Model for Estimation of Interurban Passenger Transportation Scheme

Gladys Bonilla-Enríquez
Logistics and Supply Chain Management
Universidad Popular Autónoma del Estado de Puebla, UPAEP
Puebla, Puebla, México
gbonillae@live.com.mx

Santiago-Omar Caballero-Morales
Logistics and Supply Chain Management
Universidad Popular Autónoma del Estado de Puebla, UPAEP
Puebla, Puebla, México
scaballero1979@yahoo.com

***Abstract*—Passenger transportation planning is important to reduce the emission of contaminants and expenses involved in the operation of vehicles used for this purpose. Determining the optimal number of vehicles to provide an efficient transportation service is required. While transportation logistics currently supports advanced and complex methods to address this situation, an alternative method can be more appropriate for interurban passenger transportation. In this paper a mathematical model is presented for fast estimation of (a) the number of transportation services to be scheduled per hour, (b) the number of transportation services to be performed by each vehicle, and (c) the number of vehicles to perform all transportation services. Factorial analysis and computer simulation were considered for static and dynamic assessment of the mathematical model. Experiments with numerical examples showed that the parameters estimated with the model are reliable if variability is already considered within the main variables of the model such as transportation time and number of incoming passengers.**

Keywords—simulation; interurban transportation; resource planning

I. INTRODUCTION

Logistics is an inclusive process associated with good management of resources, services, people, and decisions to ensure timely response to customer expectations and achieving organizational objectives [1]. For transportation services, logistics is an important step to ensure service coverage and optimal resource acquisition (e.g., vehicles, terminals, etc.) [2,3]. Recently, transportation planning has become an important subject of green road transportation to optimize routes and reduce CO_2 emissions [4,5]. Logistics is more relevant for public transportation in developing countries where the quality of the service and renewal of vehicles are dependent of limited economic resources [6].

Interurban passenger transportation establishes connections between cities and communities. In rural areas, interurban transportation requires particular planning considerations because these areas are characterized by low density of population and reduced coverage by bus line networks [7]. Because people living in these areas have limited economic resources, passenger transportation companies must optimize all vehicle utilization in order to achieve profits without affecting service quality. Sustainable mobility and reduction in CO_2 emissions is also sought in interurban transportation [8].

In this work a mathematical model is presented to support passenger transportation planning for small companies that provide interurban transportation services. The model assumes that the following information is available or known: (a) average number of passengers to be served, (b) time of the transportation service, (c) service hours, and (d) capacity of each vehicle.

With this information the model can estimate the following main information: number of vehicles required to provide the transportation service, number of service runs per hour, and number of service runs per vehicle. If variability (caused by maintenance, failures or traffic delays) is considered within the number of passengers to be served, and the time of the transportation service, the model can provide a reliable transportation schedule as verified by computer simulation.

II. MATHEMATICAL MODEL

A. Objective Function and Assumptions

The model is aimed to determine the following information regarding the service schedule:

- H_R = number of transportation services (runs) to be scheduled per hour.

- N = number of vehicles required to cover all transportation services (runs).
- V_R = number of transportation services (runs) to be performed by each vehicle through the length of a work schedule.

The most significant expense for the transportation company comes from the number of vehicles required to cover the service of passenger transportation (i.e., N). H_R and V_R are related to the capacity of the company to provide the transportation service to all passengers within a period of time or work schedule. In order to determine this information the following variables are defined:

- t_s = the time of the first run (e.g., 04:00 hrs).
- t_f = the time of the last run (e.g., 22:00 hrs).
- M = the length of the work schedule. It is estimated as $M = t_f - t_s$.
- A = the number of passengers (clients) to be serviced through the period of time M. It is assumed that M is fixed.
- B = the capacity of each vehicle (i.e., the number of passengers that can be assigned to a single vehicle = number of seats in the vehicle). It is assumed that all vehicles have the same capacity.
- k = time required by each vehicle to complete a transportation service (from the station point to the destination point including the return to the station point). This time includes time delays (variability) caused by traffic, parking, reconditioning, and failures.

The number of passengers per unit of time can be estimated as A/M. Because these passengers must be served by a number of transportation services, H_R can be estimated as:

$$H_R = (A/M)/B = A/(MB). \quad (1)$$

Then, the number of runs per vehicle can be estimated as:

$$V_R = M/k. \quad (2)$$

The total number of passengers given by A can be served by A/B service runs that are provided by V_R runs of N vehicles. Thus, N can be estimated as:

$$A/B = NV_R. \quad (3)$$

$$N = (Ak)/(BM). \quad (4)$$

B. Factorial Analysis

In order to test the objective function for N a factorial analysis was performed with different values for A, B, t_f, t_s, and k. In Table I the values considered for these variables are presented.

TABLE I. VALUES FOR FACTORIAL ANALYSIS

Variables	**Values**			
A	100	200	300	400
B	10	12	15	
t_f	20:00 hrs	22:00 hrs		
t_s	04:00 hrs	06:00 hrs		
k	2.5 hrs	4.0 hrs		

Minitab was used for the factorial analysis of the cases generated with the values presented in Table I and Fig. 1 presents the three main interaction plots of N considering the variables A, B and k through all values of t_f and t_s. The following events regarding N are observed:

- *Interaction Plot 1*: An inverse linear relationship is observed between the required number of vehicles (N) and the number of passengers to be served (A) as the capacity of the required vehicles (B) increases. The number of required vehicles (N) is increased if the number of passengers (A) increases. However the number of vehicles may decrease significantly if the capacity of the vehicles (B) is increased. Thus, 400 passengers can be served with approximately six vehicles if each vehicle has 15 seats. With approximately the same number of vehicles, 300 passengers can be served if each vehicle has 10 seats.

- *Interaction Plot 2*: A positive linear relationship is observed between the required number of vehicles (N) and the number of passengers (A) as the length of the run (k) increases. If the length of the run is small (i.e. k = 2.5 hrs) then 400 passengers can be served with approximately six vehicles. However, if k increases (i.e., k = 4.0 hrs) then nine vehicles are required to serve the same number of passengers. The same pattern is observed for 100, 200 and 300 passengers.
- *Interaction Plot 3*: An inverse linear relationship is observed between the required number of vehicles (N) and the capacity of these vehicles (B). However the number of required vehicles (N) is linearly positive to the length of the run (k). If the length of the run is small (i.e., k = 2.5 hrs) few vehicles are required if these have a large capacity. If the capacity is decreased then the number of vehicles increases. If k increases (i.e., k=4.0 hrs) more vehicles are required if these have a small and large capacity.

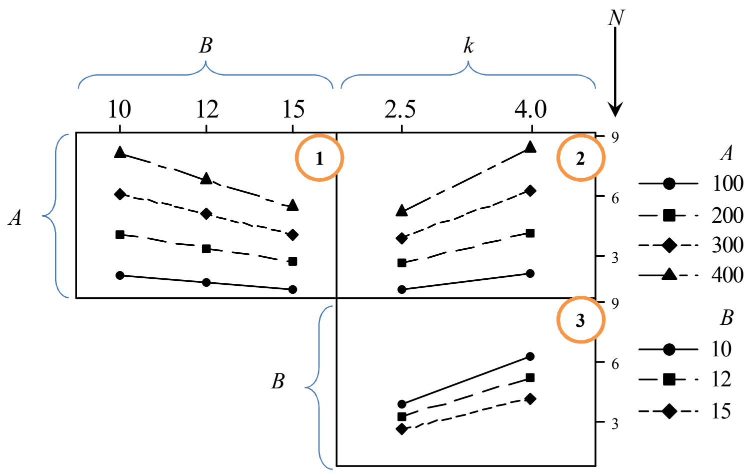

Fig. 1. Interaction plots for N

C. Numerical Examples

In this section a brief explanation about the use of the mathematical model is presented. For this purpose three cases that were randomly selected from those generated for the factorial analysis were considered. The schedules estimated with (1), (2), and (4) are presented in Fig. 2 for the following cases:

a) *Data:* $A = 300$, $B = 12$, t_f= 22:00 hrs, t_s = 6:00 hrs, k = 2.5 hrs.
M = 22:00 hrs – 6:00 hrs = 16 hrs
$H_R = A/(MB) = 300/(16\times12) = 1.56 \approx \rightarrow \{1, 2\}$ transportation services per hour.
$V_R = (M/k) = 16/2.5 = 6.4 \rightarrow \{6, 7\}$ runs per vehicle through M.
$N = (Ak)/(BM) = (300\times2.5)/(12\times16) = 3.90 \approx 4$ vehicles.

b) *Data:* $A = 100$, $B = 10$, t_f= 20:00 hrs, t_s = 4:00 hrs, k = 2.5 hrs.
M = 20:00 hrs – 4:00 hrs = 16 hrs
$H_R = A/(MB) = 100/(16\times10) = 0.62$, because $H_R<1$ the unit of time is increased until $H_R \geq 1$ (in this case, one transportation service is scheduled approximately each two hours).
$V_R = (M/k) = 16/2.5 = 6.4 \rightarrow \{6, 7\}$ runs per vehicle through M.
$N = (Ak)/(BM) = (100\times2.5)/(10\times16) = 1.56 \approx 2$ vehicles.

c) *Data:* $A = 400$, $B = 15$, t_f= 22:00 hrs, t_s = 4:00 hrs, k = 4.0 hrs.
M = 22:00 hrs – 4:00 hrs = 18 hrs
$H_R = A/(MB) = 400/(18\times15) = 1.48 \rightarrow \{1, 2\}$ transportation services per hour.
$V_R = (M/k) = 18/4.0 = 4.5 \rightarrow \{4, 5\}$ runs per vehicle through M.
$N = (Ak)/(BM) = (400\times4.0)/(15\times18) = 5.92 \approx 6$ vehicles.

The schedules presented in Fig. 2 are general approximations given by (4). Particularly for c) the exact number for H_R is 1.48. Thus, either one or two vehicles or service runs can be assigned to each time slot (unit of time = one hour). By considering two vehicles there is service coverage for three consecutive hours. However there is an hour with no coverage after this period of three hours. If one vehicle is considered there is coverage for all hours, however all hours can be covered with four vehicles. Nevertheless, the schedule can be improved with additional information regarding the time slots with more clients, leading to more suitable assignation of vehicles (e.g., two service runs at 06:00 and 07:00 hrs, and one service run at 08:00 and 9:00 hrs).

For initial estimation of the number of resources to be required by the company to provide the transportation service (1), (2) and (4) can provide an upper bound for H_R, V_R, and N respectively. A dynamic assessment of these estimations can be performed with support of computer simulation. Instantaneous utilization, which is an important parameter for assessment of resources, can be measured with this tool. Another advantage of computer simulation is the evaluation of "what-if" scenarios to understand the behavior of the modeled system when changes in the input parameters (e.g., number of clients, number of resources, operation times, etc.) are performed.

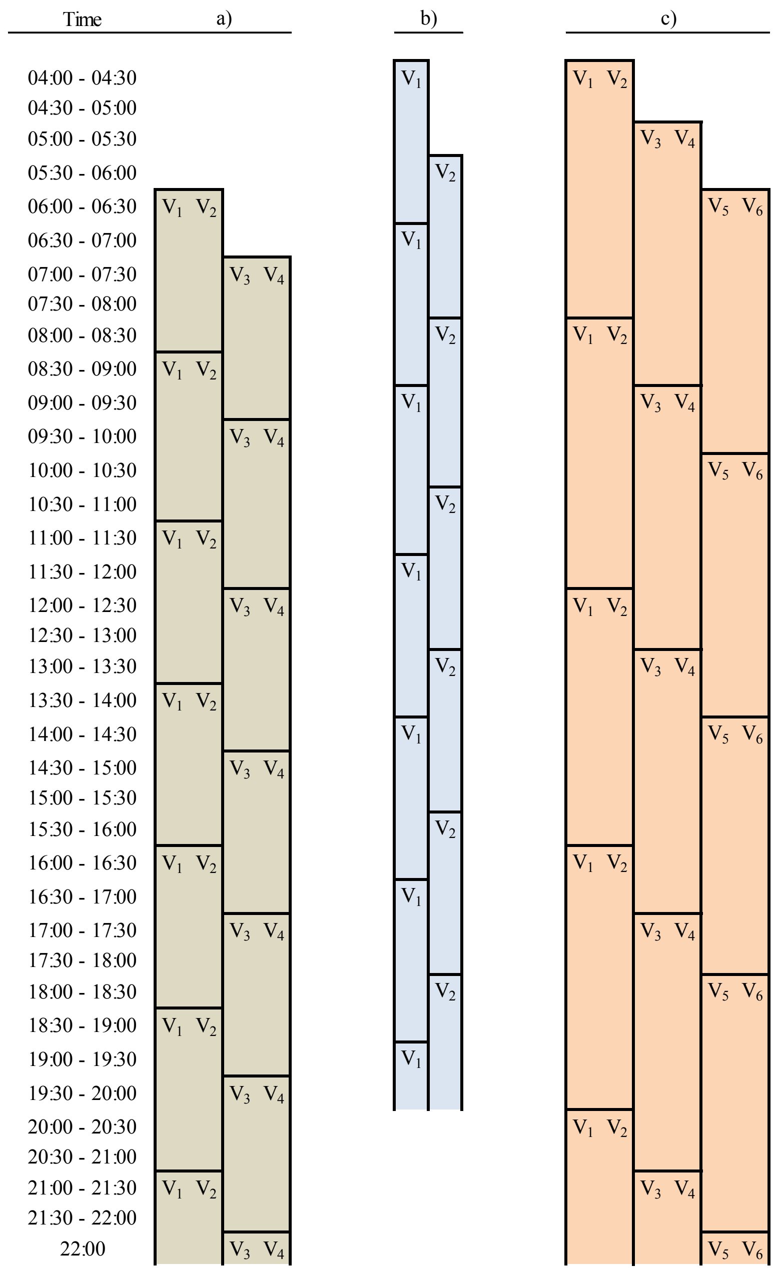

Fig. 2. Estimated schedules for numerical examples

III. COMPUTER SIMULATION ANALYSIS

The schedules presented in Fig. 2 were validated through computer simulation and the software Arena © [9] was considered for this purpose. Fig. 3 presents the simulation models that were built to represent each of the case studies described in Section II.C with the associated schedules presented in Fig. 2.

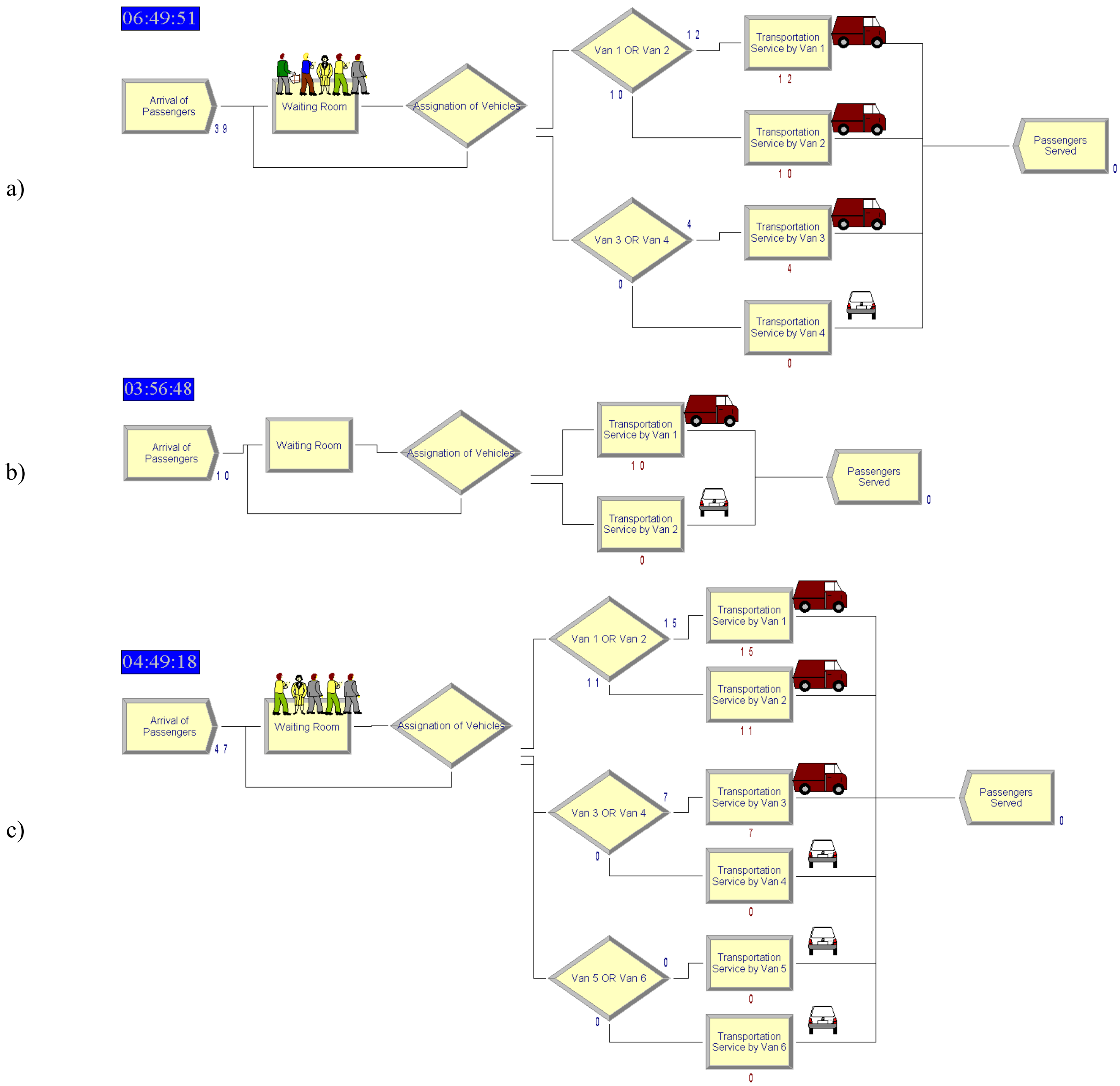

Fig. 3. Arena models for dynamic assessment of the numerical examples.

Dynamic assessment was performed by adding external variability to the initial parameters of the case studies. For all cases an increase of 15% for *A* was considered. Also, *k* was considered to be normally distributed with a standard deviation of 10% the value of *k*. The parameters to be measured were: resource utilization (in this case, resource = vehicle), number of entities processed (i.e., clients/passengers served), and waiting time for passengers. The results of the simulation are presented in Table II.

TABLE II. SIMULATION RESULTS

Case	Incoming Passengers *A*	Transportation Time *k*	Waiting Time (hrs.)	Vehicles	Utilization	Passengers Served	
a)	300	2.5	0.55	V_1	0.70	84	300
				V_2	0.60	72	
				V_3	0.60	72	
				V_4	0.60	72	
	300	Norm(2.5,0.25)	1.32	V_1	0.65	77	300
				V_2	0.62	75	
				V_3	0.62	75	
				V_4	0.60	73	
	345	2.5	0.63	V_1	0.70	84	334
				V_2	0.68	82	
				V_3	0.70	84	
				V_4	0.70	84	
	345	Norm(2.5,0.25)	1.35	V_1	0.65	77	304
				V_2	0.62	75	
				V_3	0.64	77	
				V_4	0.62	75	
b)	100	2.5	0.20	V_1	0.52	50	100
				V_2	0.52	50	
	100	Norm(2.5,0.25)	0.53	V_1	0.58	56	100
				V_2	0.47	44	
	115	2.5	0.35	V_1	0.58	56	115
				V_2	0.61	59	
	115	Norm(2.5,0.25)	1.08	V_1	0.63	60	105
				V_2	0.48	45	
c)	400	4.0	0.17	V_1	0.67	70	400
				V_2	0.57	60	
				V_3	0.71	75	
				V_4	0.69	72	
				V_5	0.64	67	
				V_6	0.53	56	
	400	Norm(4.0,0.4)	1.04	V_1	0.60	62	381
				V_2	0.60	64	
				V_3	0.59	62	
				V_4	0.61	64	
				V_5	0.57	60	
				V_6	0.64	69	
	460	4.0	0.18	V_1	0.67	70	423
				V_2	0.57	60	
				V_3	0.71	75	
				V_4	0.69	72	
				V_5	0.71	75	
				V_6	0.68	71	
	460	Norm(4.0,0.4)	1.04	V_1	0.60	62	381
				V_2	0.60	64	
				V_3	0.59	62	
				V_4	0.61	64	
				V_5	0.58	60	
				V_6	0.63	69	

For the case a), if A = 300 passengers, the transportation scheme estimated by (4) has the capability to serve all passengers, even if the transportation time given by k has a variability of 10%. Passengers' waiting time is increased if some variability is added to k (0.55 hrs → 1.32 hrs). However if A is increased by 15% (A=345) then the scheme presents problems to serve all passengers even if k remains fixed: 334/345 = 97.0% coverage with k=2.5, and 304/345 = 88.0% coverage with k=Norm(2.5,0.25). The same is observed for the case b).

For the case c) k is larger (k=4.0 hrs) and the variability represents a significant amount of time (0.4 hrs). As a consequence, even if A remains fixed (A=400) the transportation scheme presents problems to serve all passengers if variability is added to k. Because the transportation time is larger, and there are more incoming passengers than in cases a) and b), the system is more affected by changes in these parameters. Thus, planning should consider these potential problems when estimating transportation schedules.

However, if $k = k_0 + \theta$, and $A = A_0 + \beta$, where θ and β are fixed variability values based on historical data from the real system for k and A respectively, the transportation scheme provided by (4) can be more reliable. Thus, for the case c): k_0=4.0 hrs, θ = 0.40 hrs; and A_0=400, β = 60. The new transportation scheme according to (4) would be: $H_R = 1.6 \approx 2.0$ transportation services per hour, $V_R = \{4, 5\}$ runs per vehicle through M, and $N = 7.5 \approx 8$ vehicles. As presented in Table II, if no additional variability is added, the simulation model with these parameters has a reliable performance.

IV. Conclusions and Future Work

As discussed in Section III the transportation scheme presented by (4) can be a reliable tool if the parameters of the real system such as A, k and M include variability which can be integrated by traffic delays, failures and maintenance. Future work is focused on extending the mathematical model to integrate external variability and linear programming to consider variable H_R, V_R and B for the service schedule.

References

[1] D.P. Ballesteros Riveros and P.P. Ballesteros Silva, "Importance of logistics management (Importancia de la administración logística*, in Spanish*)," Scientia Et Technica, Vol. XIV, No. 38, pp. 217-222, 2008.

[2] C.A. Moncada Aristizábal and J. Burbano Valente, "Business structure model for public transportation (Modelo de estructura empresarial para el transporte público colectivo, *in Spanish*)," Universitas Psychologica, Vol. 4, No. 3, pp. 325-337, 2005.

[3] C. Cipoletta Tomassian, G. Pérez Salas and R.J. Sánchez, Integrated policies for infrastructure, transport and logistics: International experiences and initial proposals (Políticas integradas de infraestructura, transporte y logística: Experiencias internacionales y propuestas iniciales, *in Spanish*). Santiago de Chile, Chile: United Nations, 2010.

[4] E. Demir, T. Bektas and G. Laporte, "A review of recent research on green road freight transportation," European Journal of Operational Research, Vol. 237, pp. 775-793, 2014.

[5] E. Demir, T. Bektas and G. Laporte, "A comparative analysis of several vehicle emission models for road freight transportation," Transportation Research Part D, Vol. 16, pp. 347-357, 2011.

[6] L. A. Rivas Tovar, J. A. Chávez Espejel, B. Maldonado Hernández, A. Chávez, S. Carmona Tapia, E. V. Cienfuegos Sarabia and D. Molina García, "Incentives and disincentives for public transport systems in London, Madrid and Mexico City (Incentivos y desincentivos en los sistemas de transporte público en Londres, Madrid y Ciudad de México, *in Spanish*)," INNOVAR Revista de Ciencias Administrativas y Sociales, Vol. 17, No. 30, pp. 113-131, 2007.

[7] G. Stefancic, Z. Pilih and M. Stankovic, "Technology of Urban, Interurban and Rural Passenger Transport," Promet-Traffic & Transportation, Vol. 18, No. 1, pp. 39 - 42, 2006.

[8] P. Kageson, "The Future for Interurban Passenger Transport: Bringing Citizens Closer Together," 18th International Transport Research Symposium, Madrid, Spain, Discussion Paper No. 2009-28, pp. 1 – 27, 2009.

[9] W.D. Kelton, R. Sadowski and N. Zupick, Simulation with Arena. New York, USA: McGraw-Hill, 6th Ed, 2015.

Biography

Gladys Bonilla-Enriquez is a Ph.D. student in Logistics and Supply Chain Management at the Universidad Popular Autónoma del Estado de Puebla, UPAEP, in Mexico. She holds a M.S. in Business Administration from Universidad del Valle de Mexico, UVM, and B.S. in Computer Science from Universidad Tecnologica de la Mixteca, UTM, in Mexico. She has published journal and conference papers. Her research interests include manufacturing, customer service, simulation, supply chain management.

Santiago-Omar Caballero-Morales is currently a professor-researcher in the Department of Logistics and Supply Chain Management at the Universidad Popular Autónoma del Estado de Puebla (UPAEP) in Mexico. He holds a B.Sc. degree in Electronics and Communications Engineering from the University of the Americas-Puebla, a M.Sc. degree in Industrial Engineering from the University of the Americas-Puebla, and a Ph.D. degree in Computer Science (Speech Recognition) from the University of East Anglia. Since 2011 he has been a member of he National System of Researchers (SNI) in Mexico and currently holds the Level-1 distinction. He has been an active reviewer for international journals as PLOS ONE, Computers & Industrial Engineering, and Expert Systems with Applications. His research interests are quality control, operations research, combinatorial optimization, pattern recognition, automatic speech translation, analysis and simulation of manufacturing processes, and human-robot interaction.