Modeling and Analysis of Bus Routing Operations at Kuwait Public Transport Company

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Abstract

This paper presents a model and related analysis for scheduling and routing of public buses in Kuwait. First, current bus scheduling system is analyzed in order to identify potential areas for improvements and to investigate appropriate solution approaches. Necessary data are then either collected or estimated depending on availability. The modeling and the analysis are carried out using the collected data. Finally, the resulting bus schedules and routes are evaluated using cost measures. The results show significant improvements and cost savings for the public transport system.

Keywords:
Bus routing, bus scheduling, vehicle routing, city bus scheduling, time tables, heuristic, linear program

1. Introduction

Bus scheduling and routing problems have been studied for more than 40 years. There are plenty of research papers published in the literature. A brief list of related papers are presented in references [1-10]. Most of the models are based on basic tools in operations research, with specific applications developed for the problems considered. In this study, we considered the bus routing problem faced in Kuwait Public Transport Company (KPTC), which has 40 bus routes that connect different parts of the city together with 600 buses operating in these routes. In this paper we present a model and related analysis of the routes in order to improve current scheduling operations and reduce total cost with better service to the passengers. First, current bus scheduling system in KPTC is analyzed in order to identify potential areas for improvements and to investigate appropriate solution approaches for improvement. Necessary data are either collected or estimated depending on availability. The modeling and the analysis are then carried out using the collected data. The resulting bus schedules and routes are then evaluated using some cost measures. The results show significant improvements and cost savings. In order to analyze the public transport system, a complete study of the current routes and schedules is necessary, which in turn requires some important definitions used in the system. These definitions are listed below:

A Major Station is a station where the bus trip starts. A bus cycles are considered complete when the bus returns again to the starting station after leaving the ending station.

A Minor Station is the ending station on the route. It is the last station the bus visits before going back to the starting station.

A Letter is a bus that is working either during a day or a night shift.

A Cycle is the distance that is travelled by a bus from the major station to the minor station and vice versa and it consists of 2 trips.

A Bus Stop is an area where passengers board the bus or are dropped off.

Inter Arrival Time is the specified time interval between a working bus and the next working bus in the same station which is followed on the same route.

Going Trip is the distance that a bus travels from the major to the minor station.

Returning Trip is the distance that a bus travels from the minor to the major station.

In KPTC, currently there are 40 routes that cover almost all areas in Kuwait. Also there are 15 stations that serve as major or minor station. Some of these stations are used by a single route while others are used by several routes. The company schedules their buses on each route based on the season, days of the week, and time of the day. Seasons are divided into Summer, Winter and Ramadan, while days of the week are divided into Friday, Saturday and normal days (rest of the days). Each day's schedule is then further divided into day and night shifts. Furthermore, there are some routes that only operate on Fridays. These schedule variations are done to take into account differences in demand during two shifts in each route. For example, passengers who take Fridays or Saturdays off from their work cause reduction in demands on some routes while increasing demands on others, hence, the change in schedules. Research and Development Department of the company tends to keep the number of buses per shift constant. This causes the inter-arrival per shift to be constant as well without taking into account hour-to-hour variation in number of passengers. Also, the company has different methodologies to provide ticketing service to the passengers, either by ticketing system or by subscription with the price per route length considered in all trips. KPTC provides different packages of subscription and each package covers a set of routes to serve passengers who transport in certain areas. The subscription helps in increasing the revenue but it cannot track which route the passengers use.

After analyzing the system, it was observed that the number of passengers had high variability during different working hours in a day, while the number of buses operating were kept constant. This resulted in some buses moving empty while some others being over crowded resulting a bad service to the passengers. Therefore, we had to focus on this problem, which was found on all routes in the company. Modeling and analysis are carried out to develop some procedures in order to reallocate the buses to routes throughout the day. By solving this problem, we aim at reducing the running costs of different routes and increasing their efficiency. Extra buses have to be allocated to higher income routes in order to generate additional revenue. However, this has to be done within the company's main objective, which is to cover the whole city with available buses and the routes. Also, the company's policies regarding bus allocation has be taken into consideration. Out of the company's 40 routes, it was possible only to address 32 routes due to the limitation of data availability. The remaining 8 routes that were excluded were the ones with the lowest usage rates and the least profitable among all routes. Furthermore, the Friday schedules of all routes were exempted from the analysis because these schedules were different from other days of the week.

2. Modeling of Bus Routing System

After analyzing the system, the following approach was devised to solve the bus routing and scheduling problem considered. The approach consists of four steps.

2. 1. Development of a Linear Programming Model:

First a linear programming model was developed to obtain an initial solution for the routing problem, which could be used as a base for further improvement. The aim is to get the optimal number of assigned seats per route per time slot. LP would result in optimal numbers under specified constraints. GAMS software was used to run the LP model, which is described next.

As mentioned above, 32 routes that cover most of Kuwait areas were included in the model. The routes numbers selected were as follows:

11, 12, 13, 15, 16, 17, 18, 19, 21, 23, 24, 34, 38, 39, 40, 41, 51, 59, 66, 99, 101, 102, 103, 105, 106, 139, 500, 501, 506, 507, 999, 1022

Each route had a different cycle time according to the destination. The total number of buses assigned to 32 routes was 400 buses; 109 of size 30, 143 of size 40, 11 of size 43, and 137 of size 46, which resulted in 15,765 available seats. Currently, the numbers of passengers on each route fluctuate during the day, while the number of buses operating is kept constant on each route. The passenger density per time slot was estimated for each route and a minimum number of buses was set to ensure that there are at least 1 bus per hour for any route at any time of the day. The details of calculation to determine this minimum will be presented later. The LP formulation is as follows:

Minimize $$Z = \sum_{i=1}^{32} \frac{X_i}{P_i}$$

Subject to:

$$X_i \geq P_i$$

$$\sum_{i=1}^{32} X_i \leq N$$

$$X_i \geq 30M_i \qquad i=1,\dots,32$$

Where,

i = Route No. (32 Routes: 11, 12, 13, …, 1022)

P_i = Number of passengers on route i.

N = Total number of available seats

M_i = Minimum number of buses on route i

X_i = Decision variable; number of assigned seats on route *i.*

The objective function minimizes the number of seat-hours assigned to each passenger under the three constraints as: (a) each passenger is assigned at least one seat-hour; (b) total number of assigned seat-hours on all routes must be less than or equal to available number of seat-hours; (c) number of seat-hours assigned to route i must exceed the minimum number of buses of size 30. The model was used to get the optimal number of assigned seats per route per time slot. However, few considerations were taken into account both in terms of the functionality of the model itself and its output. In particular, the model was run for each of 20 time slots separately in order to limit the number of variables to 100. Although there were different bus sizes, the last constraint used bus size 30, which is the smallest, because the bus type for each route was not decided yet. Using bus size 30 ensured that it did not assign more than necessary; but could assign few. The number of buses will be checked to make sure M_i is met for all time slots. The results obtained could be fractional and rounded later.

2. 2. Assignment of Bus Types to the Routes

After obtaining the solution for the LP model, which gives the number of seats assigned to each route, the result has to be converted to the number buses per route per time slot. The following manually created criteria to re-assign bus type to each route were used:

a) Bus type or size has to be proportionally increased/decreased according to the increase/decrease in the number of seats or number of passengers.
b) Bus type or size is inversely increased/decreased according to decrease/increase in the cycle time of the route; i.e. with increase in cycle time, inter-arrival time has to decrease and hence the size of the bus.

From (a) and (b), a ratio R was calculated by dividing the number of seats by the cycle time. Bus types were then assigned to routes according to the highest ratio to lowest and the available number of each bus type.

2. 3. Consideration of Time Shifts

Different routes have similar patterns throughout the day. The peak hours and peak-off hours are very similar as seen in figure 1. Time slots were grouped into 4 shifts, excluding the first two and the last two hours of work. This was done as it was deemed unpractical to change bus schedule from one hour to another which makes the whole process so complex to apply. These shifts were decided after studying the trends in the graph of changes in seats per time slot for all routes together. Figure 2 illustrates the time slots and the corresponding total seats. The shifts were: 1st shift from 4:00 AM to 6:00 AM; 2nd shift from 6:00 AM to 9:00 AM; 3rd shift from 9:00 AM to 13:00 PM; 4th shift from 13:00 PM to 18:00 PM; 5th shift from 18:00 PM to 22; and 6th shift from 22:00 PM to 24:00 PM. After deciding the time shifts, the maximum number of seats in each shift was used for the whole hours of the shift to ensure a full coverage of demand.

2. 4. Establishing Bus Schedules

After finding the optimal number of buses for each time slot and shift, actual bus schedules were to be determined next. As our solution requires changing the number of buses on each shift, we proposed to *stop* extra buses at the stations until they are needed again within the day. That is when the bus starts running on the route again. One of the biggest issues is that if we let buses stop and run as the drivers or customers want, it would make the inter-arrival times between buses inconsistent. That can cause a major loss of customer goodwill and some passengers might see different buses on the same route every 3 minutes while others wait over an hour. To make sure that this problem does not occur, a fixed inter-arrival time was implemented between shift changes to ensure consistency of inter-arrivals. In order to achieve this objective, bus *delaying* was employed. Asking the driver of the bus to wait a few minutes at the station after shift change can re-arrange the buses. For example, if we have 3 buses working on a 90min cycle time route (i.e. inter-arrival time of 30 minutes) and we want to reduce it to 2 buses (i.e. inter-arrival time of 45 minutes) then we would require that 1 of 3 buss stop and another to wait for 15 minutes once he reaches the station while the last bus would continue normally. So the inter-arrival time would be 45 minutes between the 2 remaining buses instead of 30 minutes and 60 minutes if the 2nd

bus was not stopped. Bus schedules were made for each route. A sample is shown in Table 1 for route 101. The delays show how long a bus should wait after reaching a station as scheduled.

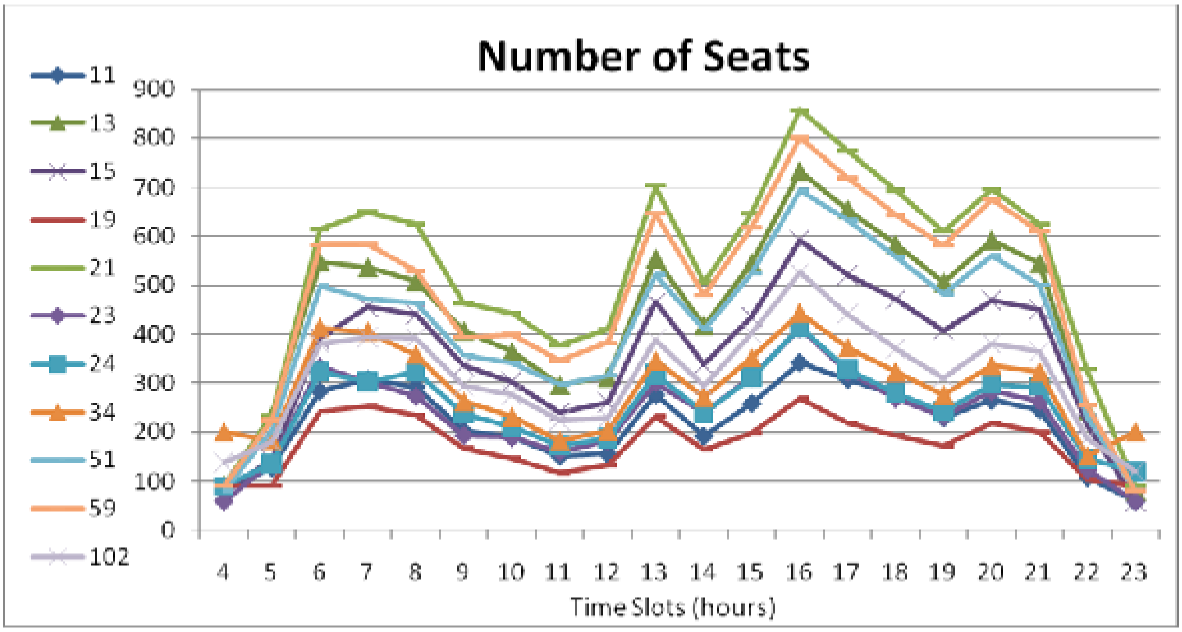

Figure 1: Changes in the number of seats per time slot for selected 11 routes.

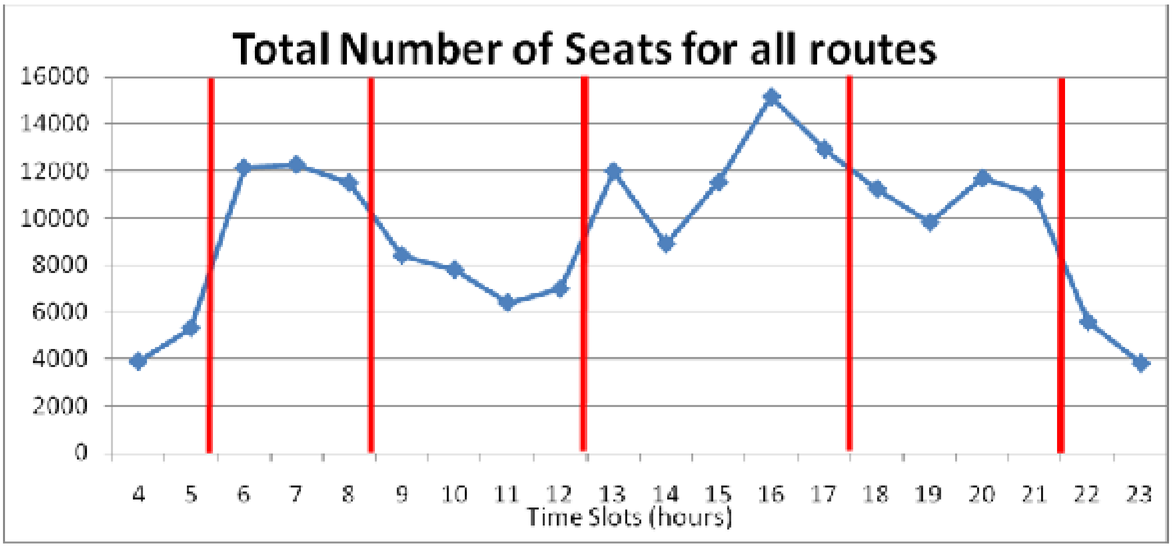

Figure 2: Total number of seats for all routes per time slot with the allocated shifts

2. 5. Estimation of Bus Utilizations

To compare the solution with the current system, some performance measures are needed. One of the performance measures that will be used is the utilization of the buses. A lot of work was done to calculate the utilization of the current system. In the end, utilization of each time slot per route was found. First the following equitation is used for utilization calculation.

Utilization= Average Number of Passengers Getting on Bus/Passenger Capacity of Bus

Utilization is basically the ratio of number of passengers to the passenger capacity. The number of passengers refers to the average number of passengers getting on the bus within the time slot, while passenger capacity is how many passengers the route can handle for that time slot. Each of these data values were estimated and can be found in the following section. Also below is a detailed description of how utilization was found with respect to the data.

Table 1: An example bus schedule for route 101.

Bus	Major	D	Minor	D	Major	D	Minor	D	Major	D	Minor	D	Major	D	Minor	D	Major	D	Minor	D	Major	D	Minor
1			04:00		06:00		08:00		10:00	13	12:13		14:13	13	16:26		18:26		20:26		22:26		00:26
2			05:00		07:00	20	09:20	13	11:33		13:33	13	15:46		17:46		19:46		21:46		23:46		01:46
3	04:00		06:00	13	08:13		10:13		12:13		14:13		16:13		18:13	13	19:26		21:26		23:26		01:26
4	05:00		07:00	6	09:06								13:59		15:59		17:59		19:59				
5			06:40	13	08530		10:53		12:53		14:53	13	17:06		19:06		21:06		23:06		01:06		
6			07:33		09:33		11:33		13:33		15:33		17:33		19:33	13	21:46		23:46		01:46		
7					06:26		08:26				13:19		15:19		17:19		19:19						
8					06:53		08:53		10:53		12:53		14:53		16:53		18:53	13	21:06		23:06		01:06
9					07:46		09:46				14:39		16:39		18:39								

2. 6. Data Collection

Total Number of Passengers per Route per Hour:

This was calculated based on different ticketing systems used in KPTC buses for a period of 6 months (from October 2009 to March 2010). Number of passengers was found for every hour for that period for each route (over 90,000 data values). The average number of passengers per hour for the top 4 routes can be found in table 2. The company has three different types of ticketing systems as: Automated Tickets; Manual Tickets; and Subscription Passes. The number of passenger per route per time slot (hour) for each type of ticketing system was found separately. Number of passengers was estimated for every hour as:

$$\text{Total Number of Passengers} = TP_h + SP_h = AP_h + MP_h + SP_h$$

Where, TP_h stands for tickets passengers per hour while SP_h is subscription passengers per hour. Number of passengers is basically the sum of those two. Ticket passengers can be divided furthermore into automated tickets and manual tickets. AP_h and MP_h stand for automated and manual passengers per hour. The estimation of ticket passengers and subscription passengers can be found in details below.

Table 2: Average number of total passengers per hour for top 4 routes.

Route	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg
16	73	515	987	940	932	677	612	493	574	1024	751	996	1312	1105	949	806	997	945	516	27	762
21	28	231	616	649	625	464	443	379	410	702	504	645	856	774	694	610	695	625	329	17	517
51	12	201	498	473	465	356	342	296	315	521	410	523	692	634	557	481	559	502	230	6	405
59	26	224	583	584	529	394	400	345	382	647	481	617	799	720	644	580	674	610	255	5	479

Percentage of Automated Tickets Passengers (AP%):

$$AP\% = \frac{AR}{AR + MR + 3SR}$$

AR is the revenue generated from automated passengers. MR is the revenue from manual passengers. SR is the revenue from subscription passengers. The latter was multiplied by 3 because passengers using subscription rides are 3 times as many as normal passengers for the same revenue. It was estimated that any passenger using the subscription rides 4-8 times a day (6 times on average), while other passengers ride twice a day. That is how subscription passengers ride 3 times as much as tickets passengers for every KD. The revenues were available for each month separately for each route. AP% was found for each route.

Automated Ticket Passengers per Hour:

The number of passengers for this type was available for every hour for a 6 month period for each route in a data file provided by the company.

Manual Ticket Passengers per Hour:
For estimating the manual tickets passengers only the revenue per month per route was available. This revenue was used to get the ratio of manual passengers to automated passengers per month. The ratio was used to get the number of passengers per hour from the automated passengers per hour as follows:

$$MP_h = AP_h \times \frac{MP_m}{AP_m}$$

Where MP_h and MP_m stand for manual tickets passengers per hour and per month, respectively. and AP_h and AP_m stand for automated tickets passengers per hour and per month, respectively. The ratio of MP_m to AP_m is assumed to be the same as the ratio of MR_m to AR_m. MR and AR stand for manual and automated revenues. Since passengers using manual or automated tickets have to pay the same price, the ratios of passengers and revenues will be the same. The equation is valid with the assumption that manual ticket holders' behavior throughout the day is similar to the behavior of automated ticket holders.

Subscription Passengers per Hour:

$$SP_h = AP_d \times \frac{SP\%}{AP\%} \times SP_{HD}$$

SP_h stands for subscription passengers per hour. They are the subscription passengers that use their passes to ride the bus. AP_d is the sum of automated passengers for a single day. SP% stands for the subscription passengers' percentage for each month; it was found that it is constant over the different 6 months. The value of SP% was 49.22%. AP% is the percentage of monthly automated passengers as explained above. SP_{HD} is the distribution of subscription passengers each day over different hours of the day.

$$SP_{HD} = \frac{TotP_{HD} - TP\% \times TP_{HD}}{SP\%}$$

Where, $TotP_{HD}$ is the total passengers' hourly distribution over the day. How we got $TotP_{HD}$ is explained in details later. TP_{HD} is the ticket passengers' distribution over the day. It was found from the data file we have for the 6 months of automated passengers. We assumed that automated ticket passengers and manual ticket passengers have the same behavior since the latter is only used when automated system is unavailable. Therefore, automated passenger hourly distribution is the same as the total tickets hourly distribution which is the summation of automated and manual. TP% and SP% are as explained above and are 50.78% and 49.26%, respectively. The equation above is a re-arrangement of the weighted average of ticket and subscription passengers' hourly distribution. Below is the original equation for clarification. Also, a comparison between the 3 types of hourly distributions clarifies how $TotP_{HD}$ is the weighted average and how SP_{HD} was found from $TotP_{HD}$ and TP_{HD} as seen in figure 3.

$$TotP_{HD} = SP_{HD} \times SP\% + TP_{HD} \times TP\%$$

We got $TotP_{HD}$ by using a manual study the company did. The study calculated the number of passengers riding the bus for each hour separately for both directions of the route. The study was done for several routes. The hourly distribution we got from it is for all passengers.

Passenger Capacity:

$$\text{Passenger Capacity} = \frac{BC \times AL_h}{\text{Avg Time}}$$

Passenger capacity refers to the maximum number of passengers a route can handle in an hour. BC is bus capacity and it is the size of the bus (e.g. 30 seats). AL_h stands for the actual number of letters assigned to a route at a certain hour. Avg. Time refers to the estimated average time a passenger stays on the bus. For our calculations, we took it to be 0.75 hour. AL_h was calculated from scheduled letters as will be explained later.

Minimum Number of Buses (Mi) from the Model:
One of the things the model was addressing was the minimum number of buses allowed at anytime. This value came from the idea that at any route at anytime there should be a bus passing by at least every hour. One of KPTC's main objectives is to provide coverage. To increase customer satisfaction, a maximum of 1-hour inter-arrival between buses was set.

M_i = Cycle Time/ 60 minutes

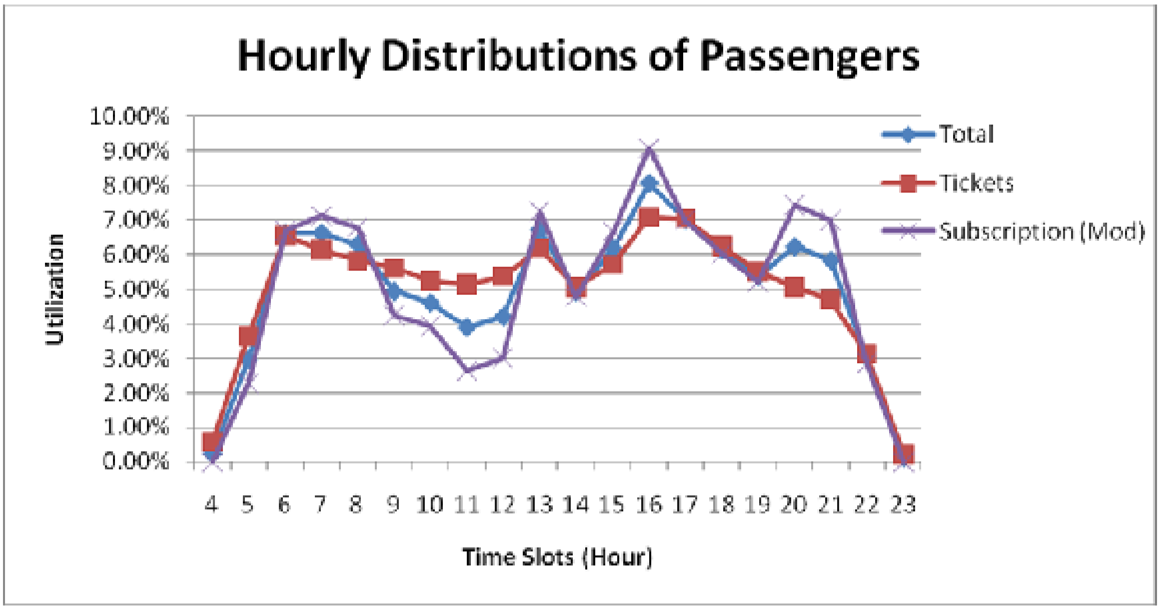

Figure 3: A comparison of hourly distributions for total, tickets, and subscription passengers.

Bus Types:
The company has 4 different types of buses that differ in their capacity of passengers. These bus capacities are 46, 43, 40, and 30 passengers. Currently, the company assigns the type of buses per route based on their density of passengers only. Each route has a scheduled number of buses assigned to it. In the model, the scheduled number of buses used were 400 buses for the 32 routes. The available numbers of buses of each type were 109 of size 30, 143 of size 143, 11 of size 43, and 137 of size 46.

Actual Letters (Number of Buses) per Hour:
The actual number of buses operating throughout 2009 was found to be less than the scheduled number. The issue is due to insufficient number of buses or drivers throughout the year. We estimated the actual number of letters (buses in a route) for each hour as follows.

$$AL_h = SL_h \times R_{\frac{AL}{SL}}$$

SL_h is the scheduled number of buses per hour. It was collected from their current schedules based on how many buses should be running each hour. $R_{AL/SL}$ is the ratio of actual percentage of buses running throughout the month compared to the scheduled ones. On average, it was found to be around 86-90%. The ratio is different for each route. AL_h was calculated for every hour everyday for each route.

Utilization of the Buses in the Current System:
The utilization of the bus is the ratio of total passengers to passenger capacity as explained before. As we found that the current system schedules provide constant passenger capacity although passenger densities vary. We found the utilization of each hour for each route of the months of October 2009 to March 2010. The average utilization for each time slot (hour) was found. There was a lot of variation in the utilizations. Highest utilization was at hour 16:00. That is the highest peak over the day as seen in figure 4. This is because of higher passenger density. For hour 22:00, the utilization is higher than hour 21:00 because buses start to stop operating around that time so even though the passengers are less, the utilization is higher due to decreasing number of buses. Utilization over different routes is varying as well. For each route, a 95% CI (confidence interval) was constructed. The average and both upper and lower limits of each route are shown in figure 5.

Number of (bus-hours) per day:
From the company's records, we got the number of buses operating per route per time slot from which we calculated the total number of bus-hours per route and hence the total number of bus-hours per day which was 7239 for the current system as seen in table 3.

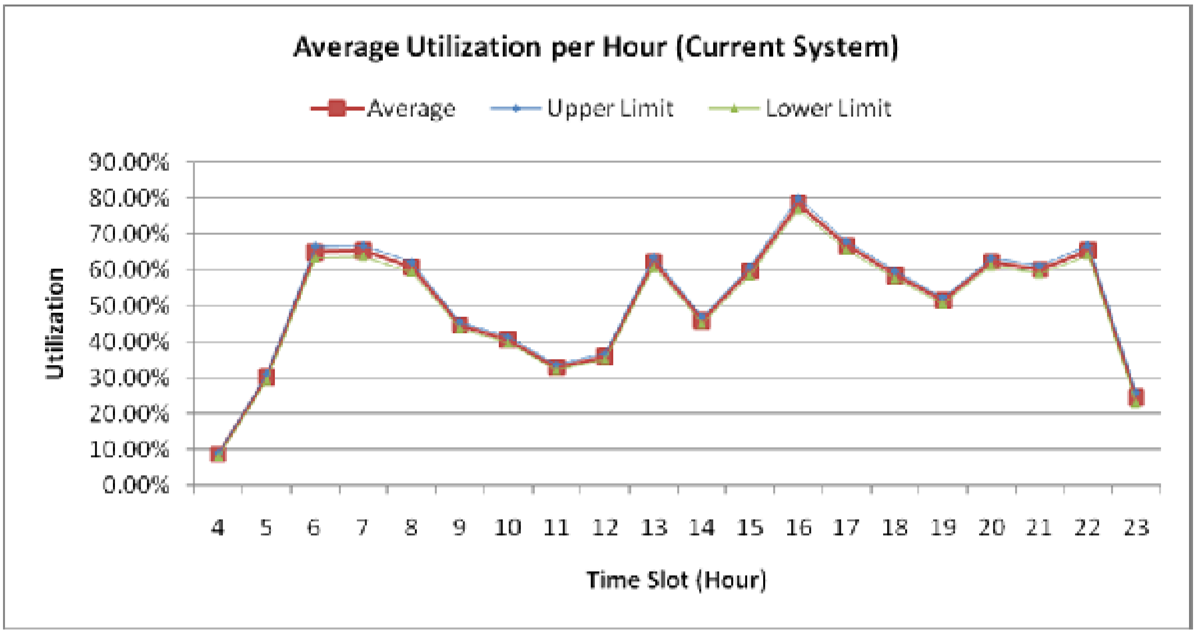

Figure 4: Average utilization per time slot (hour) over all routes of current system.

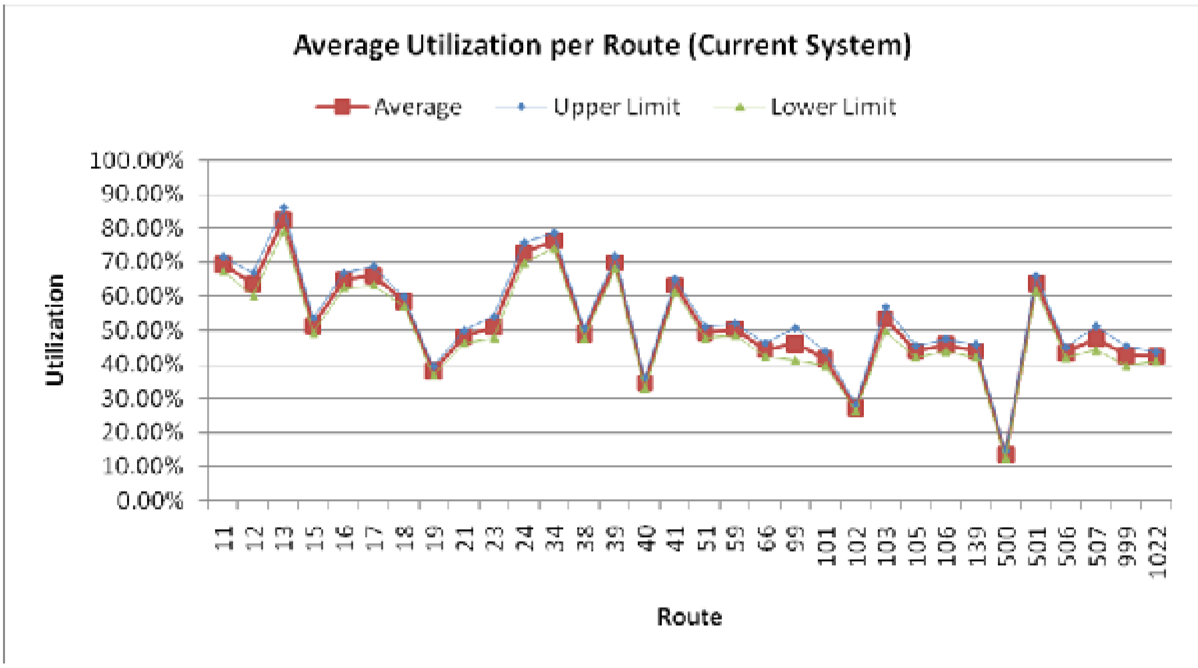

Figure 5: Average utilization per route over all hours of the current system.

Table 3: Number of buses in operation per hour and bus-hours for the top 4 routes and the total for 32 routes.

Route	Bus per Hour																				Total
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Bus-Hours
16	9	23	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	23	14	2	431
21	6	18	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	21	6	0	381
51	3	15	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	15	5	0	323
59	3	14	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	14	4	0	305
Total 32 Routes	118	364	409	410	411	411	411	411	411	411	411	411	411	411	410	409	408	396	195	10	7239

Cost Calculations:
The following are the major direct costs associated with operating the buses in the current system.

(i) Drivers Salaries and Overtime:
Drivers in the KPTC are divided into 3 different categories in terms of their salaries. These salaries are 135, 155 and 200 KD per month. In all our calculations, we used 155 KD as the average of all drivers' salaries as there was more drivers in each of the 135 and 155 categories than in the 200 category. Total cost due to salaries per route was calculated using the average salary and the number of drivers per route that was taken from the company's records. The estimated total of driver salaries per month in the current system is 123,845 KD.

As for the over-time cost, the company pays drivers for each hour of over-time the equivalent of their normal hourly cost. Using the average salary, the over-time hourly cost will be:

$$\frac{155\ KD}{26\ (working\ days\ of\ a\ month) \times 8\ (hours\ of\ work\ per\ day)} = \frac{155}{26 \times 8} = 0.745\ KD/hr$$

The total cost of over-time per route was calculated based on the number of pre-allocated over-time hours in the drivers' daily schedules from the company. The total over-time cost for the company in the current system is estimated to be 10,423.8 KD. Table 4 summarizes salaries and over-time costs for the top 4 routes and the total for 32 routes considered.

Table 4: Driver's salary and overtime in the current system.

Route	Number of driver	Overtime (hours)	Salary (KD)	Overtime cost per month (KD)
16	48	48	7440	930
21	44	27	6820	523
51	38	11	5890	213
59	36	17	5580	329
Total (32 Routes)	799	538	123,845	10,424

(ii) Fuel Costs:
Fuel is what makes the bus run. Without it, no bus will operate. The current system costs for top 4 routes and the total of the 32 routes are listed in table 5.

(iii) Replaced Parts Costs:
The replaced parts are the costs associated with replacing bus parts in the maintenance garage. Since the bus runs around 18-20 hours daily, parts breakdown frequently. The current replaced part costs for top 4 routes and the total of the 32 routes are listed in table 5.

(iv) Bus Depreciation Costs:
The depreciation is how much of the bus value is lost yearly due to using it. The company usually depreciates the buses over 6 years. The current system costs for top 4 routes and the total of 32 routes are listed in table 5.

Table 5: Bus-hours and fuel, depreciation, and spare parts costs of the current system.

Route	Bus-hrs per day	Fuel per day (KD)	Fuel per month (KD)	Dep. per day (KD)	Dep. per month (KD)	Parts per day (KD)	Parts per month (KD)
16	431	314	8153	299	7766	241	6273
21	381	269	7000	225	5857	203	5268
51	323	248	6456	328	8535	198	5139
59	305	220	5720	359	9338	196	5102
Total (32 Routes)	**7239**	**5754**	**149592**	**5216**	**135612**	**5631**	**146401**

(v) Driver schedules:
In the current system, drivers have to work 8 hour-shifts per day for 6 days per week. In reality, they also do one to three hours of over-time per shift. The total number of drivers needed to fulfill the current schedule is 799 drivers as given in table 4.

3. Model Output and Analysis of Results

In this section, the optimal number of seats per route per time slot, and hence the number and types of buses, which will result from the linear programming model, is discussed. These values will eventually result in changed driver schedules and salaries, fuel consumption, bus maintenances and depreciations. All such changes put together will form our proposed improved system that should tackle the main problem in the company's current route system and schedules.

3.1. Model Output

After running the LP model, we got the number of optimal assigned seats for each route per time slot. Table 6 shows the output of the model for top 4 routes per time slot. Using the criteria mentioned above for bus type selection per route, the results in table 7 are obtained. After deciding the bus type per route, the number of buses per hour per route was calculated. Afterward, the maximum number of buses per shift was allocated for the whole shift in each route to ensure full coverage as shown in table 8.

Table 6: Output from the model (optimal number of seats) for top 4 routes.

Route	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
16	90	516	987	941	933	677	613	494	574	1024	751	997	1312	1106	950	807	997	945	517	90
21	60	231	616	650	626	464	443	379	410	703	505	646	857	775	695	611	696	626	329	60
51	60	202	498	473	465	357	342	297	316	521	410	524	693	635	558	482	560	502	231	60
59	60	224	583	585	530	394	400	346	382	647	481	618	800	720	644	581	675	610	255	60

Table 7: Assigned bus types and numbers per route (*Selected bus type per route is highlighted)

Route	Max seats	CT (min)	Ratio	Number of buses per Type*			
				46	43	40	30
59	800	90	8.89	**18**	19	20	27
16	1312	180	7.29	**29**	31	33	44
21	857	120	7.14	**19**	20	22	29
51	693	100	6.93	**16**	17	18	24
15	592	90	6.58	**13**	14	15	20
13	733	120	6.11	**16**	18	19	25
18	598	140	4.27	**13**	14	15	20
506	557	160	3.48	**13**	13	14	19
23	602	120	3.43	9	10	**11**	14
66	432	180	3.34	14	15	**16**	21
102	412	160	3.29	12	13	**14**	18
103	526	140	3.14	10	11	**11**	15
106	440	200	3.10	14	15	**16**	21
507	620	140	3.09	10	**11**	11	15
11	342	120	2.85	8	8	**9**	12
24	607	150	2.77	10	10	**11**	14
39	372	220	2.76	14	15	**16**	21
41	415	140	2.66	9	9	**10**	13
999	511	200	2.56	12	12	**13**	18
139	337	140	2.41	8	8	**9**	12
34	443	200	2.22	10	11	12	**15**
12	506	160	2.19	8	9	9	**12**
105	351	250	2.02	11	12	13	**17**
1022	130	160	1.69	6	7	7	**10**
19	268	160	1.68	6	7	**7**	9
501	371	80	1.62	3	4	4	**5**
38	271	180	1.58	7	7	8	**10**
40	285	260	1.43	9	9	10	**13**
17	217	160	1.36	5	6	6	**8**
99	209	175	1.19	5	5	6	**7**
101	254	240	1.06	6	6	7	**9**
500	90	180	0.50	2	3	3	**3**

Table 8: Assigned number of buses for top 4 routes per shift.

Route	Bus per Shift					
	1	2	3	4	5	6
16	12	22	15	29	22	12
21	6	15	11	19	16	8
51	5	11	8	16	13	6
59	5	13	9	18	15	6

3.2. Bus Allocation and Utilizations in the Improved Routing System

Balancing bus utilizations was one of the main goals of the improved system. After making all the schedules, the utilization had to be recalculated for the new system to make sure the goal was met. One might think the average utilization should be constant over all hours since our solution basically builds up on that. But the shifts made and other constraints affected the resulting utilization to have some variations. The improved average utilizations for all routes per hour were rather close to expected. For the utilization per route, the utilizations are almost a straight line except for route 500. The reason was that route 500 had low passenger density but the constraint of minimum number of buses forced it to use more buses than needed. This is what causes it to have such a low utilization as seen in figure 6.

Per hour utilization had more variation because of the fixed number of buses for each shift. Hours with fewer passengers than the maximum passenger of that shift will have lower utilization. Hours 4:00 and 23:00 have very low utilization because those 2 hours are starting and ending hours where the number of passenger is very low and number of buses reflects hours 5:00 and 22:00. Overall, the utilization is balanced out as seen in figure 7. For each route, a 95% CI (confidence interval) was constructed. Similarly, a 95% CI was constructed for each hour as well. The CI's represent what values the average weekly utilizations would be 95% of the time if the improved system would be implemented.

From the model's output, we eventually got the number of buses operating per route per time slot from which we calculated the total number of bus-hours per route and hence the total number of bus-hours per day which was 5830 for the improved system as shown in table 9.

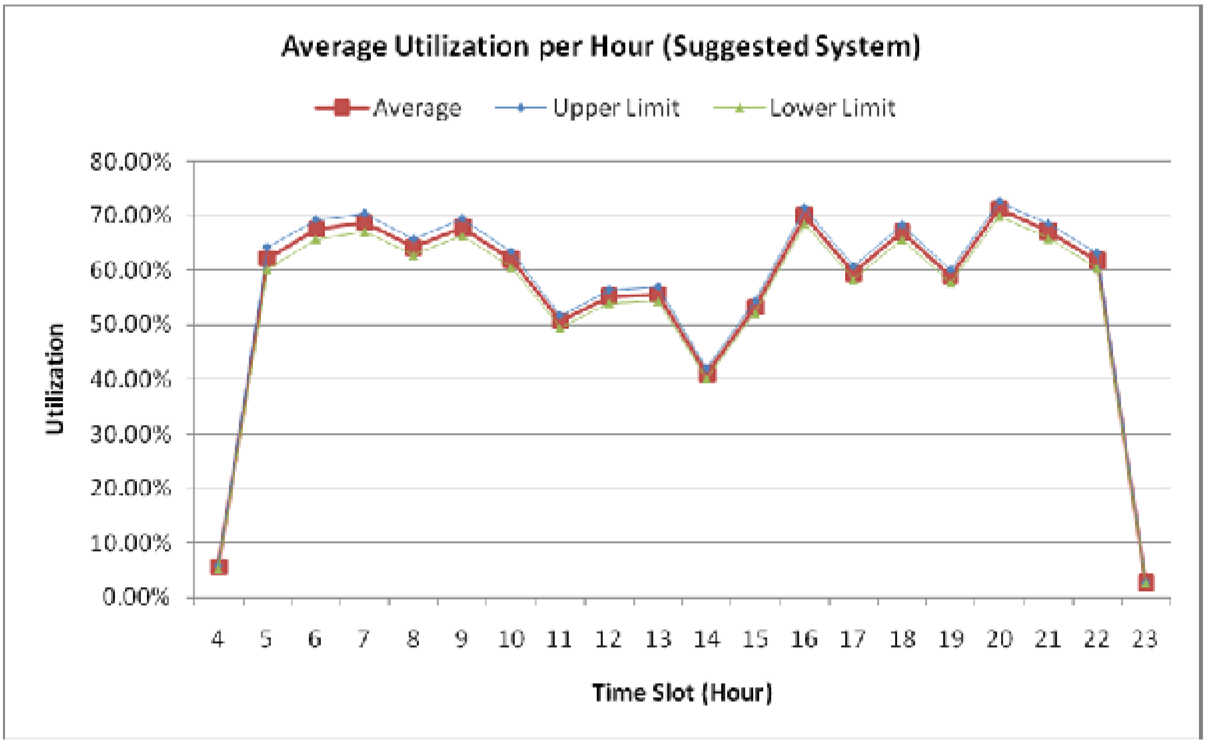

Figure 6: Average utilization per time slot (hour) over all routes of improved system.

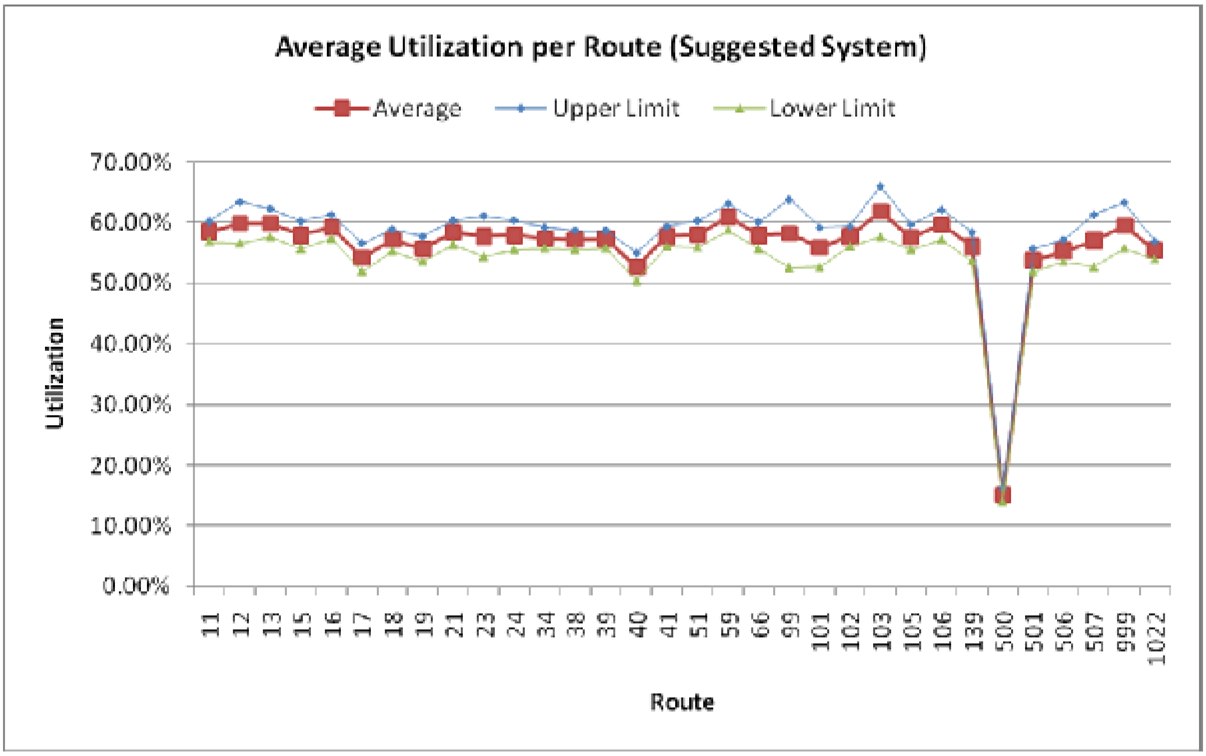

Figure 7: Average utilization per route over all hours of the improved system.

Table 9: Number of buses in operation per hour and bus-hours for the top 4 routes and the total for 32 routes in the improved system..

Route	Bus per Hour																				Total
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
16	12	12	22	22	22	15	15	15	15	29	29	29	29	29	22	22	22	22	12	12	407
21	6	6	15	15	15	11	11	11	11	19	19	19	19	19	16	16	16	16	8	8	276
51	5	5	11	11	11	8	8	8	8	16	16	16	16	16	13	13	13	13	6	6	219
59	5	5	13	13	13	9	9	9	9	18	18	18	18	18	15	15	15	15	6	6	247
Total (32 Routes)	157	157	336	336	336	231	231	231	231	400	400	400	400	400	312	312	312	312	168	168	5830

3. 3. Costs in the Improved Routing System

Major expected costs associated with operating the buses according to the improved system are explained in this section. First, the driver salaries are calculated using the same method given in data collection section for driver salaries in current system. Driver salaries in the improved system resulted in estimated total of 114,080 KD per month as shown in table 10. Fuel consumption costs are listed per day and per month for top 4 routes and the total over 32 routes in table 11, which also shows the expected costs of replacing parts and the bus depreciation. Depreciation was based on the fact that the company used each bus for 6 years and runs 20-hours a day. However, in the improved system, the numbers of years are estimated to be 7.5 years because the bus runs around 16-hours a day on average.

3. 4. Driver Schedules in the Improved Routing System

In the improved system, drivers are meant to complete 48 hours of driving per 6 days of a week with varying number of hours per shift from one day to another. For example, one driver can work 4.5 hours one day, followed by 5 hours the next day, then 7 hours, 10.5 hours, and so on till they complete their 48 hours of the week. Hours done passed the 48 limit per week for the drivers will then be counted as over-time for them. The total number of drivers needed for this schedule is 736 drivers which is less than the current schedule as the number of bus-hours has been reduced in the improved system. An example of the drivers' schedule for one route is illustrated for route 11 in table 12. The Table shows which shifts each driver works. For example, drivers 1 and 2 will work in shifts 1 and 2 which will make them work a total of 4.5 hours each as shown at the right side of the table. Another example is drivers 11, 12, 13, and 14, which will work during shifts 4 and 5 for a total of 9 hours each. The bottom right of the table shows the average working hours for a driver working on this route. If a single driver works all the scheduled hours, he would have an average of 7.74 hours a day of work which is approximately 46.5 hours a week. That way, the company will not need to pay him overtime.

Table 10: Number of Drivers and salaries for the improved system.

Route	Number of Drivers	Salary
16	51	7905
21	34	5270
51	27	4185
59	31	4805
Total (32 Routes)	736	114080

Table 11: Bus-hours and fuel, depreciation, and parts costs for the improved system.

Route	Bus-hrs per day	Fuel per day (KD)	Fuel per month (KD)	Dep. per day (KD)	Dep. per month (KD)	Parts per day (KD)	Parts per month (KD)
16	407	296	7699	282	7333	228	5924
21	276	195	5071	163	4243	147	3817
51	219	168	4377	223	5787	134	3484
59	247	178	4632	291	7563	159	4132
All 32 routes	**5830**	**4689**	**121919**	**4209**	**109422**	**4584**	**119177**

4. Overall Improvement of the Proposed System

Analysis and comparisons made between current system in the KPTC and the improved one that resulted from this project revealed different improvements in more than one area. As mentioned in previous section, utilization in the current system was 55% while in the improved one it went up to 61%, which represented a 10% increase in utilization. Furthermore, comparing the graphs of utilization shown by figure 8 for per route and figure 9 for per hour, we can see that the improved system results in a more balanced utilization which in turn can potentially provide the company with such benefits as less buses running empty and more customers using KPTC during the time slots when passengers seek alternative buses due to full KPTC buses. In the first graph (figure 8) for the average utilization per route, it can be seen that only route 500 has very low utilization in both cases of current and improved systems. That is because route 500 had a low passenger density; but it was forced by the model to have the minimum number of buses to use, which is more buses than needed, and hence lower utilization. In terms of the working hours for the 32 routes, there will be a 20% reduction in working bus-hours in the improved system compared to the current one (5830 hours compared to 7239 hours in the current system). Such reduction will results in the following: Fuel costs will be reduced by 1064 KD per day (18.5%) in the improved system which is equivalent to a 27,664 KD of saving per month. Costs of replacing spare parts in the current system reach 146,401 KD for all routes per month, while in the improved system, these cost are reduced by 27,224 KD, which represent a 18.6% of expected savings. The improved system promises a saving of 26,190 KD in depreciation costs per month which is equivalent to a 19.3% reduction of such costs in the current system which was around 135,612 KD per month. Reduction in bus-hours resulted in the reduction of needed number of drivers and hence their salaries. By applying the improved system, the number of drivers will go down from 799 to 736 drivers. Accordingly, the estimated total drivers' salaries will be reduced from 123,845 KD to 114,080 KD with the over-time hours reduced from 10,423 KD to zero. Overall, the improved system will result in a reduction of 20,188 KD which correspond to 15% savings in costs in this category.

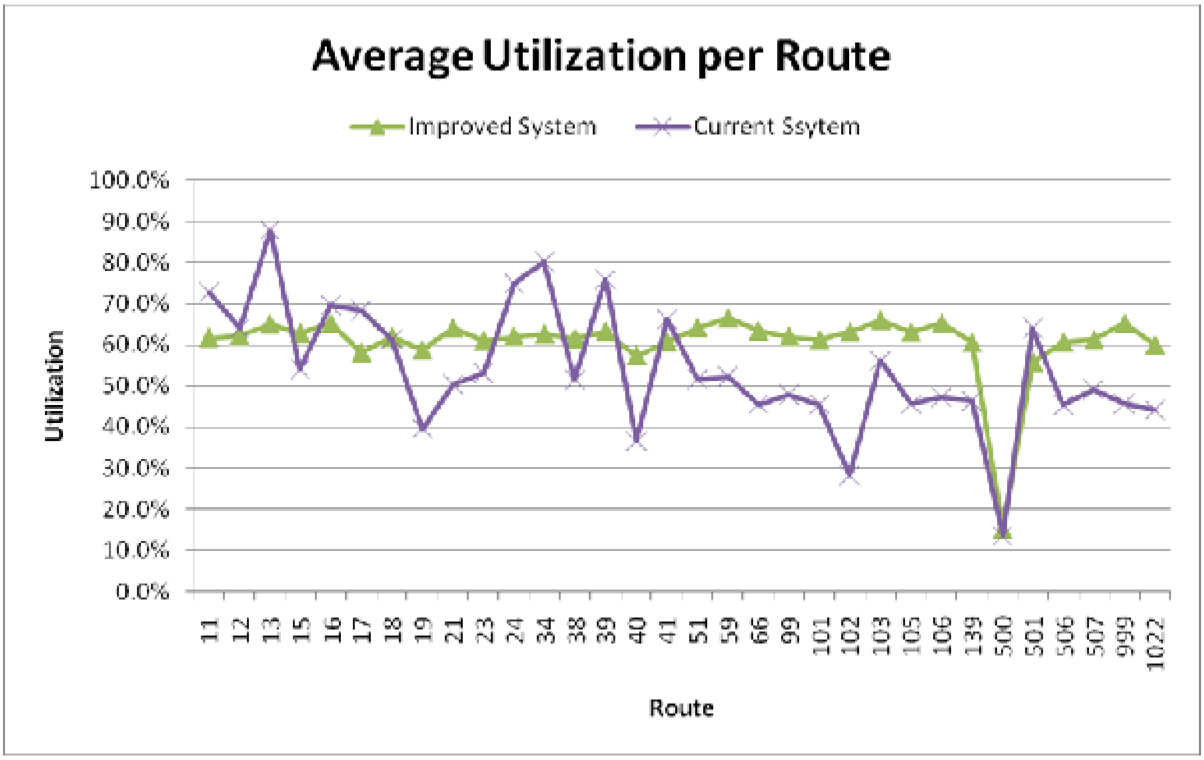

Figure 8: A comparison of average utilization per route for current and improved systems.

Table 12: Drivers' schedule for route 11

Driver	Shift						Working Hours
	1	2	3	4	5	6	
1							4.5
2							4.5
3							8.5
4							8.5
5							7
6							7
7							7
8							7
9							5
10							5
11							9
12							9
13							9
14							9
15							10.5
16							10.5
17							10.5
					Average Hours		7.74

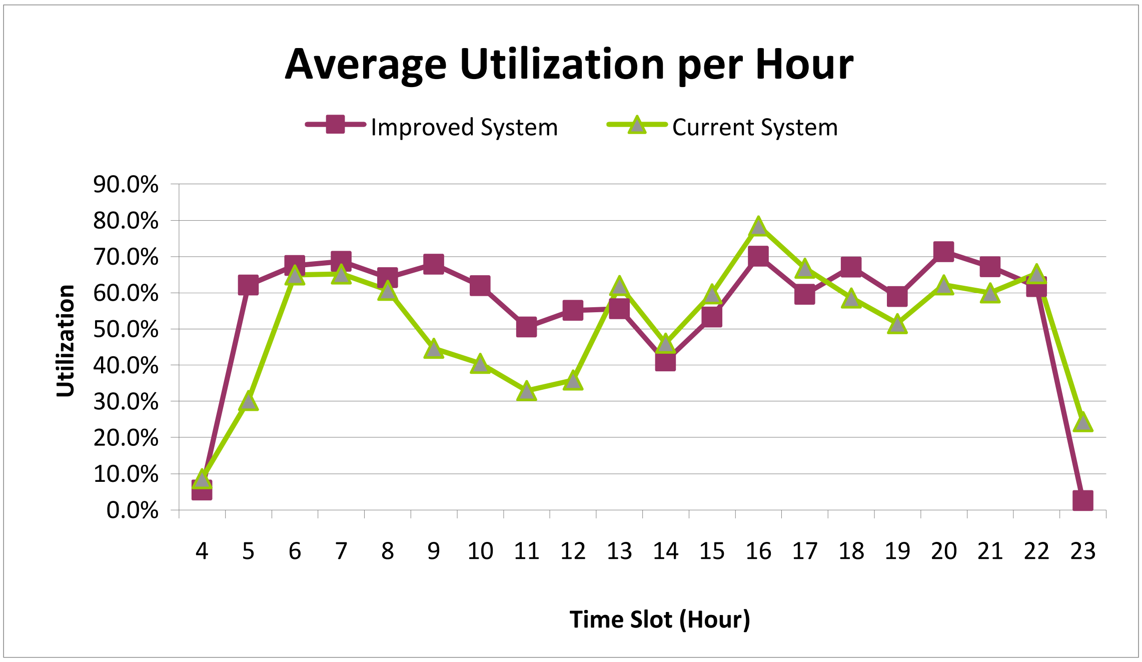

Figure 9: A comparison of average utilization per hour for current and improved systems.

It has to be noted here that the company requires more drivers than it need to run all routes as in any single time there have to be a number of drivers on their annual leaves which makes the estimated salaries, both in the current and improved systems, less than what they should be. Accordingly, the size of reduction in costs could be different from the calculated one here; however, the percentage of reduction should remain, more or less, the same at 15%. Cost savings for all cost types together is rather big. As we calculated the savings for winter season only and without Fridays, our cost per month represents 26 days only. We did not calculate annual savings because we did not take into account summer season. For the total savings and comparison of the costs see table 13 and Figure 10. The improved drivers' schedule will provide the company with the flexibility needed to match the new bus schedules. It also improve drivers attendance and reduces their sick leaves by providing them with light days were than can have more time for themselves.

Table 13: A comparison of current and improved systems different costs and saving.

Type	Current System (KD/month)	Improved System (KD/month)	Saving (KD/month)	Saving (%)
Drivers Salaries	134,269	114,108	20,161	15%
Fuel	149,592	121,919	27,673	18%
Replaced Parts	146,401	119,177	27,224	19%
Buses Deprecation	135,612	109,422	26,190	19%
Total	565,874	464,626	101,248	18%

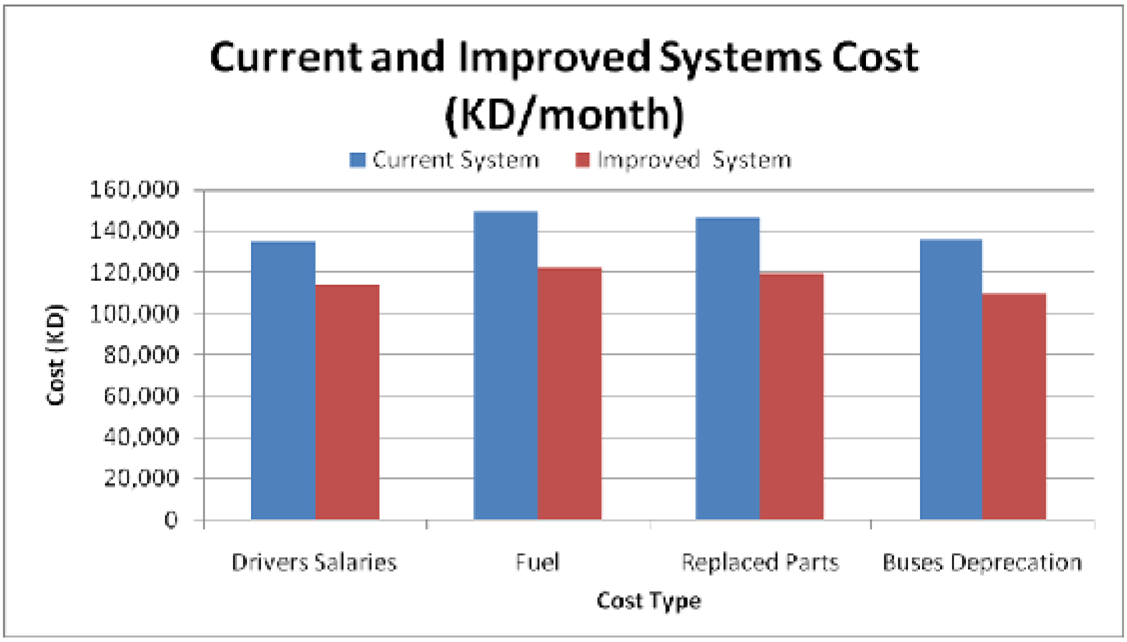

Figure 10: Comparison between current and improved systems cost for all cost types.

5. Conclusions

After analyzing the current system in KPTC with regard to its routes and schedules, we concluded that the main problem was the constant number of buses running in all routes at different times of the day while the number of passengers varied from time to time during the day. Linear programming model was applied, following the data collection, to get the optimal number of seats (buses) per route per time slot. The new routing system obtained from the model output will have new schedules for buses and drivers that vary in accordance with passenger demands per time slot. This will result in an improved utilization by 10% with a balanced bus utilization along the routes as well as reducing working hours by 20% which eventually will result in saving costs of salaries by 15%, fuel by 18%, replaced parts by 19%, and deprecation of buses by 19%. Overall, the proposed system is estimated to produce around 100,000 KD in savings per month. The results show that the modeling approach presented in this paper can result in significant improvements in the bus routing system.

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