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SIMULATION OF A NIGHT TAXI-BUS SERVICE FOR THE HISTORICAL CENTER OF ROME

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ABSTRACT

The Municipality of Rome plans to introduce a taxi-bus system as a night service. A micro-simulation model was developed to estimate the needed information. Two major topics regarding this model are presented. First, the iteration process for input parameters is described. The number of potential customers is determined by means of an external modal split model. Two input parameters (frequency of trips and travel times) for the external model are estimated by the micro-simulation model. An iteration process was used. The second topic is the integration of an optimization model into the micro-simulation model. Both simulation and optimization components were implemented in the simulation system SLX®.

1 INTRODUCTION

A taxi-bus system is a logistical dial-a-ride system. In a typical dial-a-ride system, users call a control center by phone or via Internet and ask for a ride at a desired time from their origin to their destination. Vehicles operate in fixed areas, while routes and frequency of trips are variable and demand-dependent. The control center collects all calls to be served, creates groups of customers and selects a vehicle to serve the customers. The investigated taxi-bus system of Rome differs in some respects from this standard in that the route of taxi-buses is variable but the frequency is fixed.

Most cinemas, theatres, restaurants, and discotheques in Rome are located in the historical center. This causes immense private traffic flows during the night hours, when access to the historical center is not restricted to residents only (as it is during the day). To help reduce private traffic flows and related side effects (pollution, noise, accidents), the Municipality of Rome plans to introduce a night taxi-bus service to connect the historical center of Rome (ZTL, for *Zona a Traffico Limitato*, limited traffic zone) with those parts of the city lying just inside the Grande Raccordo Anulare (GRA), the outer ring road, about 15 km from the center of Rome. The service will run daily from 20:00 to 02:00 hours. The area covered by the service will be partitioned into a number of corridors running between the GRA and the ZTL. Each corridor can be seen as the "catchment area" for one of the main radial roads (via Tiburtina, via Ardeatina, via Nomentana, etc.) leading out from the center. Each corridor will be given its own fleet of taxi-buses. Each vehicle seats eight passengers plus the driver.

For the trip into the ZTL, customers board a taxi-bus anywhere along the corridor and leave it at predefined stops inside the ZTL. Outbound customers board the taxi-bus at defined stops inside the ZTL and alight anywhere inside their destination corridor. This taxi-bus system is more flexible than a traditional bus system because customers who want to travel to the ZTL are picked up directly at their desired point and need not walk to a stop as in a traditional bus network. In comparison with a common taxi system, a taxi-bus is less flexible because the frequency of taxi-buses is fixed and the stops inside the ZTL are fixed. The Municipality of Rome is interested in basic information for such a taxi-bus system – convenient frequency, number of vehicles, number of customers transported and expected revenues. It is not possible to obtain this different kind of information from analytical models, and a micro-simulation model was accordingly developed to estimate the needed information.

Two major topics regarding this micro-simulation model must be distinguished. First, the iteration process for input parameters is described. A significant input parameter (the number of potential customers) is determined by means of an external modal split model. Two input parameters (frequency of trips and travel times) for the modal split model are, however, estimated by the micro-simulation model. An iteration process was therefore necessary to solve this problem. The second topic is the integration of an optimization model into the micro-simulation model.

The second section describes the basic structure of the micro-simulation model. Section 3 characterizes the derivation of necessary input data, and Section 4 focuses on the iteration process of dedicated input parameters. The development and integration of an optimization model inside the micro-simulation model is discussed in Section 5. The main results are presented in Section 6. A summary in Section 7 concludes the paper.

2 MICRO-SIMULATION MODEL OF A TAXI-BUS SERVICE

The goal of the developed micro-simulation model is the calculation of fleet-oriented and customer-relevant information from operating taxi-bus service. Examples for such information are travel time for each customer served, running times by each taxi-bus in the fleet and distances covered by each taxi-bus. Following significant active object classes were chosen based on this requirement: customers, customer sources, taxi-buses, and the control center (see Figure 1).

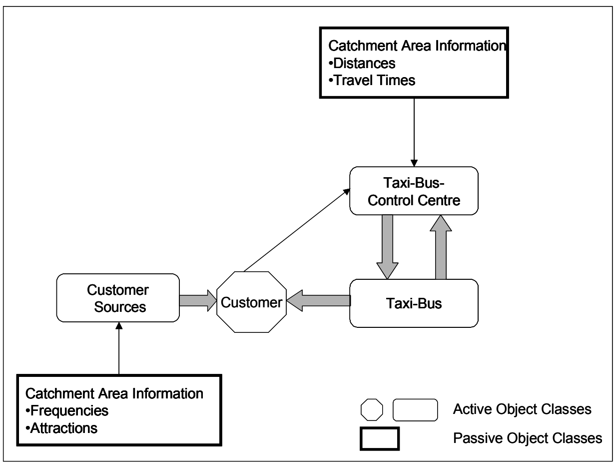

Figure 1: Relations between Significant Object Classes

Attributes for customer objects are the origin and destination point, and registration time. Customer objects are instantiated; they are waiting until a taxi-bus picks them up and until they reach the destination point. Customer objects are temporary in the model. Customer source objects create new customers. The inter-arrival times for customers depend on estimated frequency classes. Taxi-bus objects are permanently in the model. These objects get their orders from the control center. Such an order includes the driving route and the identification of the grouped passengers. The control center is the link between customers and taxi-buses and governs the system strategically. The center collects all the calls, groups customers having common origins and destinations, finds the best route to pick up and drop off all customers, chooses the taxi-bus to assign to each group, and finally sends information to taxi-buses. The control center has to calculate the optimized route for every order.

Two additional passive object classes are required. Objects of these classes operate as data storage. They contain such information about catchment areas as frequencies and distances between different points inside.

The entire micro-simulation model is implemented in the simulation system SLX® (Henriksen 1999a). A PROOF-based post-run animation (Henriksen 1999b) can be linked.

3 DERIVATION OF INPUT PARAMETERS

Simulation is the imitation of the operation of a real-world process or system over time (Banks 1998). The described micro-simulation model has to represent the non-existent taxi-bus system of Rome. Some input parameters for this simulation, such as distances, could be directly derived or measured from the real traffic network. Other input parameters, such as the number of potential customers, were derived indirectly. The model was tested on two sample corridors, corresponding to the catchment areas of via Tiburtina and via Ardeatina. The derivation of input parameters is shown for the Tiburtina catchment area.

3.1 Corridors and Zones

The area covered by the Municipality of Rome was subdivided into 463 traffic zones (362 inside the GRA). The ZTL was subdivided into 23 traffic zones, each with its own taxi-bus stop. Every traffic zone inside the GRA was associated with a centroid, connected to the road network by means of fictitious links. Each centroid has two coordinates (x, y), in meters, in the UTM (Universal Transverse Mercator) system. The catchment area of via Tiburtina (see Figure 2) is selected for demonstration purpose. About 178,000 people live in this area.

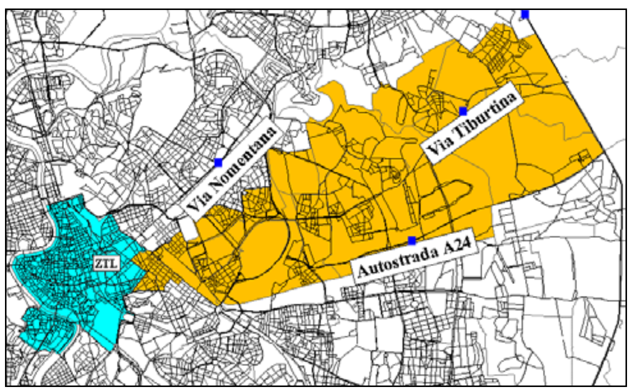

Figure 2: The Catchment Area of via Tiburtina

3.2 Deterministic Input Data

The Tiburtina catchment was subdivided into 34 traffic zones. Each corridor has a depot (or parking area), located near the GRA, where taxi-buses start their journeys to the ZTL. Each corridor also has a number of gates through which taxi-buses enter or leave the ZTL. The Tiburtina catchment has 3 entrance gates and 2 exit gates. The annulus between the GRA and the ZTL was subdivided into two concentric fare zones. The first zone, internal and close to the ZTL, has a lower fare, while the fare of the second zone is 50% higher.

3.3 Stochastic Input Data

The major input parameter is the number of potential customers. In order to quantify potential customers for the taxi-bus system, travelers' behavior on a typical day was analyzed. The analysis based on a telephone survey on a sample of 20,000 people living in the Municipality of Rome. The survey took into account all trips made by the sample on a typical day (between 0:00 and 24:00), for any purposes and using any transport means.

The survey showed that about 1.37% of the sample made trips to the ZTL between 20:00 and 02:00. Applying such a percentage to people over age 14 living inside the GRA but outside the ZTL, 25,311 people move to the ZTL between 20:00 and 02:00 on a typical day, using any transport means. Applying the calculation to the Tiburtina catchment, 1907 people intend to travel to the ZTL between 20:00 and 02:00 using any transport means. Assuming that travelers are uniformly distributed over the four-hour peak period. (20:00–24:00), then about 475 customers per hour wish to travel from the Tiburtina catchment into the ZTL and the same number want to return (every hour) between 22:00 and 02:00.

How many people will use the taxi-bus system? Potential customers were quantified on the basis of the external Logit model developed by the University of Rome (Filippi *et al.* 2000). The Logit model proved that the number of customers can vary depending on three factors: travel time (i.e., trip duration), trip frequency and trip fare (discussed in more detail below, Section 4).

After detection of the number of potential customers, it had to be determined how the customers are spread over the catchment area. The average number of hourly calls generated in each zone was assumed to be proportional to the number of people living in the zone. Seven frequency classes were considered which mark the time between two calls in a single zone. Each zone was assigned a frequency class. It was assumed that the time between two calls is exponentially distributed.

In the next step customers' destinations had to be specified. Each destination point was assigned a probability to be chosen. Again, the average number of hourly calls attracted by each zone was assumed to be proportional to people living in the zone. As for the 23 points inside the ZTL, they have been assigned the same probability to be chosen as destinations.

As for travel distances and travel times between zones, minimum paths for each couple of zones were identified and quantified using TransCAD® (Caliper Corporation 1996) on the basis of the Roman road network. TransCAD's travel times were calculated for empty roads only. In the model a modified normal distribution function was used. This function generates only values that are greater than the mean.

4 INPUT PARAMETERS ITERATION

One of the main input parameters for the micro-simulation model is the rate of arrival of potential customers for the taxis-bus system. This rate was determined by another model, an external modal split model. This modal split model was applied to four categories of travelers (car users, standard taxi users, Metro users and bus users) and quantified their shift towards the new taxi-bus service. The modal split model is a binomial Logit model, based on stated preference data. Each interviewee was asked to choose between his/her current choice and the new taxi-bus service under different scenarios. Each scenario presented different values ('levels') of three variables:

- Travel time (defined as percentage increase compared to a trip on a normal taxi),
- Trip fare (distinguishing two fare zones based on distance from the ZTL),
- Trip frequency.

The parameter 'travel time' was estimated in a simplified micro-simulation model and is used as input parameter by the Logit model. Trip fare is an input parameter for both the Logit and the micro-simulation model. Two different fare couples were chosen for the experiments. Trip frequency was used as input parameter for both the modal split model and the micro-simulation model. The value for this parameter had to be changed iteratively in both models. The taxi-bus system was dimensioned taking into account three constraints (see Figure 3):

- The average lateness in departure must be 10 seconds or less (*Lateness accepted*). When frequency of trips is high (15 minutes or less), an average lateness of less than 10 seconds assures high regularity of services. The micro-simulation model proved that an average lateness of 60–70 seconds leads to a maximum lateness of about 15 minutes, i.e. to the cancellation of one trip (the lateness is basically equal to the frequency). Lateness of less than 10 seconds, however, keeps the maximum

lateness generally under 4 minutes, thus leading to a high level of service to the users.
- The taxi-buses must on average be able to serve 80% or more of all calls received in the peak hour (*Service rate accepted*). This constraint was introduced to avoid making taxi-buses run nearly empty during the non-peak hours, when the demand is much lower. The 20% of customers not served at the end of the peak hour will have a chance to be served in the following hour or to shift to other transport means (bus, car, normal taxi, etc.).
- The average number of passengers served by each trip must be 7.8 or more (*Usage accepted*). This constraint reflects the point of view of the service operator. Since the trip fare is lower and the trip duration is longer than those of a normal taxi, taxi-buses should carry as many passengers as possible to be economically profitable for the operator. Since the frequency of trips is fixed though calls are random, in some cases it is not possible to have eight passengers for each trip. The micro-simulation model proved that when trip frequency is very high (5 minutes or less), the objective of full taxi-buses requires an excess of calls over the number of customers served that is often in conflict with the second constraint. The constraint of 7.8 passengers or more considers acceptable the possibility of one vacant seat every 5 trips, thus reconciling the objective of maximizing operator's revenues with the condition of fixed departures.

The micro-simulation and the Logit models were iteratively applied until constraints were satisfied. The logic of the iteration process is outlined in Figure 3.

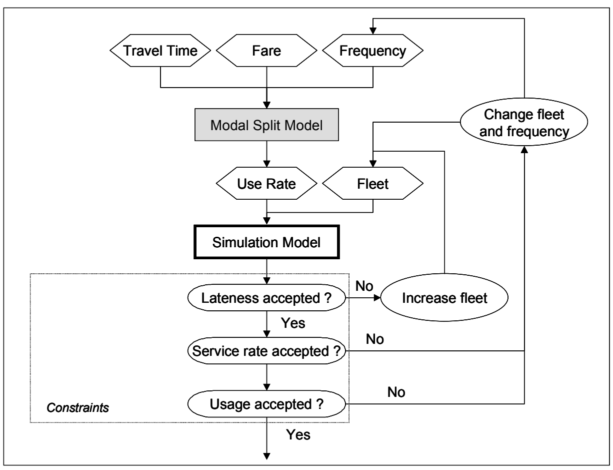

Figure 3: Iteration Process for Input Parameters

If the first constraint is not satisfied (average lateness in departure >10 s), the number of vehicles must be increased. Variations in the number of vehicles, without any changes to frequency of trips, do not cause changes in the demand. It is thus not necessary to apply the modal split model again in order to quantify potential users. It is enough to apply the micro-simulation model taking into account the increased fleet.

If the second constraint is not satisfied (% of calls served <80%, on average), the frequency of trips (and, consequently, the number of vehicles) needs to be increased. An increase of frequency causes an increase in the demand; it is therefore necessary to apply the modal split model to quantify the new value of potential users. Once potential users are known, the micro-simulation model can be applied accordingly.

If the third constraint is not satisfied (average customers served by each trip <7.8), the service is over-sized and taxi-buses run with few passengers. The frequency of trips (and, consequently, the number of vehicles) needs to be reduced. This causes a reduction of the demand. It is therefore necessary to apply the modal split model again prior to running the simulation again.

The two models have been iteratively applied until all three constraints were satisfied on both sample corridors (via Tiburtina and via Ardeatina), thus identifying the optimal frequency of trips and number of vehicles to be assigned to each corridor.

5 INTEGRATED OPTIMIZATION

5.1 Problem Description

The taxi-bus control center determines the appropriate stops for every trip. Different strategies can be used for determination of this sequence. A simple strategy was implemented in an early project phase. All customers wait at their start point until a taxi-bus picks them up. Their calls are received and queued with FIFO-discipline in the control center. In this simple strategy the control center selects the waiting customers and assigns an available taxi-bus to the next waiting customers. The departure time of taxi-buses is determined by the fixed frequency. The control center calculates an optimized route for every trip.

Optimization goal is the determination of the shortest tour, i.e. the travel time of the tour has to be minimized. The approach used is based on the well-known Traveling-Salesman-Problem (TSP). The problem analyzed is an open, asymmetric TSP problem: *open*, because the first and the last point on each route are not the same; *asymmetric*, because the distance from point A to point B can be (and generally is) different from the distance from B to A.

The route is not fixed, and the number of points to be visited on each trip (into the ZTL or outbound) varies according to the random process of demand generation. A trip to the ZTL is illustrated schematically in Figure 4. The taxi-bus departs from a depot located near the GRA, picks customers up at n_s source points, enters the ZTL through one of n_{gi} possible in-gates, and drops customers off in n_d destination points.

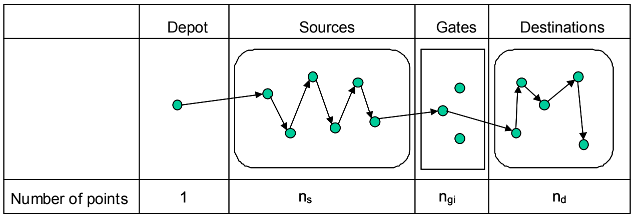

Figure 4: Typology of Points for the Traveling Salesman Problem

The best route needs to be identified out of ($n_s!\cdot n_{gi}\cdot n_d!$) possible routes for an inbound trip (to the ZTL). Referring to the Tiburtina corridor (3 in-gates), 8 being the capacity of each taxi-bus, it is possible to have (8 passengers having 8 different sources and 8 different destinations) n_s=8, n_d=8 and n_{gi}=3, i.e. 8!·3·8! (about 5 billion) possible routes. The same is true for an outbound trip (from the ZTL).

5.2 Principles for Coupling Simulation and Optimization

There are two principal kinds of coupling simulation and optimization (see Figure 5).

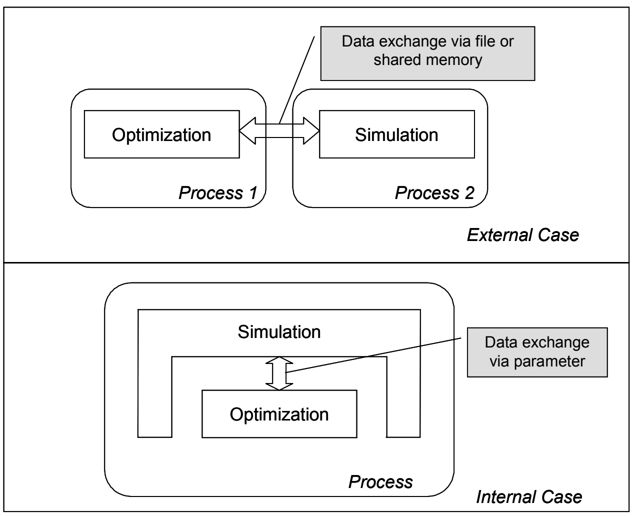

Figure 5: External and Internal Coupling

The *external* case is characterized by two components (simulation and optimization) working in their own process environment. The components exchange data via files or shared memory. This exchange does not occur during the simulation run; it is executed before or after the simulation run. A typical application of this case is the optimization of manufacturing layout, whereas the layout is evaluated by the simulation.

The other coupling case is called *internal.* In this case the two components are integrated into a single process. Simulation and optimization form one process. The interaction between these components takes place during the simulation run. Data are exchanged via parameters (shared memory). The internal case offers a main advantage in relation to couple simulation and optimization for the determination of the best taxi-bus route. The invocation of the optimization component is much faster than in the external case. This fact must be respected because the optimization must be called very often.

5.3 Implementation Aspects

In order to simplify the optimization problem, each route was split into two sub-routes: *boarding* (the taxi-bus picks the customers up and goes to the nearest gate) and *delivering* (from the gate to the destination points). In such a way, the original optimization problem is split into two easier-to-solve sub-problems.

As a consequence, the number of possible routes for an inbound trip is reduced to ($n_s!\cdot n_{gi}$) for the boarding problem and to $n_d!$ for the delivering problem. Referring to the example made in section 5.1 (n_s=8, n_d=8 and n_{gi}=3), it is necessary to find out the two best routes out of two sets of 120,960 and 40,320 possible routes respectively, instead of finding out one best route out of a set of about 5 billion possible routes. For an outbound trip the situation is specular: ($n_d!\cdot n_{go}$, where n_{go} is the number of the out-gates) possible routes for the boarding problem, $n_s!$ for the delivering one. In both cases the optimization problem is significantly simplified.

For each sub-problem the best route is identified out of all possible routes. However, such a procedure does not ensure that the sum of the two best sub-routes is the best route for the original problem. Figure 6 illustrates a particular case where the best route (the sequence 1-2-3-4) is not the sum of the two best sub-routes (1-2-5 and 5-4 respectively).

The procedure of problem splitting has two main advantages:

1. If the travel time between gates is short (say, a couple of minutes), the difference between the best route and the sum of the two best sub-routes is negligible.
2. If original optimization problem is split, the number of possible routes to be explored is significantly reduced and the model runs much faster.

The algorithm adopted to determine the best route for each sub-problem is the Branch-and-Bound. Given a reference route whose travel time is t_0, the algorithm cuts the other possible routes as soon as their travel time is higher than t_0. If a route is found whose travel time is $t_1<t_0$, it is taken as the new reference route and the exploration contin-

ues. The algorithm excludes entire sets of routes without the necessity of evaluating the total travel time for each of them.

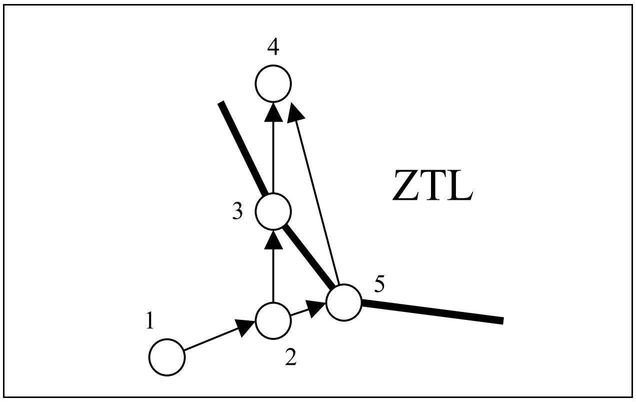

Figure 6: The Best Route is Not the Sum of the Two Optimal Sub-Routes

A *heuristic method* was developed to establish a proper reference route for each sub-problem. By this method, the reference route is the one having all points to visit ordered according to the ascending travel time from the starting point. A “good” reference route makes the exploration of all possible routes much faster, since only a limited number of complete routes need to be calculated.

The optimization algorithm must be invoked many times during one simulation run. It must be called about 80 times for the simulation of one hour of operation time of the taxi-bus system for one corridor.

The internal case (see section 5.2) was selected for coupling the simulation and optimization components. The optimization component was embedded inside the simulation component. The computer time for invoking the optimization component can be disregarded.

Simulation component and optimization component both were implemented with the simulation language SLX® (Henriksen 1999a). The available SLX-features support an effective model development process and the whole micro-simulation model is characterized by very fast simulation run-times.

6 RESULTS

The input parameters trip fare, trip frequency, number of taxi-buses (fleet) and user rate form a scenario. One simulation run covered the taxi-bus operating time between 20:00 and 02:00. Fifty simulation runs were conducted for each scenario. The result parameters were estimated based on these runs for the peak hour only. A 95%-confidence interval was calculated for every result parameter.

As for the Tiburtina corridor (see Table 1), the first fare solution (€4.1 for the inner zone, €6.2 for the outer) requires 22 vehicles along the corridor, with a trip frequency of 4 minutes. Average revenues are about €900 per hour. Figure 7 shows as an example the influence of the number of taxi-buses on revenue. For other results see Filippi *et al.* (2000).

Table 1: Results for Tiburtina Corridor

Service characteristics	Trip fare	
	€4.1/6.2	€5.2/7.7
Fleet	22 taxi-buses	15 taxi-buses
Frequency	A trip every 4 minutes	A trip every 7 minutes
Average lateness in departure	7.6 seconds	4.0 seconds
Percentage of customers served in peak hour (average)	92.1%	92.6%
Customers served in peak hour (average)	232.5	136.1
Customers served by each trip in peak hour (average)	7.9	8.0
Average hourly revenues for the entire fleet	€900	€650

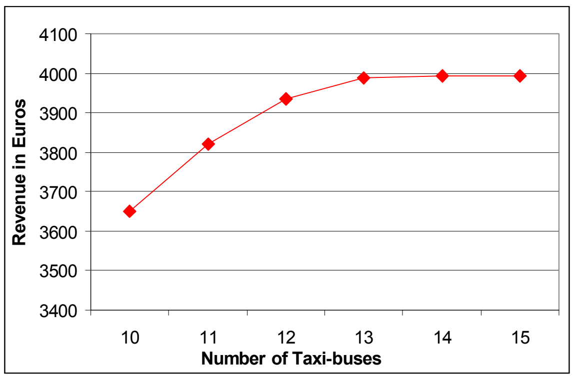

Figure 7: Influence of Number of Taxi-Buses on Revenue

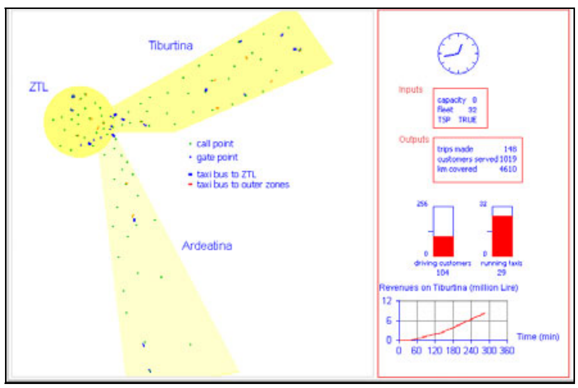

Figure 8: Snapshot of the Animation

An animation can be created optionally. Figure 8 contains a snapshot from the animation developed with PROOF-Animation®.

7 CONCLUDING SUMMARY

The paper focused on two problems that were solved in relation to the development and use of a micro-simulation model of a taxi-bus system. The first problem is the iteration process for determining input parameters of the micro-simulation model. Some outputs of the micro-simulation model are input parameters for a modal split model that delivers input parameters for the micro-simulation model.

The second problem is the multiple calls to an optimization method inside a simulation run. The problem was solved based on the embedding of the optimization component inside the micro-simulation model. The complexity of the optimization problem could be reduced, so that run times for simulation experiments could be accepted. Object-based simulation languages with excellent run-time features are predestinate against slow GUI-based simulation systems.

The next topics to be addressed within the simulation project are the improvement of the model interface and the interoperability between the micro-simulation and the Logit model. Cost aspects will also be introduced.

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