MAS SIMULATION FOR DECISION MAKING IN URBAN POLICY DESIGN: BICYCLE INFRASTRUCTURE

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ABSTRACT

Urban policies requires a deep knowledge about the dynamics that can affect the acceptability of the investments by the population, considering not only the present context but also the different future scenarios that can emerge. In this paper, an agent based simulation model to evaluate the impact of different urban bicycle infrastructure investments is described as an excellent tool to mitigate the risk in the decision making process. It is well accepted that a critical factor to extend the use of bicycle in a city for mobility purposes is to achieve a minimum amount of citizens satisfied with the bicycle infrastructures, which will act as a seed to extend the use of bicycles by influencing their communities. Thus, the main idea is to prioritize those investments that can contribute to achieve the critical mass of urban cyclists.

Keywords: Simulation, modeling, policy design, CPN, MAS, Bicycle, Infrastructure, decision support system

1. INTRODUCTION

Simulation techniques offer the right experimental framework for a new way of thinking about individual and population feedback dynamics, based on ideas about the emergence of complex behaviour from relatively simple activities (Simon 1996).

While some simulation modellers emphasize the desire for understanding and others emphasize the need for making predictions, urban policy design should aim at least to satisfy the following two goals:

- Explanatory model: To help citizens understand their neighbourhood area in order to control and change it.
- Predictive model: the urban policy decision makers need tools to predict the impact of their decisions on the future use of the infrastructures and services under design, within real social context scenarios.

Thus, a better understanding of some features of the social world should pave the way to develop simulation models that could reproduce the dynamics of some behaviour in order to 'look into the future'. Despite the modelling difficulties, both goals are not incompatible: a successful explanatory model can be used to generate acceptable predictions, while a good predictive model can contribute to a better understanding. Moreover, a trade-off between accuracy and simplicity should always be kept in mind during the modelling phase (Axelrod 1997).

The role of citizens in e-government should be seen as a rich source of knowledge about the phenomenon being modelled, thus their involvement in the understanding of the context scenario and the experimentation of different policy alternatives through simulation models could raise their interest in the policy design process and could improve their level of knowledge about the issues at hand, transforming opinions into valuable implications. To deal with such citizen engagement in e-participation, the research efforts in new simulation developments should not be placed in better representation of simulation results, but it should instead focus on fostering model transparency for explanatory and predictive urban policy purposes.

Among the different modelling formalisms (Gilbert N. 2005, Li An 2012), agent-based simulation is well suited to e-participation, since end-users not properly familiarized with modelling usually catch easily the idea of autonomous agents carrying out activities and communicating with each other in a way similar to citizens interactions (Ramanath and Gilbert 2004). By means of a Multi Agent System (MAS) simulation platform, a library of causal models to allow citizens to test the benefits and shortcomings of different proposed urban policies and check new policies according to their own beliefs has been developed in the FP7 project FUPOL (Piera et al., 2013; Buil and Piera, 2013; Piera et al., 2014).

This paper presents the use case in Bicycle infrastructure developed for the city of Skopje, Macedonia. The objective of the model is to help city planners to schedule the infrastructure investments to increase the number of bicycle users in the city. They expect to double the number of users in few years, going from the current number of bikers, which is around 2.5% of the population, up to 5% of the

population, a percentage typical of northern European cities, where bicycle transport is a consolidated option.
In this paper it is introduced in section II a description of the Skopje facilities to support bicycle mobility, while in section III it is proposed a MAS model approach to improve the decision making process. Section IV provides a short background on the use of coloured petri net modeling formalism which is used to open the state space of the system to better understand the model causality and evaluate the reacheability of some system states. Finally, section V illustrates the results obtained.

2. PROBLEM DESCRIPTION

Intermodal passenger transport, also called mixed-mode commuting, involves using two or more modes of transportation in a journey. The goal of mixed-mode commuting is often to combine the strengths (and offset the weaknesses) of various transportation options. A major goal of modern intermodal passenger transport is to reduce dependence on the automobile as the major mode of ground transportation and increase use of public transport.
The benefits of the use of bicycles for flexible mobility, emission reductions, physical activity benefits, reduced congestion and fuel use, individual financial savings and support for multimodal transport connections are well known and accepted by the transport community. However, there are some barriers that should be properly addressed to successfully promote the use of bicycle as an alternative to well consolidated transport means.
Among the barriers, safety is a major concern including a perceived lack of suitable bicycle infrastructure, as well as regular a negative attitude of some car drivers. Considering the former concern, it has been reported that the right location of bicycle docking stations to be better integrated with public transport, as well as suburban locations, beyond the inner areas bordering the municipalities is a critical factor to be analysed.
All main access roads to Skopje lead straight to the city centre. Mainly used transport means in Skopje include:

- public busses,
- taxis,
- individual cars,
- individual bicycles,
- individual motorbikes,
- pedestrians

The city infrastructure mostly provides space where people can park their cars in an outdoor parking place or parking garage. The problem with which Skopje is facing is the lack of bicycle parking lots. Furthermore, bicycle rental services are also scarce or even non-existent.

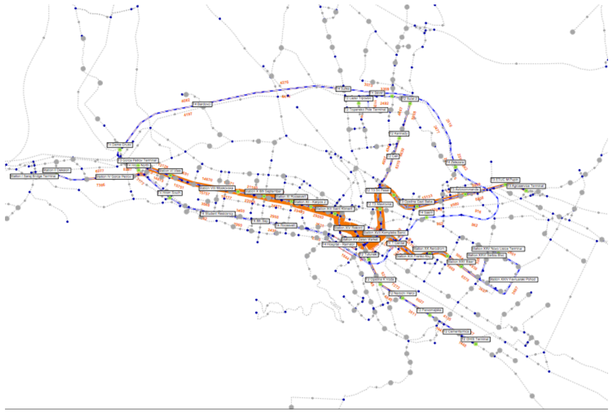

Figure 1: Bus Station in Skopje City

Usually, city centre is already well serviced by public transport (see figure 1) but linking suburbs and major destinations lacks of enough bicycle infrastructures. Furthermore, bicycle lanes use to fail to provide a continuous route to their destination and that leads to longer route in order to avoid ''problem spots''.
The use of a bicycle can, for example, make an (inexpensive compared to a car), a typical 10km bus journey attractive even if the endpoints of the journey each sit 1km out from the stations: the 20 minutes walking time becomes 8 minutes bicycling time. As in the example above, location plays a large role in mixed mode commuting. Rapid transit such as express bus may cover most of the distance, but sit too far out from commute endpoints. At approximately 5 km/h walking, 3 km represents about 40 minutes of commute time; whereas a bicycle may pace 15 km/h leisurely, cutting this time to 10 minutes. When the commuter finds the distance between the originating endpoint (e.g. the home) and the destination (e.g. the place of employment) too far to be enjoyable or practical, commute by car or motorcycle to the station may remain practical, as long as the commute from the far end station to the destination is practical by walking, a carry-on cycle, or another rapid transit such as a local or shuttle bus.
In general, locations close to major transit such as rail stations carry higher land value and thus higher costs to rent or purchase. A commuter may select a location further out than practical walking distance but not more than practical cycling distance to reduce housing costs. Similarly, a commuter can close an even further distance quickly with a bike, motorcycle, or car, allowing for the selection of a more preferred living area somewhat further from the station than would be viable by walking or simple bicycle.
For a proper planning of their infrastructures, the Skopje municipality required a decision support tool to:

- Predict the increment of bicycle users depending on the bicycle facility investments (renting stations, parkings, and signalised paths in good shape).
- Study the locations and capacities of renting stations and parkings.

- Determine which paths will be more used by citizens and thus should be maintained properly.

A simulation model has been developed to support two types of experiments with two different objectives:

- **Simulation 1 Best Configuration for a given Budget**: To select the renting stations and parkings configuration which can impact with better increment of bicycles users in Skopje.
- **Simulation 2 Analysing the use of Bicycles in Skopje**: To allow citizens get a better understanding of the usability of bicycle facilities considering different scenarios, in order to support the municipality investment proposal and/or to provide evidence of the benefits o a different investment proposal. Thus, end-users will be able to modify the location of renting stations, parking capacities, pavement improvements, etc.

For both simulations it is considered the amount of funds expected to be available in order to deploy any of the bicycle facilities.

3. MODEL DESCRIPTION

The model consists in a set of stations that can be origins and/or destinations (bus stations, train stations and points of interest), a set of tracks between these stations (not all stations are connected), and the users. Stations are fixed and they can be renting bike stations or/and bikes parking (for private bikes). It is considered that, at each station, a renting station can already exist, can be planned, can be possible or cannot be possible. Similar alternatives are considered also for bicycle parkings.

Tracks are fixed. There is one track for each possible connection between stations. These tracks can already be an existing bike path, can be a planned bike path, can be a possible bike path or they can never be a bike path.

Tracks and stations planned can be treated as existing, thus it can be tested what would happen if they would be available. Possible tracks and stations can be set as existing to also test what would happen if they would be available.

User agents can use the bike or not. Ones using bikes have defined trips that are performed depending on weather conditions and tracks and stations condition. A user that can make a trip by bike or by another transport system will use one or the other depending on its satisfaction with the tracks and the stations included in its trips. If it usually uses the bike but the city of Skopje invest during several years in other stations and tracks, even though the tracks it uses are crowded and without a built bike path or a bike path in bad conditions, its satisfaction will decrease and it can imply that the user skip the use of the bike to start using the alternative transport system. On the other hand, the satisfaction (about bike infrastructures) of one user that usually takes some other transport system will increase if it exist a good combination of well conditioned tracks, and parking station at its destination, with an appropriate capacity to easily find a spot to park the bike.

The satisfaction of the users can be also modified by occupancy conflicts at renting stations or at parkings, and finally also by the satisfaction of the neighbours: If the majority is satisfied, its satisfaction will increase, if not, it will decrease. There are several opinion formation models that can be applied in order to use the neighbours' satisfaction to modify the satisfaction of one agent. Two of these opinion formation models have been already tested obtaining good results.

The first one counts the satisfied and unsatisfied neighbours around the agent and its satisfaction is modified following these rules:

1. If more than 50% of the neighbours consulted are satisfied, the satisfaction of the agent increases.
2. If more than 50% of the neighbours consulted are unsatisfied, the satisfaction of the agent decreases.
3.

The second opinion formation model also counts the satisfied and unsatisfied neighbours, and is formalized by means of the (Weidlich, 2000) model:

$$\mu \uparrow = \sigma \exp(U)$$

$$\mu \downarrow = \sigma \exp(-U)$$

$$U = \pi + k \frac{n \uparrow - n \downarrow}{n \uparrow + n \downarrow}$$

In which

$\mu\uparrow$: is the probability of the individual transition from no to yes while $\mu\downarrow$ is the probability of individual transition from yes to no.

σ is a flexibility parameter. High values increase the probability of an opinion transition leading with more opinion changes.

Π is a preference parameter, in which a high value increases the probability of changing to yes, while a low value will decrease the probability of changing to no. A 0 value means neither yes neither no is preferred.

k is a coupling parameter used to represent the influence of a yes majority on an individual change to yes (the same is true for the influence of a no majority on an individual change to no). A high value of k means a high influence while a zero value means that individual transition probabilities do not depends on the population opinion distribution.

$n\uparrow$ and $n\downarrow$ represents the amount of individuals with a yes option and a no option respectively.

4. CPN DESCRIPTION

The description of the causality of the different events that can affect the acceptability of the proposed investment distribution in the Bicycle Inter-Modality model, has been defined using the CPN modelling formalism.

In order to simulate the policy acceptability according to a certain time horizon, some citizen attribute information can change on a time based mechanism according to the boundary conditions. Thus, a prediction of an increment of population in a municipality, or a new set of stations can be considered to evaluate the impact on the proposed investments.

Table 1: Events formilized in CPN

Transition	Meaning
T0	Initialization of the CPN model using the Boundary Conditions that specify the simulation scenario: Initializes the activities, resources, user group and weather attributes defined in the previous section.
T1	Initialization of a trip: For a user group, it is generated a bike trip considering the user group profile and the simulation clock.
T2	Renting a bike: For a particular user group, it is generated randomly considering the time preferences the renting of a bike in a station.
T3	Parking a bike at the destiny: Transition T1 generates a time event T2 which updates the variables regarding the docking information and the use of tracks.
T4	Returning a rented bike at the destiny: Transition T1 and T2 provide the information to generate a time event that represents the return of a renting bike.
T5	Return trip: Each time a transition T3 is fired, it generates a transition T5 which is delayed according to the profile information. This transition updates the docking information.
T6	End of a trip: Transition T5 generates a time event T6 which updates the variables regarding the use of tracks.
T7	Opinion formation: This transition evaluates the acceptability of the bike investments policy by a member of a user group chosen randomly
T8	Opinion formation: This transition evaluates the rejection of the bike investments by a member of a user group chosen randomly
T9	Satisfaction: This transition evaluates for each user group its affinity to the proposed investments.
T10	Distributing investments in renting facilities, docking and tracks: This transition is not part of the Bicycle Inter-Modality dynamics, instead it will be implemented in the observer agent, and will try to deal with a better trade-off between the investments by evaluating its impact on the amount of kike users.

Figure 2 illustrates the CPN model of transition T9 : satisfaction evaluation for each user group about the proposed investments

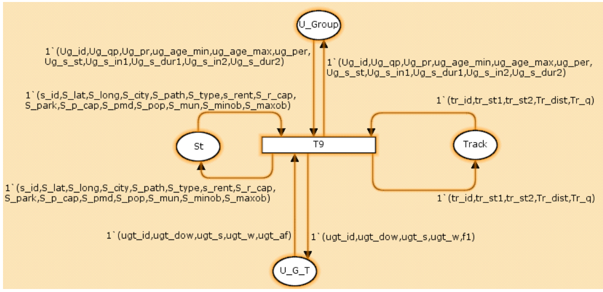

Figure 2: CPN model of T9

Bike users have been formalized in CPN considering the following attributes:

- id: it is the agent id, automatically generated.
- groupID: it is the group Id taken from the input tables.
- profile: indicates the type of user.
- description: Indicates an area or neighbourhood, or indicates that it has an exact location for the house.
- age: it indicates the age of the agent.
- destination: it indicates the Municipality destination (code).
- destinationID: it indicates the exact ID of the destination station.
- originID: it indicates the exact ID of the origin station.
- tripStations: set of ordered stations from origin to destination.
- duration: duration of the trip between stations
- startTime: time to start the first trip (going to destination).

- backTime: time to start the second trip (going back to origin).
- durationTotal: duration of the trip.
- distance: length of the trip.
- personality: Level of personality of the agent.
- satisfaction: Level of satisfaction about the bicycle infrastructure.
- tripStatus: variable in which the status of the tracks are added in order to generate a global status.
- trackID: id of the performed trip.
- stationID: The station where the user is parking or taking a bike.
- pDay: Day parameter to determine if the bike is used.
- WEcomp: Parameter to determine if the pDay value for weekend is complementary or not, which means that bike must be used one of the two days.
- weVisit: indicates if a complementary weekend, the bike has been already used.
- pMonth: Month parameter to determine if the bike is used.
- pWeather: Weather parameter to determine it user uses the bike.
- park: Indicates if the user bike is parked in a bike parking slot.

5. MAS DESCRIPTION

The MAS model consists in a set of stations that can be origins and/or destinations (bus stations, train stations and points of interest), a set of tracks between these stations (not all stations are connected), and the users. Stations are fixed and they can already exist, can be planned, can be possible or cannot be possible.

Tracks are also fixed and they connect two stations. Minimum distance tracks are just considered and the distance with other tracks, not directly connected, is calculated using some graph search algorithm, as for example, the Dijkstra's Algorithm. It finds the shortest path from a point in a graph (origin station) to a destination. These tracks can also be an existing bike path, can be a planned bike path, can be a possible bike path or they can never be a bike path.

User agents can use bike or not. Ones using bikes have defined trips that are performed depending on weather conditions and tracks and stations condition. A user that can make a trip by bike or by another transport system will use one or the other depending on its satisfaction with the transport system it selects.

This satisfaction can increase or decrease depending on the profile of the user (citizen) and/or the quality of the infrastructure of the transport system it is using. For example, for bikers, it will depend on the condition of the tracks, its occupancy, also on the capacity of the station at the destination, and its occupancy. Satisfaction of users is also affected by others opinions. There are several opinion formation models that can be applied in order to use the neighbours' satisfaction to modify the satisfaction of one agent. During the development of other models two of these opinion formation models have been already tested obtaining good results; therefore, they are also used for this model. The satisfaction is the factor that will make a citizen start using the bike or stop using the bike.

The simulator works in two different modes:

1. Municipality Mode: Used to compare different actions (defined by officials) taking in to account the available budget. Once all options are evaluated, it determines which set of measures are the most adequate according to their impact. It is a mode specially created for city officials.
2. Citizens Mode: Used to test different options introducing few small modifications into the default configuration defined by the city officials. It allows the users "to play" with the simulator and send suggestions, based on the results, to the city officials.

In Figure 3 it is illustrated the flow of information and actions implemented in the bike user Agent when deciding its mobility to a preferred destination. As reported in (Piera 2014), the CPN model formalization is used to validate the model events by means of the reachability tree, while the MAS implementation is used for experimentation purposes of specific parameterized scenarios. Thus, Agent behaviour is always codified as a DES considering the CPN events.

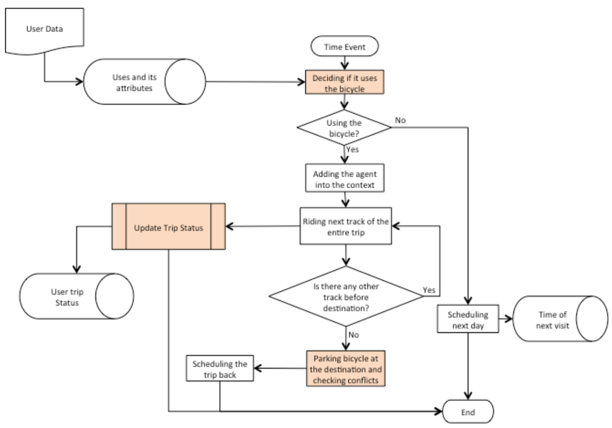

Figure 3: User Agents behaviour. Trip to Destination. Time event dependant process

In figure 4 it is illustrated the opinion formation method to update user satisfaction by track status while in figure 5 illustrates the opinion formation method to update user satisfaction by neighbour opinión influence.

Different model validation techniques has been used to properly parametrize the Agents opinions dynamics in order to obtain realistic increments of bike users.

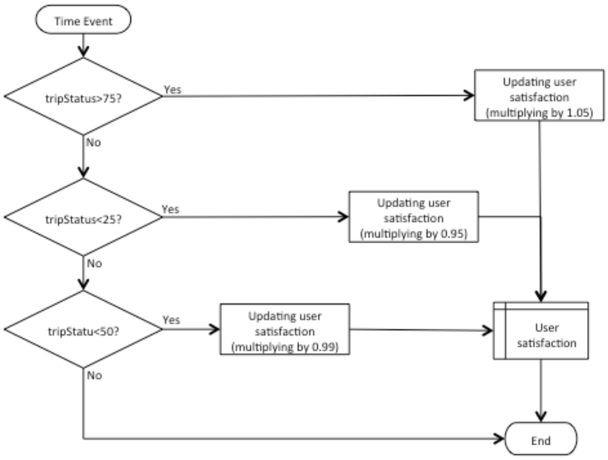

Figure 4: Opinion formation method to update user satisfaction by track status

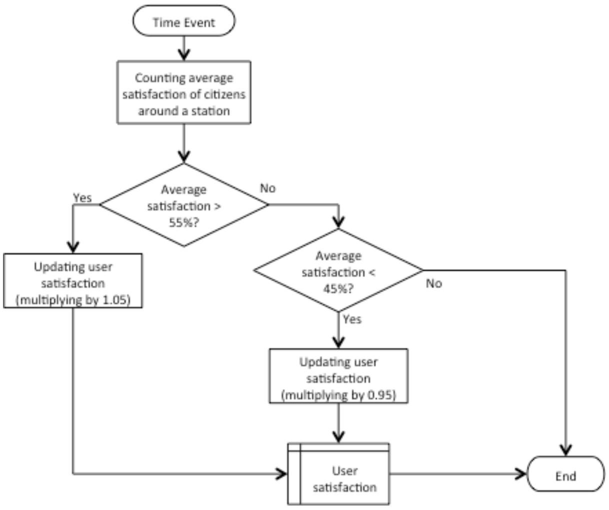

Figure 5: Opinion Formation method to update user satisfaction by neighbours

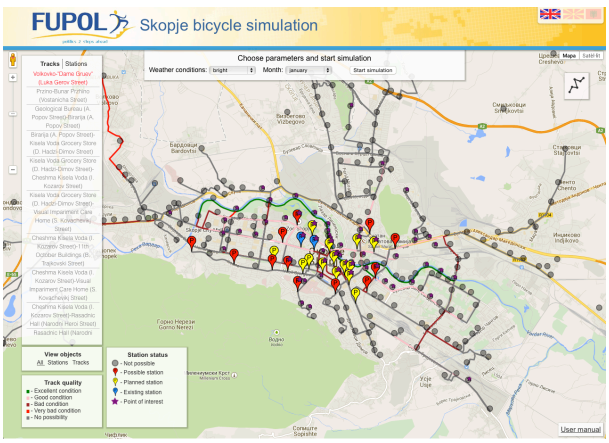

Figure 6: Bicycle Infrastructure in Skopje (Stations and tracks

6. MAS VALIDATION

Figure 6 presents the web simulator with the map showing the stations and the tracks. Stations can be Impossible, Possible, Planned or Existing, depending on the possibility or not to have parking station in that spot. Tracks can be also Impossible, Possible, Planned or Existing.

The implemented ABM validation was based on the structure and parameterization analysis by field experts, and the comparison of the observed model behaviour with the monitorized real system behaviour. This type of validation is called plausability. Bicycle infrastructure experts participated on the model development. Several conceptual models were developed to check field expert opinions till a consensus on the causal relationships was agreed between experts in conformity with historical data used. Thus, experts through different experiments confirmed that both, the conceptual model implemented in CPN and the MAS model implemented in Repast "looks logical"; satisfying the first part of the plausability validation. The second part of the validation is to test the simulation model by comparing results generated with the simulator with data collected from the real system. For that reason, a fieldwork was organized in the city of Skopje, and several persons got data from some of the sources in the system during 6 different days: Saturday, October 11th 2014; Sunday, October 12th 2014; Tuesday, October 14th 2014; and Wednesday, October 15th 2014; from 7:00 to 19:00; and Saturday, November 8th 2014; and Wednesday, November 12th 2014; from 9:00 to 14:00.

Two different plausibility validation test have been performed.

6.1. Users by Hour

Differences between simulation results and real data regarding the number of bikers per hour are very high for all the measured points due to two main reasons:

a) The random generation of the origins for a given destination

b) The distribution of the departure hours

Origin is directly related to the entire trip duration; therefore, it also affects the departure hours. The distribution of the departure hours should be different for the users with same origin and destination. Some times it could be equal, but not for all users, and not always.

In figure 7 it is represented the bike users for L70 track during Sunday, October 12th 2014. Since the total amount of users is the same for real data and simulation, extra parameterization effort is required to find out how many origins and times must be correctly generated in order to get similar number of bikers by hours for both simulation and real system. It would be necessary to determine the distribution of bikers by hour using all the data collected, instead of using the arrival time minus the time of the trip.

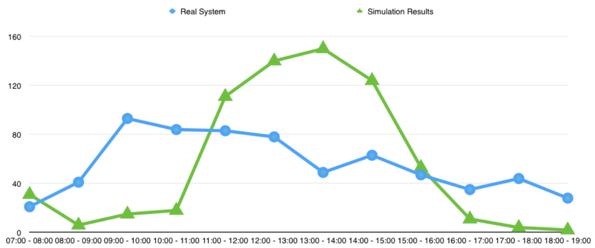

Figure 7: Hourly Bikers evolution on Sunday, October 12th 2014

6.2. Users by Day

Table 2 and Figure 8 show the total bikers going through station L70 during the collecting data days. First row of the table and the line in blue of the figure represent the number of bikers observed in the real system. Second row of the table and line in green of the figure represent the mean value of a set of 20 simulation's runs. Last two rows of the table and yellow and orange lines of the figure, respectively, represent the minimum and maximum number of bikers obtained during the 20 simulation's runs.

Table 2: Total Bicycle Users in L70

Data Source	Saturday 11/10/14	Sunday 12/10/14	Tuesday 14/10/14	Wednesday 15/10/14
Real System	733	666	1129	1174
Simulation Mean Value	672.7	625.3	1268.5	1145.2
Simulation Min	599	573	1127	1065
Simulation Max	745	690	1412	1279

As it can be seen, the model has been properly arranged to get simulation results closer to the reality. Due to the number of variables influencing the final results, it is not possible to adjust all the parameters of the model and get results more similar to reality. A micro modelling approach would require collecting some extra data about origins, destinations and departure times and it would allow to deep in some details out of the scope of FUPOL simulation model.

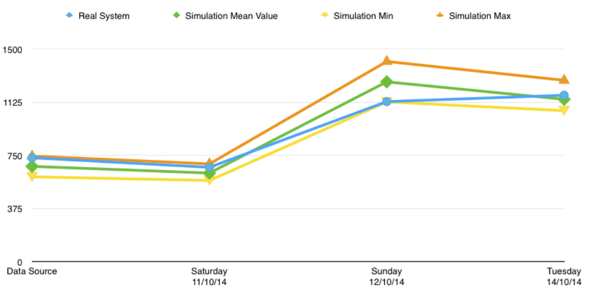

Figure 8: Total Bicycle Users in L70

7. CONCLUSIONS

The use of MAS model as decision support tool for infrastructure investment purposes has been presented as a successful approach to design urban policies in which citizens can be involved in the priorization of the investments by transforming its opinions in valuable knowledge.

The macro model implemented provides a well accepted solution for planning purposes, however it lacks of a proper micro level representation to allow citizens to obtain a better understanding of simulation results

The suggestions to improve model transparency for a better engagement of citizens as potential end-users of the simulation model are:

a) Origins and destinations should be provided in some other more realistic manner. Just this modification would modify simulation results since currently origins are randomly generated from 1 km to 3 km away of the destination
b) Routes of the bikers should be analysed and determine if using the Dikjstra algorithm is appropriate or they need to analyse the routes bikers use. Dikjstra algorithm considers the distances but not the quality of the tracks.
c) The distribution of the departure times must be modified also because not all users start the bicycle trip with the exact time they need to rich their destination. Most of them use some more time. It would be needed to collect extra data about the time bicycle users leave the house when going to some destination by bicycle. It depends on the weather? it depends on the month? All this information would be necessary to really generate the correct parameters for the simulation model.

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