Modeling Dispatching Buses with High Service Level

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***Abstract*—This paper attempts to analyze the applicability and the outcomes of implementing a new concept of buses with high service level (BHSL), which has been implemented in Europe, in Morocco. With utilizing queuing theory, the paper strives to compare service rates, an indicator of service level, of different scenarios of the BHSL over the regular buses. The work is established based upon queuing theory formulas and data extracted from surveys conducted in the city of Fes in Morocco.**

Keywords—buses dispatching; queuing theory

I. INTRODUCTION

One of the world's quickest developing sources of Greenhouse Gas Emissions (GHG) is the transport sector. The expansion of car ownership and the number of travelled kilometers are overwhelming the fuel efficiencies that were made in car industries. In order to meet objectives of reducing GHG emission from transport, individual car usage needs to be reduced. This can be realized by changing our travel habits, modes of transport, and the emissions related to each mode. Public transport has a major part in attaining these objectives and will eventually handle congestion problems.

Buses are an important form of public transportation all around the world. In cities where demand is high, it is generally met by either Metro or Tramway. One of the biggest contradictions of modern and urban transport has been the extensive focus on very costly and limited projects. For example, the tramway that operates in Casablanca was very costly. The price needed was the equivalent of building 40 universities, and still the overall public transport in Casablanca is anomalous. These are the outcomes of bad urban structure that led to degradation of the quality of the public transportation.

A new concept of high quality buses is being implemented in Europe. This is called buses with high service level BHSL that dedicate all the focus to time, efficient information system, safety, and comfort. We want to apply the same concept in Fes for many reasons: First, the city is the second city in Morocco in terms of habitants and still it does not have any tram or metro. The university counts many students (major users of buses), tourists, and employees.

The work done consists of creating a model analyzing the different findings, and choosing the best dispatching scenario that serves the passengers and enhances the quality of the service provided.

The model gives result about probability that no customer is waiting, probability a customer has to wait, the number of customers waiting, and the time they will spend in the queues. The analysis included four different bus types, five bus stops and targeting peak (P) and regular periods (R).

The work also included a forecast of the possible lines where the project can be implemented.

II. PROBLEM SETTING

A. BHSL Service Level

First, Morocco is committed to a policy of sustainable development by developing its national charter of environment and being part of important ecofriendly and energy efficient projects. Public transport is an economic and ecological solution to the energy consumption issues; a bus fuel consumption is low compared to individual cars. For example, a 100 seat bus fuel consumption is 34 liter per 100 km while the consumption of an individual car is 7.8 liter.

The BHSL will eventually upgrade the level of service provided by making it more attractive to car drivers. Also, in Morocco, the majority of the passengers are either students or people from a category social. If everyone starts taking buses, a mitigation of social categories will be established.

The cars use will be considerably lowered, and so will greenhouse gas emission. By this achievement the city will suffer less from the human, environment, and economic impacts of these emissions, and will attain urban development.

The project will consider an extensive and comprehensive vision of the mobility around all the city and its outskirts. Specific considerations will be given to soft modes of transport like bicycle.

B. The BHSL Setup

The set up rests on an axial platform of 7m wide. The platform must meet strong structural requirements concerning the layer foundation, the surface layers, and take into considerations slipping, noise, and visual considerations. Stops will each be 50 meter long, with 30 m quay and minimum of 3 m width. A system will be installed to manage and offer service to passengers.

III. MODELING BUSES DISPATCHING- QUEUING THEORY

Queuing theory is one of the oldest tools used in management science where it was used for solving telephone congestion in the 20th century by a Danish mathematician A.K.Erlang. Queuing theory is the mathematical study of queuing lines, it uses a set of mathematical formulas to predict properties of the waiting processes with a random arrival and service time in the waiting lines or queues. The literature on queuing theory and the diverse areas of its applications has grown massively over time (Prabhu [11]; Takagi and Boguslavsky [13];. Medhi [5]; Otokiti [7]) covered papers on application of queuing in industrial settings. Queuing formulas are usually applied to a limited number of pre-determined, simplified models of real processes for which analytical formulas can be developed. Queuing system occurs any time customer's demand for services and the server(s) are temporally engaged. They are the obvious probabilistic models when dealing with scenarios of congestions and blockages. Therefore, it seems very logical to view the services or operations of emergency department and intensive care unit as a queuing system: patients needing the services of the units wait in a queue to be served and leave the system after service. Queuing modeling have been applied in many sectors, namely health care, Owojori [8], Ozcan [9]. In transport, Osorio [6], Hongqi [3] applied queuing theory to solve service system queue phenomenon related to bus transit dispatch. Buses were considered as dynamic service windows.

Bouzeine, Gendreau, and Nguyen [2] undertook a detailed study of the bus stop problem in congested transit networks. Authors proposed a new general model for which we prove a number of good properties and we give equivalent formulations. Two cases were examined, with and without capacity constraints.

Pan [10] endeavors to apply M/M/1/N queuing model with variable input rates and variable service rates to observe the behavior of impatient customers is established in an attempt to maintain a prompt service for the business thus maximizing the profit. The analysis is based on some performance indicators like the loss probability for the customers not entering the system after the arrival, the mean of the customers who leaves the system being impatient, and the loss probability for the customers not joining the queue due to the limited capacity of the system.

Zherovyi, [14] explores queuing systems models where variable service rates depending on the queue length can be applied, and customers can arrive in groups (similar to transport service systems, where passengers are observed to arrive to stations in groups at peak periods like the start of work, lunch time and the end of work). The paper uses MM1 queue system with threshold of switching service between 2 regimes when the number of customers changes.

Customers can be served in 2 regimes, the service time is exponentially distributed in each regime using leveled service rates, the first regime operates in case the number of customers does not exceed the threshold, otherwise the system switches to the second regime having the highest rate. The change of the system's state follows an Ergodic process described in details in the paper.

The process is based on 4 parameters, beside the regular considerations of service rate and arrival rate, the model uses k the customers arriving to the system in the same group, and a_k the probability of having k customers in a given group. The contribution of this paper would be applicable in buses dispatching in case the consideration of a possible change of bus capacity from lower to higher capacity in peak periods.

Scheller and Vesilo [12] strives to conduct acomparative study of FIFO GGs that shows how various slow servers can give lower delays than one single fast server.

Kroese and Schmidt [4], assued in a similar context of the present paper's problematic, the server is travelling and the customers are wainting to be served in fixed places. After choosing their positions on the circle, according to a uniform distribution, they wait for a single server who travels on the circle.The paper gives a partial solution of Markov pooling models assuming that arriving customers are distributed over a circle C according to a uniform distribution on C and the cyclic server's movement is governed by Brownian motion with drift (continuous version of case of Markov pooling model).

Some models tackled the trade-off between the cost and good service levels by quantifying the minimum cost to accept for assure a good quality of service.

Adedayo [1] asserts that short queues are correlated with customer's satisfaction, though costly. However, managers are willing to allow some waiting if a significant saving in service balances the waiting costs.

The model used in this paper assumes a service time and passenger arrival time both approximately looked upon as Poisson distribution. Given fixed passenger carrying capacity, M/M/s queuing model of bus service can be set up, where servers s are thought of as carrying capacity expressed in terms of seats available in the bus. According to the analysis of passenger flow, the survey designed yields to useful data collection, data being processed result in information used to determine the parameters of Poisson distribution, namely the arrival and the service rate. According to the analysis of 4 scenarios, each of case is related to a specific bus capacity. The service rate was tracked to analysis the improvement of the service level upon the change of the capacity of the bus, using queuing model to optimize bus dispatch. Case study indicates that satisfactory results can be obtained.

A. Notation in Queing Models

- Arrival Rate λ : This represents the average of the customers who need to be served within a specific period of time.
- Capacitated Queue: represents the limit of the number of customers who can stay in the queue.
- Customers: can be human, work in process, raw materials, messages, or any entity that can be fitted into a line to wait for being processed.
- A queue is a combination of customers that wait for a specific service (q)

- Queue discipline represents the priority system that a customer receives service in a specific form. The most known discipline is FIFO which stand for First in First out.
- Service rate μ: represents the average of customers a system can serve within a specific period of time.
- Stochastic processes: they are system in which the time interval between events is a random variable. The arrival and service rates are used as stochastic processes using probability distributions.

B. *Queuing Equations*

The formulas for determining the operating characteristics for the *multiple-server model* are based on the same assumptions as the single-server model, i.e. Poisson arrival rate, exponential service times, and infinite queue length, and FIFO queue discipline. Also, recall that in the single-server model, $\mu > \lambda$; however, in the multiple-server model, $s\mu > \lambda$, where s is the number of servers.

- Expected or Average number of units in the bus station

$$L_q = \sum_{n=s}^{N} (n-s) P_n \tag{1}$$

- Expected waiting time in the bus station:

$$W_q = \frac{L_q}{\overline{\lambda}} \tag{2}$$

- Probability that the service facility is idle:

$$P_0 = 1 \Bigg/ \left[\sum_{n=0}^{s-1} \frac{N!}{(N-n)!n!} \left(\frac{\lambda}{\mu}\right)^n + \sum_{n=s}^{N} \frac{N!}{(N-n)!s!s^{n-s}} \left(\frac{\lambda}{\mu}\right)^n \right] \tag{3}$$

- Probability that there are n units in the system:

$$\text{If } 0 \le n \le s, \qquad P_n = \frac{N!}{(N-n)!n!} \left(\frac{\lambda}{\mu}\right)^n P_0$$

$$\text{If } s \le n \le N, \qquad P_n = \frac{N!}{(N-n)!s!s^{n-s}} \left(\frac{\lambda}{\mu}\right)^n P_0$$

$$\text{If } n > N, \qquad P_n = 0 \tag{4}$$

IV. SURVEY CONDUCTED FINDINGS, GRAPHS, INTERPRETATIONS

A survey was conducted among some habitants to detect the lines and stops where the waiting time is considerably high, particularly in peak periods related to work. The results were as follow:

First Line: line 13 with first stop in “Faculté des Sciences Techniques”, second stop “Milles Roses”, and the third stop “Atlas”.

In this line, we noticed a very high demand rate especially at the first stop which is situated near the University. In rush hours i.e. 8 am, 12 pm, and 4pm the waiting time can vary from 10 to 15 min.

The second line: Line 42 with the first stop in “Faculté de Medecine”, second stop at “Narjisse”, and third stop at “ElMedina”. We noticed that there is a problem of waiting time that needs to be tackled. Therefore, we decided to apply the queuing theory to address these issues.

In order to find the best dispatching pattern of buses, a model was created using excel to run simulations. This model is using queuing theories equations to find some characteristics that define and improve the service quality the buses are offering. Also, results are compared between the four different scenarios we considered while running the simulations in which each scenario represents a bus configuration in terms of holding capacity formulated as seats available. In order to obtain precise results we considered 5 bus stops.

For example, the probability of no customers are in the system is to be determined for the four scenarios in the 5 stops with 2 pick periods each. To have a good service level, the bus with low probability will be chosen.

The first scenario is 120 seats, the second scenario 2 regular buses with 60 seats each, the third scenario is one expanded bus with 200 seats, and finally the fourth scenario is two expanded buses with 100 seats each.

Concerning the average number of customers, for an enhanced quality, the number of customers waiting needs to be low. For the time a customer waits in the line has also to be small. The probability a customer has to wait needs again to be small for an upgraded service quality.

After running the simulation we got the following results.

TABLE I. PROBABILITY THAT NO CUSTOMERS ARE IN THE SYSTEM, PO

	P1	R1	P2	R2	P3	R3	P4	R4	P5	R5
Senario 1	60	60	40,35088	64,55696	60	71,42857	69,69697	81,81818	60	
Senario 2	54,24165	42,85714	37,93103	46,06742	50	44	57,30337	66,66667	45,45455	41
Senario 3	71,42857	53,84615	63,26531	63,52201	73,07692	71,42857	75	77,77778	73,91304	67
Senario 4	63,48774	43,88489	60,64257	69,93464	63,63636	53,84615	84,21053	83,90805	53,84615	44

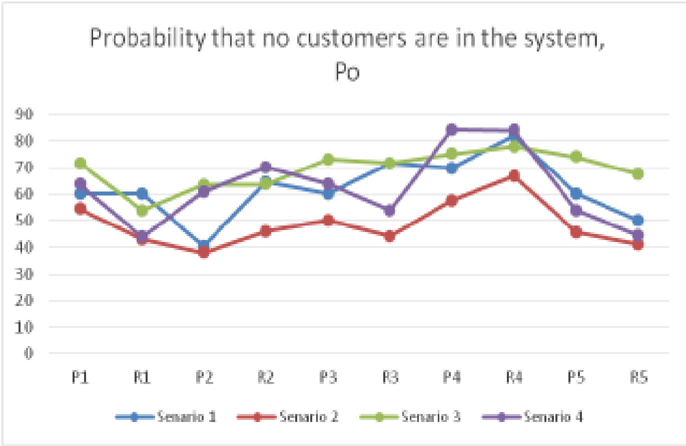

Fig. 1. Representation of the probability that no Customer is waiting for the four scenarios caption

TABLE II. AVERAGE NUMBER OF CUSTOMERS IN THE WAITING LINE, LQ

	P1	R1	P2	R2	P3	R3	P4	R4	P5	R5
Senario 1	0,033333	0,033333	0,187376	0,020956	0,033333	0,009524	0,011764	0,00202	0,033333	0,083333
Senario 2	0,057259	0,152381	0,228527	0,116567	0,083333	0,138586	0,043175	0,016667	0,122727	0,17507
Senario 3	0,009524	0,059341	0,023996	0,023365	0,007715	0,009524	0,005952	0,003968	0,006905	0,015281
Senario 4	0,023448	0,13992	0,03129	0,011434	0,023088	0,059341	0,001269	0,00135	0,059341	0,132063

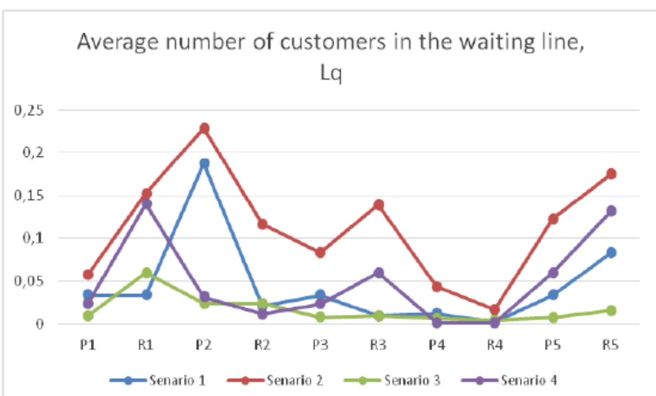

Fig. 2. Representation of the number of customer waiting for the four scenarios caption

TABLE III. AVERAGE TIME A CUSTOMER SPENDS IN THE WAITING LINE,WQ

	P1	R1	P2	R2	P3	R3	P4	R4	P5	R5
Senario 1	0,044444	0,133333	0,220442	0,074842	0,074074	0,063492	0,047054	0,025253	0,033333	0,138889
Senario 2	0,064336	0,380952	0,253918	0,242848	0,138889	0,39596	0,113618	0,104167	0,081818	0,233427
Senario 3	0,019048	0,197802	0,053325	0,080568	0,027553	0,063492	0,029762	0,039683	0,011509	0,04366
Senario 4	0,034997	0,358769	0,063858	0,049713	0,05772	0,21978	0,010573	0,019288	0,049451	0,191396

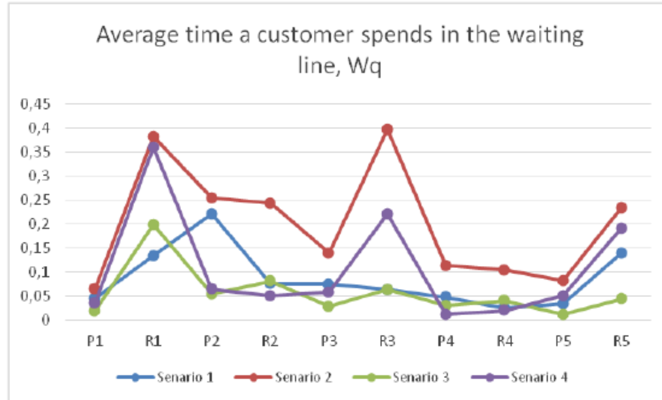

Fig. 3. Representation of the Average Time a Customer spends waiting for the four scenarios

TABLE IV. PROBABILITY AN ARRIVING CUSTOMER HAS TO WAIT, PW

	P1	R1	P2	R2	P3	R3	P4	R4	P5	bhsl
Senario 1	0,1	0,1	0,253509	0,076339	0,1	0,047619	0,054113	0,018182	0,1	0,166667
Senario 2	0,13575	0,228571	0,27931	0,199136	0,166667	0,217778	0,115891	0,066667	0,204545	0,245098
Senario 3	0,047619	0,138462	0,082653	0,081374	0,04188	0,047619	0,035714	0,027778	0,03913	0,063307
Senario 4	0,081544	0,218849	0,096426	0,053193	0,080808	0,138462	0,013534	0,01408	0,138462	0,21245

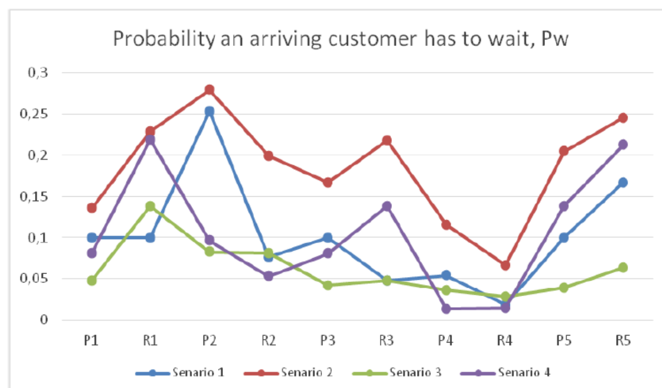

Fig. 4. Representation of the Probability that an Arriving Customer has to wait for the four scenarios

V. RESULTS INTERPRETATION

For the first scenario, the probability that a customer does not need to wait is relatively low compared to the fourth scenario. The second scenario represented by the red line has the lowest probability of no customer is waiting where we can visualize that all the lines are above the red line. The third scenario provides a good percentage about the existing of no customer in the system.

The first and second scenarios give very high number of customers waiting in the line. The fourth scenario result remains acceptable; but the best scenario is the third scenario with very low average number of customers waiting in the line.

Concerning the average time a customer spends in the line, we can see from figure that the second scenario (red line) is the worst scenario since in average it provides a large waiting time.

It is followed by the fourth scenario, then comes the first scenario by acceptable average waiting time. Here again the best scenario is the fourth scenario where we can see clearly that it provides low average waiting time.

For the last graph, it is related to probability an arriving customer has to wait. Again the second scenario does not seem to be a good scenario to enhance the customer satisfaction since it has the highest probabilities. The first and fourth scenarios come right after with moderately high probabilities, and finally the fourth scenario comes as the best scenario with the lowest probabilities a customer needs to wait.

To conclude, the best scenario is the fourth one with 0.7 and 0.4 service and arrival rates.

VI. Conclusion

This is a contribution to the Moroccan urban agency concerning the dispatching issues. The investigated issues have been addressed via the analysis of the implementation of BHSL using queuing theory. The issues originated from the fact that the same bus, considered as mutilserver system, is assigned to many stations, considered as sites from which customers are serviced, thus the service rates at all the subsequent stations cannot be independent, they are actually related because the servicing pattern of different passengers in station "C" depends on the free seats (servers) available at station "B", and the service rate at "B" changes upon on the free seats available at station "A", and so on.

This paper tried to use statistical analysis applied to queuing theory to configurate a good queuing system for buses dispatch, with regard to improved service level at some stations studied in the big city of Fes-Morocco.

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Biography

Dr. Kissani is a professor in the School of Science and Engineering since spring 2010. She received her Bachelor degree in Operations Research with Honors from the Engineering School INSEA in Rabat and both Master and Ph.D. degrees from Laval University in Canada. She is an expert in logistics and management science and has worked on the implementation of optimization models using various Decision Support Systems (Supply Chain Studio, Promodel, Supply Chain Guru…), for companies having critical needs for redesigning their supply chain following a situation of merger, expansion, or cost minimization. One of the consulting mandates, with AXIA, was related to the redesign of Natura supply chain, a cosmetic Brazilian firm to match some expansion needs. Her teaching interests include production and operations management and management science topics. She has been the recipient of numerous awards and nominations (FORAC, NSERC). Her research interests include Green and Lean aspects in supply chain and logistics. She has done significant research work and published over top quality international conferences.