 guides on shift, while in the original model 22 guides were required for a total transit time of zero.

Table 17 is a summary of the critical results based on all of the results of this model, giving more weight to minimizing touch pools over minimizing total transit time.

Table 17. Weekend model summary of critical results with greet treated as a soft station.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
3	14	Infeasible		111
3	**15**	**109**	**-33**	**76**
3	16	86	-24	62
3	17	70	-28	42
3	18	56	-28	28
3	19	42	-28	14
2	20	28	-28	0

C. WEEKDAY MODEL WITH GREET TREATED AS A SOFT STATION AND AN ADDITIONAL GUIDE ADDED TO EACH TOUCH POOL

The weekday guide shift model was modified by changing the greet station to a soft station while adding an additional guide to each of the touch pool stations. The touch pool requirements were increased to reflect increased demand at these stations during the summer and winter holidays. The model modification results in 12 hard stations per time period, with seven of them being touch pools.

1. Minimum Staffing Requirements

The minimum staffing results of the new model compared to the original model are listed in Table 18. Despite the relaxation of the greet constraint the demand for guides has increased due to the higher demand at the touch pools. It follows that 42 guides are required since there are seven touch pool stations in each of the six periods. It also matches our intuition that we need 21 guides when two touch pools are allowed and 14 guides when three touch pools are allowed. For the first time, the minimum guides per shift are different when we relax the maximum touch pools allowed per guide from three to four. When four touch pools are allowed the minimum number of guides is limited by the number of hard stations which has been increased to 12.

Table 18. Weekday minimum staffing requirements with greet treated as a soft station and an additional guide added to each touch pool.

Maximum touch pools allowed per guide	Original model minimum number of guides per shift	Δ	New model minimum number of guides per shift
1	30	+12	42
2	15	+6	21
3	11	+3	14
4	11	+1	12

2. Minimize Volunteer Transit Time Between Stations

The transit times of the new model compared to the original model are listed in Table 19. The minimum number of guides required when two touch pools are allowed has increased to 21, up from 15 in the original model. The total transit time for 21 guides has increased from 10 minutes to 30 minutes. In the original model when two touch pools are allowed per guide the total transit time reached zero with only 22 guides, while the new model requires 24 guides to achieve a total transit time of zero.

The minimum number of guides required when three touch pools are allowed has increased to 14, up from 11 in the original model. The total transit time for 14 guides has increased from 97 minutes to 191 minutes. The new model achieves zero total transit time with 24 guides.

Table 19. Weekday minimize volunteer transit time results with greet treated as a soft station and an additional guide added to each touch pool.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
2	15	81		Infeasible
2	**21**	**10**	**+20**	**30**
2	22	0	+20	20
2	23	0	+10	10
2	24	0	0	0
3	11	202		Infeasible
3	**14**	**97**	**+94**	**191**
3	15	74	+80	154

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
3	16	60	+58	118
3	17	50	+38	88
3	18	40	+24	64
3	19	30	+20	50
3	20	20	+20	40
3	21	10	+20	30
3	22	0	+20	20
3	23	0	+10	10
3	24	0	0	0
4	11	201		Infeasible
4	**12**	**158**	**+117**	**275**
4	13	126	+92	218
4	14	97	+85	182
4	15	74	+80	154
4	16	60	+58	118
4	17	50	+38	88
4	18	40	+24	64
4	19	30	+20	50
4	20	20	+20	40
4	21	10	+20	30
4	22	0	+20	20
4	23	0	+10	10
4	24	0	0	0

The minimum number of guides required when four touch pools are allowed has increased to 12, up from 11 in the original model. This is consistent in the original model because the limiting factor is the number of hard stations. While there were only 11 hard stations in the original model there are 12 in the new model. The new model with four touch pools has increased the total transit time from 158 minutes in the original model to 275 minutes for 12 guides in the new model.

While the updated model only has a net gain of one hard station over the original model, the increase from five to seven touch pools yielded dramatically different results. Luckily, since the weekday model does not have any breaks required, the results continue to match our intuition and basic arithmetic. Table 20 is a summary of the critical results of this model, giving more weight to minimizing touch pools over minimizing total transit time.

Table 20. Weekday model summary of critical results with greet treated as a soft station and an additional guide added to each touch pool.

Maximum Touch Pools Allowed per Guide	Number of Guides Available	Original Model Total Transit Time	Δ	New Model Total Transit Time
4	12	158	+117	275
4	13	126	+92	218
3	14	97	+94	191
3	15	74	+80	154
3	16	60	+58	118
3	17	50	+38	88
3	18	40	+24	64
3	19	30	+20	50
3	20	20	+20	40
2	21	10	+20	30
2	22	0	+20	20
2	23	0	+10	10
2	24	0	0	0

D. WEEKEND MODEL WITH GREET TREATED AS A SOFT STATION AND AN ADDITIONAL GUIDE ADDED TO EACH TOUCH POOL

The weekend guide shift model was similarly modified by changing the greet station to a soft station while adding an additional guide to each touch pool. As previously discussed, the model modification results in 12 hard stations per time period, with seven of them being touch pools.

1. Minimum Staffing Requirements

The minimum staffing results of the new model compared to the original model are listed in Table 21. Despite the relaxation of the greet constraint, the demand for guides has increased due to the higher demand at the touch pools. It follows that 56 guides are required since there are seven touch pool stations in each of the eight levels. It also matches our intuition that we need 28 when two touch pools are allowed and 19 guides when three touch pools are allowed. Similar to the weekday model, the minimum guides per shift are different when we relax the maximum touch pools allowed per guide from three to four. When four touch pools are allowed the minimum number of guides is 16, which does not match the intuition we applied to the previous touch pool scenarios where the results were consistent with simple division. In this case the break constraint is limiting the minimum staffing requirements from decreasing further.

Table 21. Weekend minimum staffing requirements with greet treated as a soft station and an additional guide added to each touch pool.

Maximum touch pools allowed per guide	Original model minimum number of guides per shift	Δ	New model minimum number of guides per shift
1	40	+16	56
2	20	+8	28
3	15	+4	19
4	15	+1	16

2. Minimize Volunteer Transit Time Between Stations

The transit times of the new model compared to the original model are listed in Table 22. The minimum number of guides required when three touch pools are allowed has increased to 19, up from 15 in the original model. The total transit time for 19 guides has increased from 42 minutes to 77 minutes. The new model achieves a total transit time of zero with 24 guides while the original model achieved it with only 22 guides.

The minimum number of guides required when four touch pools are allowed has increased to 16, up from 15 in the original model. While this only appears to be a marginal increase, the total transit time for 16 guides has increased from 86 minutes in the original model to 171 minutes in the new model.

Table 22. Weekend minimize volunteer transit time results with greet treated as a soft station and an additional guide added to each touch pool.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
2	20	28		Infeasible
2	**28**	**0**	**0**	**0**
3	15	109		Infeasible
3	**19**	**42**	**+35**	**77**
3	20	28	+28	56
3	21	14	+28	42
3	22	0	+28	28
3	23	0	+14	14
3	24	0	0	0
4	15	106		Infeasible
4	**16**	**86**	**+85**	**171**
4	17	70	+57	127
4	18	56	+35	91
4	19	42	+28	70
4	20	28	+28	56
4	21	14	+28	42
4	22	0	+28	28
4	23	0	+14	14
4	24	0	0	0

While the updated model only has a net gain of one hard station over the original model, the increase from five to seven touch pools yielded dramatically different results. Table 23 is a summary of the critical results of this model, giving more weight to minimizing touch pools over minimizing total transit time.

Table 23. Weekend minimize volunteer transit time results with greet treated as a soft station and an additional guide added to each touch pool.

Maximum touch pools allowed per guide	Number of guides available	Original model total transit time	Δ	New model total transit time
4	16	86	+85	171
4	17	70	+57	127
4	18	56	+35	91
3	19	42	+35	77
3	20	28	+28	56
3	21	14	+28	42
3	22	0	+28	28
3	23	0	+14	14
3	24	0	0	0

Both the weekday and weekend scenarios show how minor relaxations and restrictions to the model change the results. It is worth noting that the GAMS code used in these scenarios was the same as the original model. The only adjustments made were to the data stets that GAMS reads into the code from various comma separated value files. The results of these scenarios were achieved by manipulating the lower bounds on the arc data set. Areas for future work could be achieved from similar manipulations of just the data set, while keeping the GAMS code unchanged.

V. CONCLUSIONS AND AREAS FOR FUTURE WORK

This thesis modeled the guide schedule as a network and solved it using linear programing. We identified the minimum guide staffing required to meet various constraints. The results of the weekday model followed our intuition very well and could be solved using simple arithmetic, while the results of the weekend model were more complicated due to the break requirement. We identified how manipulating demand at the hard stations changed both the minimum staffing requirements and time the guides spent transiting the Aquarium.

The model results gave the volunteer recruitment office a new tool to develop target recruiting levels that are resilient to both no-show and drop-ins. It showed the importance of guides finding a substitute when they know they are going to be absent, since there are cases where a single absence doubles the time a guide spends transiting the Aquarium. The volunteer recruitment office has used this model to run additional scenarios to model changes to the station priorities list with different levels of guide staffing.

This thesis was useful to the guide shift captains because it proposed guide schedules that minimized the total transit time of all the guides on the shift. Several shift captains have adopted the templates and have used them on their shifts. Those that chose not to adopt the templates have used the results to validate the composition of their schedules.

All guides have a better understanding of the schedule limitations at various levels of staffing. Additionally, prior to this thesis, there was a strong opinion among the guides that the shift captain role was outside their ability since the scheduling process appeared not only difficult to execute, but impossible to understand. The analysis of the guide scheduling process as a network helped many guides visualize and understand the assignment process. Several guides expressed interest in taking on the shift captain role following a presentation of the results of this thesis.

A limitation of the model is that there may be multiple optimal schedules that achieve the same minimum total transit time. Despite this limitation the schedules that were generated are good templates that the shift captains can refine manually to accommodate special requests and non-routine MBA events. Visualizing the network, identifying nodes and edges, and moving flow from one side of the graph to another was easy and enjoyable; however, translating this into a workable GAMS code was very difficult. While GAMS produced excellent results, future use of this model requires a working knowledge of GAMS. A future project would be converting the user interface into a spreadsheet system that automatically promulgates a schedule following shift captain input.

APPENDIX A. SAMPLE WEEKDAY GUIDE SCHEDULES

The following tables are sample schedules that minimize the total transit time for the guides available on a weekday shift. The empty gray boxes denote areas where a soft station can be inserted. In the 10 person model shown in Table 24, the greet station is treated as a soft station. In all other tables, greet is treated as a hard station.

Table 24. Sample 10 guide weekday schedule.

	Period	1	2	3	4	5	6
1		KTP	AV	TP	AV	KTP	TD
2		TD	MMC	KTP	TP	AV	KTP
3		MMC	KTP	TP	AV	TP	AV
4		KTP	TD	PYP	KTP	TP	AV
5		PYP	KTP	AV	TP	AV	TP
6		TP	AV	KTP	PYP	KTP	MMC
7		KTP	PYP	TD	MMC	KTP	TP
8		TP	KPT	MMC	KTP	MMC	PYP
9		AV	TP	AV	KTP	TD	KTP
10		AV	TP	KTP	TD	PYP	KTP

Table 25. Sample 11 guide weekday schedule.

	Period	1	2	3	4	5	6
1		TP	AV	TP	AV	KTP	MMC
2		KTP	TD	PYP	TD	PYP	KTP
3		GRT	KTP	MMC	KTP	AV	TP
4		MMC	KTP	TP	AV	TP	AV
5		KTP	GRT	KTP	GRT	MMC	TD
6		TD	PYP	TD	KTP	GRT	KTP
7		AV	TP	AV	TP	KTP	PYP
8		AV	TP	AV	TP	KTP	GRT
9		KTP	MMC	KTP	MMC	TP	AV
10		TP	AV	KTP	PYP	TD	KTP
11		PYP	KTP	GRT	KTP	AV	TP

Table 26. Sample 12 guide weekday schedule.

	Period	1	2	3	4	5	6
1		KTP	SFT	AV	TP	AV	TP
2		TD	PYP	TD	MMC	KTP	
3		AV	TP	AV	TP	KTP	MMC
4		GRT	KTP	GRT	KTP	TP	AV
5		MMC	KTP	TP	AV	TP	AV
6		TP	AV		KTP	GRT	KTP
7		PYP	TD	MMC	KTP	MMC	KTP
8		TP	AV	TP	AV		KTP
9		KTP	GRT	KTP		AV	TP
10		AV	TP	KTP	GRT	KTP	GRT
11		KTP	MMC	KTP	PYP	TD	PYP
12			KTP	PYP	TD	PYP	TD

Table 27. Sample 13 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP	MMC	KTP	GRT	KTP	
2		GRT	KTP	GRT	KTP	MMC	TD
3			KTP		KTP	TP	AV
4		AV	TP	AV	TP		KTP
5		TP	AV	TP	AV		KTP
6		KTP		TP	AV	TP	AV
7		AV	TP	AV	TP	KTP	
8		KTP	GRT	KTP		AV	TP
9		TD	PYP	TD	MMC	KTP	GRT
10		KTP		KTP		AV	TP
11		TP	AV		KTP	GRT	KTP
12		MMC	TD	PYP	TD	PYP	MMC
13			KTP	MMC	PYP	TD	PYP

Table 28. Sample 14 guide weekday schedule.

	Period	1	2	3	4	5	6
1		TP	AV	TP	AV		KTP
2		MMC	GRT	KTP	GRT	KTP	
3			KTP		TP	AV	TP
4		AV	TP	AV		KTP	
5		TD	PYP	TD	MMC	KTP	GRT
6			KTP		KTP	MMC	PYP
7		TP	AV	TP	AV		KTP
8		KTP		KTP		TP	AV
9		PYP	TD	MMC	PYP	TD	
10		KTP		KTP		TP	AV
11		AV	TP		KTP		KTP
12			KTP	GRT	KTP	GRT	MMC
13		GRT	MMC	PYP	TD	PYP	TD
14		KTP		AV	TP	AV	TP

Table 29. Sample 15 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP	TD		TP	AV	TP
2		TP		TD	PYP		KTP
3		AV	TP	AV		KTP	
4		TP	AV	TP		TD	PYP
5		MMC		AV	TP	AV	TP
6		KTP	GRT	MMC	GRT	KTP	
7		KTP		KTP	MMC	PYP	TD
8		AV	TP		KTP	GRT	MMC
9		TD	PYP	KTP		KTP	
10			KTP	PYP	TD		KTP
11			KTP		AV	TP	
12		GRT	MMC	GRT	KTP		KTP
13		KTP		KTP		MMC	GRT
14			AV	TP	AV	TP	
15			KTP		KTP		AV

Table 30. Sample 16 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP	TD		TP	AV	TP
2		TP		KTP		TD	PYP
3			AV	TP	AV	TP	
4		AV		KTP		KTP	
5			KTP	GRT	MMC	GRT	KTP
6		MMC	GRT	KTP		KTP	
7		KTP		MMC		TP	AV
8		GRT	MMC		KTP		KTP
9			TP	AV	TP	AV	
10			KTP		GRT		KTP
11		TP	AV	TP	AV		MMC
12		KTP		TD	PYP	MMC	GRT
13		KTP		PYP	TD	PYP	TD
14		AV	TP	AV		KTP	
15		TD	PYP		KTP		TP
16			KTP		KTP		AV

Table 31. Sample 17 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP	TD		TP	AV	TP
2			KTP		GRT		KTP
3			GRT		KTP		KTP
4		TP		GRT	MMC	PYP	MMC
5		TP	AV		TD		KTP
6		KTP		TD		KTP	
7		MMC		TP	AV	TP	AV
8			AV	TP	AV	TP	
9		AV	TP	AV	TP		TD
10		AV		KTP		KTP	
11		KTP		KTP		MMC	PYP
12			TP	AV		AV	TP
13			KTP		KTP		AV
14		GRT	MMC	PYP		KTP	
15			KTP		KTP		GRT
16		TD	PYP	MMC	PYP	TD	
17		KTP		KTP		GRT	

Table 32. Sample 18 guide weekday schedule.

	Period	1	2	3	4	5	6
1		KTP		KTP		PYP	
2			KTP		TP	AV	
3			KTP		PYP		KTP
4		TD		KTP		KTP	
5		AV	TP		TD		KTP
6			PYP	MMC	GRT	MMC	
7		KTP		GRT		KTP	
8			AV	TP	AV		TP
9			KTP		KTP		GRT
10		MMC	GRT		KTP		KTP
11		GRT	MMC	PYP	MMC		TD
12		AV	TP		KTP		MMC
13		PYP		AV	TP	AV	TP
14		TP		AV		KTP	
15		TP		TD		TP	AV
16			TD		AV	TP	AV
17			AV	TP		TD	PYP
18		KTP		KTP		GRT	

Table 33. Sample 19 guide weekday schedule.

	Period	1	2	3	4	5	6
1			**TD**	**PYP**		**PYP**	
2		**TP**		**AV**	**TP**	**AV**	
3		**TD**		**TP**	**AV**		**GRT**
4			**KTP**		**PYP**		**KTP**
5			**TP**	**AV**		**KTP**	
6		**GRT**		**KTP**		**KTP**	
7			**AV**		**TD**		**KTP**
8			**GRT**		**GRT**	**MMC**	**PYP**
9		**AV**		**TP**	**AV**	**TP**	
10		**KTP**		**KTP**		**GRT**	
11		**KTP**		**KTP**		**TD**	
12			**AV**		**KTP**		**KTP**
13			**KTP**		**TP**		**AV**
14		**TP**		**MMC**		**TP**	**AV**
15		**AV**	**TP**		**KTP**		**MMC**
16		**MMC**	**PYP**		**KTP**		**TP**
17		**PYP**	**MMC**	**GRT**		**KTP**	
18			**KTP**		**MMC**		**TD**
19		**KTP**		**TD**		**AV**	**TP**

Table 34. Sample 20 guide weekday schedule.

	Period	1	2	3	4	5	6
1		KTP		KTP		PYP	
2		TP		AV	TP		GRT
3			AV		MMC	GRT	
4			MMC	GRT		AV	
5			KTP		GRT		KTP
6			TP	AV		AV	TP
7		GRT		KTP		KTP	
8			AV		TD		KTP
9		AV		TP		TD	
10		KTP		KTP		MMC	
11		KTP		MMC		TD	AV
12			PYP		KTP		KTP
13			KTP		KTP		AV
14		TP		PYP		KTP	
15		AV	TP		TP		PYP
16		MMC	GRT		KTP		TP
17		TD		TP		KTP	
18		PYP		TD	PYP		MMC
19			TD		AV	TP	
20			KTP		AV		TD

Table 35. Sample 21 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP		PYP		AV	
2		TP		AV	TP		MMC
3			TP		AV		GRT
4		MMC		GRT		TD	
5			KTP		GRT		KTP
6			TP	AV		KTP	
7		GRT		KTP		KTP	
8			MMC		TD		KTP
9		AV		TP		KTP	
10		KTP		KTP		MMC	
11		AV		KTP		TP	
12			AV		KTP		KTP
13			KTP		KTP		AV
14		TP		MMC		PYP	
15			KTP		TP		PYP
16			GRT		MMC		TP
17		KTP		TP		GRT	
18			AV		KTP		AV
19			TD		AV	TP	
20		TD	PYP		PYP		TD
21		KTP		TD		AV	TP

Table 36. Sample 22 guide weekday schedule.

	Period	1	2	3	4	5	6
1		PYP		TD		TD	
2		TP		AV		KTP	
3			KTP		AV		GRT
4			TD		PYP		KTP
5			TP		GRT		TP
6		GRT		KTP		KTP	
7			KTP		TD		KTP
8		AV		PYP		PYP	
9		MMC		TP		TP	
10		AV		KTP		MMC	
11		KTP		KTP		GRT	
12			GRT		TP		MMC
13			KTP		TP		AV
14		TP		MMC		AV	
15			TP		KTP		PYP
16			AV		KTP		TP
17		TD		TP		TP	
18		KTP		AV		KTP	
19			AV		KTP		AV
20			MMC		MMC		TD
21		KTP		GRT		AV	
22			PYP		AV		KTP

APPENDIX B. SAMPLE WEEKEND GUIDE SCHEDULES

The following tables are sample schedules that minimize the total transit time for the guides available on a weekend shift. The empty gray boxes denote areas where a soft station can be inserted. In the 14 person model shown in Table 37, the greet station is treated as a soft station. In all other tables greet is treated as a hard station.

Table 37. Sample 14 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		PYP	MMC	KTP	BRK	TP	AV	TP	AV
2			KTP	BRK	TP	AV	TP	AV	
3		MMC	TD		KTP	BRK	TP		KTP
4		KTP		AV	TP	AV	BRK	KTP	
5		TD	PYP	MMC	KTP	BRK	KTP		TP
6		KTP		KTP	BRK	MMC	TD	PYP	TD
7			AV	TP	AV	TP	BRK	KTP	
8		AV	TP	AV	BRK	KTP	PYP	MMC	KTP
9		TP	AV	TP	AV	BRK	KTP		MMC
10		AV	TP	BRK	TD	PYP	KTP		KTP
11		KTP		TD	PYP	TD	BRK	KTP	
12			KTP		KTP	BRK	AV	TP	AV
13			KTP	PYP	MMC	KTP	BRK	AV	TP
14		TP		KTP	BRK	KTP	MMC	TD	PYP

Table 38. Sample 15 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		AV	TP	AV	BRK	KTP	GRT		KTP
2		KTP		TD	PYP	TD	BRK	KTP	
3		GRT	MMC	GRT	KTP	BRK	KTP		TP
4			AV	TP	AV	BRK	KTP		KTP
5		KTP		KTP	BRK	MMC	PYP	TD	PYP
6			KTP	BRK	KTP	GRT	MMC	PYP	TD
7		TP	AV	BRK	TD	PYP	TD		KTP
8		PYP	TD	PYP	MMC	KTP	BRK	KTP	
9		TP		MMC	GRT	KTP	BRK	KTP	
10		KTP		TP	AV	TP	BRK	MMC	GRT
11		MMC	GRT	KTP	BRK	AV	TP	AV	TP
12			KTP		KTP	BRK	AV	TP	AV
13			KTP	BRK	TP	AV	TP	AV	
14		AV	TP	AV	TP	BRK	KTP	GRT	MMC
15		TD	PYP	KTP	BRK	TP	AV	TP	AV

Table 39. Sample 16 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1			AV	TP	AV	BRK	KTP		KTP
2		MMC	GRT	MMC	GRT	KTP	BRK	KTP	
3		TP		KTP	BRK	KTP		MMC	GRT
4		AV	TP		KTP	BRK	KTP		PYP
5		PYP	TD	BRK	KTP		TP	AV	TP
6			KTP	BRK	MMC	GRT	MMC		KTP
7		KTP		KTP	BRK	TD	PYP	TD	
8		TD		KTP	BRK	TP	AV	TP	AV
9		KPT		PYP	TD	PYP	BRK	GRT	MMC
10		AV	TP	AV		KTP	BRK	KTP	
11		GRT	MMC	GRT	KTP	BRK	KTP		TP
12			PYP	TD	BRK	TP	AV	TP	AV
13			KTP	BRK	PYP	MMC	GRT		KTP
14			KTP	BRK	TP	AV	TP	AV	
15		KTP		AV	TP	AV	BRK	KTP	
16		TP	AV	TP	AV	BRK	TD	PYP	TD

Table 40. Sample 17 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		**AV**		**KTP**		**KTP**	**BRK**	**TD**	
2		**KTP**		**AV**	**BRK**	**KTP**		**AV**	**TP**
3			**KTP**	**BRK**	**TP**	**AV**	**TP**	**AV**	
4		**KTP**		**PYP**	**TD**	**BRK**	**KTP**		**PYP**
5		**GRT**	**MMC**	**BRK**	**KTP**		**TP**		**KTP**
6			**KTP**	**BRK**	**MMC**	**PYP**	**TD**	**PYP**	**TD**
7		**TD**		**KTP**	**BRK**	**TP**	**AV**		**KTP**
8			**KTP**	**BRK**	**AV**	**TP**	**AV**	**TP**	
9		**MMC**	**GRT**	**MMC**	**GRT**	**BRK**	**KTP**		**AV**
10		**TP**	**AV**	**TP**	**AV**	**BRK**	**MMC**	**GRT**	**MMC**
11		**KTP**		**GRT**		**KTP**	**BRK**	**TP**	**AV**
12		**TP**	**AV**	**TP**	**BRK**	**MMC**	**PYP**		**KTP**
13			**PYP**	**TD**	**PYP**	**TD**	**BRK**	**KTP**	
14		**AV**	**TP**		**KTP**	**BRK**	**GRT**	**MMC**	**GRT**
15			**TP**	**AV**	**TP**	**AV**	**BRK**	**KTP**	
16		**PYP**		**KTP**	**BRK**	**GRT**		**KTP**	
17			**TD**		**KTP**	**BRK**	**KTP**		**TP**

Table 41. Sample 18 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		TD	PYP	MMC		KTP	BRK	AV	
2		AV		KTP	BRK	GRT	MMC	GRT	MMC
3		KTP		GRT	MMC	PYP	BRK	PYP	
4			KTP		TD	BRK	KTP		TD
5			TP	AV	TP	BRK	KTP		AV
6			KTP		KTP	BRK	TD		TP
7		AV		KTP	BRK	TP	AV	TP	
8		GRT	MMC	PYP		TD	BRK	KTP	
9			KTP		AV	BRK	PYP	TD	PYP
10		TP		TD	PYP	MMC	BRK	KTP	
11			TP	AV		KTP	BRK	KTP	
12		TP	AV		GRT	BRK	AV		KTP
13			TD	BRK	KTP		GRT		KTP
14		KTP		TP	AV	TP	BRK	MMC	GRT
15		MMC	GRT	BRK	TP	AV	TP		KTP
16		PYP		KTP		KTP	BRK	TP	AV
17			AV		KTP	BRK	KTP		TP
18		KTP		TP	BRK	AV	TP	AV	

Table 42. Sample 19 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		**GRT**		**AV**	**BRK**	**PYP**		**AV**	**TP**
2		**AV**		**TD**	**BRK**	**GRT**	**MMC**	**GRT**	**MMC**
3			**AV**	**TP**	**AV**	**TP**	**BRK**	**KTP**	
4		**AV**		**KTP**		**KTP**	**BRK**	**TP**	
5		**TD**	**PYP**	**MMC**	**BRK**	**MMC**		**AV**	
6			**KTP**		**KTP**	**BRK**	**PYP**	**MMC**	
7			**TP**	**AV**	**TP**	**BRK**	**GRT**		**KTP**
8			**KTP**	**BRK**	**KTP**		**TP**		**AV**
9			**KTP**		**PYP**	**BRK**	**TD**	**PYP**	
10		**KTP**		**PYP**	**TD**	**BRK**	**KTP**		**TD**
11		**TP**		**GRT**		**KTP**	**BRK**	**KTP**	
12			**MMC**	**BRK**	**TP**	**AV**	**TP**		**GRT**
13		**TP**	**AV**		**GRT**	**BRK**	**KTP**		**KTP**
14			**TD**	**BRK**	**KTP**		**AV**		**KTP**
15		**KTP**		**KTP**		**TD**	**BRK**	**TD**	
16		**MMC**	**GRT**	**BRK**	**AV**	**TP**	**AV**		**PYP**
17		**PYP**		**KTP**		**KTP**	**BRK**	**TP**	**AV**
18			**TP**		**MMC**	**BRK**	**KTP**		**TP**
19		**KTP**		**TP**	**BRK**	**AV**		**KTP**	

Table 43. Sample 20 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1			TD		KTP	BRK	KTP		PYP
2		TD		KTP		GRT	BRK	TP	AV
3			TP	AV	BRK	TP		AV	
4			KTP	BRK	KTP		TD		TD
5		TP	AV		TD	PYP	BRK	KTP	
6		AV		MMC	GRT	BRK	TP		KTP
7			MMC	PYP	BRK	AV	TP		KTP
8			AV		MMC	BRK	KTP		KTP
9			PYP	BRK	PYP		KTP		TP
10		PYP		KTP		TD	BRK	KTP	
11			TP	BRK	TP	AV		TD	
12		KTP		KTP	BRK	MMC	GRT		AV
13		MMC	GRT	BRK	KTP		PYP		TP
14			KTP	BRK	TP		AV		GRT
15			KTP		AV	BRK	AV	TP	
16		GRT		TD	BRK	TP		KTP	
17		TP		AV		KTP	BRK	AV	
18		AV		TP	BRK	KTP		MMC	
19		KTP		TP	AV	BRK	MMC	PYP	
20		KTP		GRT		KTP	BRK	GRT	MMC

Table 44. Sample 21 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1		**AV**		**KTP**		**AV**	**BRK**	**TP**	
2		**TP**	**AV**		**MMC**	**PYP**	**BRK**	**TP**	
3		**KTP**		**MMC**		**KTP**	**BRK**	**MMC**	
4			**GRT**	**BRK**	**KTP**		**KTP**		**TD**
5		**TP**		**TD**	**BRK**	**TD**		**KTP**	
6		**GRT**		**AV**	**BRK**	**TP**	**AV**		**TP**
7			**TP**		**KTP**	**BRK**	**MMC**	**GRT**	**MMC**
8			**PYP**	**BRK**	**PYP**		**TP**		**KTP**
9			**KTP**	**BRK**	**AV**		**GRT**		**KTP**
10		**PYP**		**KTP**	**BRK**	**MMC**		**KTP**	
11			**TD**		**TP**	**BRK**	**AV**		**GRT**
12		**MMC**		**TP**	**BRK**	**GRT**		**TD**	
13		**TD**		**KTP**	**BRK**	**TP**		**AV**	
14			**KTP**	**BRK**	**AV**		**TP**		**AV**
15			**TP**	**BRK**	**TD**		**PYP**		**TP**
16			**MMC**	**GRT**		**KTP**	**BRK**	**KTP**	
17			**KTP**		**GRT**	**BRK**	**TD**		**KTP**
18		**AV**		**AV**	**TP**	**BRK**	**KTP**		**PYP**
19			**AV**		**KTP**	**BRK**	**KTP**		**AV**
20		**KTP**		**TP**	**BRK**	**AV**		**AV**	
21		**KTP**		**PYP**	**BRK**	**KTP**		**PYP**	

Table 45. Sample 22 guide weekend schedule.

	Period	1	2	3	4	5	6	7	8
1			TD		PYP	BRK	KTP		PYP
2		KTP		AV	BRK	PYP		KTP	
3		AV		TP		TP	BRK	AV	
4			KTP	BRK	KTP		MMC		TD
5		GRT		TD	BRK	MMC		MMC	
6			TP	BRK	TD		KTP		AV
7			AV		GRT	BRK	KTP		KTP
8			PYP		MMC	BRK	TP		KTP
9			AV	BRK	KTP		AV		KTP
10		TP		GRT	BRK	AV		TP	
11		PYP		KTP		GRT	BRK	KTP	
12		AV		KTP		AV	BRK	TP	
13			TP	BRK	TP		TD		MMC
14			KTP	BRK	AV		GRT		AV
15			GRT	BRK	KTP		PYP		TP
16			MMC		TP	BRK	TP		GRT
17		TD		KTP	BRK	KTP		GRT	
18		MMC		AV		KTP	BRK	KTP	
19		KTP		PYP		KTP	BRK	AV	
20		TP		TP	BRK	TD		PYP	
21			KTP		AV	BRK	AV		TP
22		KTP		MMC	BRK	TP		TD	

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