Use of System Dynamics for modelling customers flows from residential areas to selling centers

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Abstract: - This work aims to analyze, with the System Dynamics simulation, the impacts of a new supermarket opening in terms of the traffic flows in the surroundings of a determined urban zone, in order to help decision makers to find the most suitable area and the proper number of car parks and counters to satisfy a certain customer level service, avoiding high waiting times and, consequently, customer losses. Among the different simulation methodologies, System Dynamics has been chosen because it allows to properly model systems that continuously change over time, that are affected by time delays and whose variables depend on their conditions at the previous time step. Traffic flow systems are included in this category of systems. Moreover, the software used for simulation, Powersim Studio™, allows the integration with GIS (Geographic Informative systems), which provides useful information on road mapping and users allocation.


1 Introduction

This work focuses on the use of System Dynamics methodology devoted to analyze the customer flows from their residential areas to a hypothetic new supermarket, considering all the significant variables and dynamics that affect the vehicular traffic of the interested zone.

More specifically the work represents a feasibility study about the issue of the opening of a new supermarket in a particular area. This requires the sizing of the parking areas and the number of counters, in fact it has been demonstrated that these parameters can significantly affect the supermarket profitability.

In order to evaluate the potential customer basin served by the new selling point, the supermarket chains use typical benchmarking analysis in order to provide the services right dimension like the car parking area or the supermarket service level in terms of parking receptiveness – a person who has difficulty to find a parking, passed a certain time period, prefers to go away looking for another store with a major receptiveness – in relation to some characteristic parameters like the daytime or the rotation index.

The developed model is able to evaluate the number of people served at the supermarket and the eventual losses in terms of customers service level in the selling areas and the parking availability.

This problem has been addressed by utilizing the System Dynamics methodology, which is particularly suitable for studying complex dynamics systems that continuously change over time. Among the different software implementing the System Dynamics approach, Powersim Studio™ has been chosen also because of the possibility of integrating it with a GIS (Geographic Informative System), which is essential in locating streets, and determining the main traffic directresses based on the roads mapped in the informative system. GIS assigns customers to each road – in relation to the place where they live - and, then, it can size the customer basin, calculating the average number of cars for each road. Relying on statistics, the system allows determining the average number of transits for each road, according to the daytimes. In addiction to this “normal” flow it must be considered also the potential traffic generated by the new store opening. The GIS system assigns also the road directions.

The model proposes to analyze the traffic flows on the whole day in order to properly dimension the number of car parks and counters; moreover it tries to identify eventual bottlenecks in the supermarket car park itself or in the network.

Analyzing the literature on traffic models, Taplin in [1] reviews the range of traffic models, with particular attention
to microsimulation. The standard way of assigning traffic to a network is to find a static equilibrium from which no driver would be able to find a quicker route. This gives fairly good predictions of the link flows resulting from driver choices. Traffic is loaded on to shortest routes, times are modified by a speed-flow function, leading to reassignment to more routes, and the solution is iterated until all used routes between each Origin-Destination (O-D) pair take equal time.

An alternative is stochastic user equilibrium, taking explicit account of the variability of choice. Each route between an O-D pair that does not backtrack is given an initial share by the logit distribution. Again, travel times are modified to take into account congestion, and there is a somewhat messy iterative process to reach equilibrium.

Curiously, stochastic user equilibrium is as deterministic as ‘deterministic user equilibrium’. A criticism of equilibrium models is that the process of adjustment after a change to the network may be of more interest than the apparently stable outcome.

Microsimulation has been used for small components of the network but recent models at the single vehicle level can simulate entire urban networks, using a great deal of computer power. One uses cellular automata, such that each cell in a spatial lattice is updated according to its own state and the states of its nearby neighbors at the previous time step. More conventional microsimulations use simple rule based behavior.

Simulations are designed not only to show the emergent order but also the impact of incidents which generate spreading instabilities. Microsimulation is also used to capture the expected effects of route information, as well as indicating control and routing strategies. The System Dynamics methodology has proved to be a very good one to solve traffic flows problem, because traffic conditions constantly change in a dynamic way and they are significantly affected by previous conditions and by temporal delays.

Xue and Hudson in [2] have demonstrated the possibility of interconnecting System Dynamics methodology and traffic flow simulation studying a one-lane road section and a roundabout model based on general transportation regulations and including traffic infrastructure controllers. The two authors proposed a simulation model implemented with STELLA software, in order to build a flexible object oriented platform for any road network system devoted to improve the transport planning and management, considering all the various influences coming from the real world.

The paper is organized as follows: section 1 presents an introduction of the problem and a literature review about traffic flows problems. In section 2 a detail description of the problem and how it has been modeled through the use of System Dynamics is provided. The results obtained from the simulation are explained in section 3 and some conclusions and further research ideas are addressed in section 4.

2 Problem Description and Modeling

The goal of this research is to evaluate the impact of the logistics driveways to a sales point, and more specifically to a supermarket, helping the decision makers in the feasibility analysis for the new supermarket opening.

This section provides a description of the System Dynamics model implemented, whose layout is provided in Appendix 1.

Before designing and implementing the System Dynamics model, it has been necessary to evaluate, through the help of GIS:

1. all the streets in the considered area, by defining them in terms of longitude and latitude;
2. the minimal path in terms of distance and time;
3. the cluster of streets, which are similar, in terms of covered travel times;
4. distinguish streets between “primary” ones, representing the roads directly accessing the supermarket, and in “secondary” streets, meaning all the other roads in the considered area;
5. the number of cars per each street.

So, thanks to this tool, it has been possible to calculate time and standard distances (by road) between starting points (customers home) and ending points (store’s location).

Figure 1 shows the Via Michelin GIS Web Service Architecture.

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Figure 2 shows some of the GIS system interfaces.

![Fig. 1 The Via Michelin GIS Web Service Architecture](image-url)
In order to evaluate the level of accessibility by potential customers to the store, the following steps have been performed:

1. taking into consideration the primary streets, the average travel time of customers going to the supermarket have been calculated;
2. customers have been assigned to the fastest primary way. In other words, it has been assumed that each customer, starting from his own home, will choose the quickest way to reach the store;
3. it has been assumed that customers belonging to the same primary way will drive the same street to go to the supermarket. Such simplified assumption is necessary to define the traffic flows for each way of abduction (primary street);
4. with the use of standard indexes, the number of cars per each street has been defined.

Basically, there are two traffic flows, the “working” and the “supermarket” one. The former becomes significant in the morning, when people must go to work and then it shows a second peak in the evening when people come back home. Instead, the supermarket flow is characterized by different peaks, and the segment from home to the supermarket and on the cars in a particular daytime, while the coming back flow (from the supermarket to home) depends on the shopping time, considering factors like the supermarket selling area and the queues at the counters.

The combination of the two flows determines, for each primary way and each daytime, the real travel time that each customer spends to reach the supermarket and to come back home, including possible waiting for finding a parking slot.

The System Dynamics model, shown in Appendix 1, adopts the framework of a closed loop: it starts considering people with their cars parked at their home and ends when people come back home from the supermarket. Starting from his house, a person travels to the store in a particular daytime using a particular route of access, and finding a certain traffic flow. When he arrives to the store abduction segment (which is the road where it is located the point of access of the supermarket car park), he has to verify if there are parking slots available in the supermarket area: if not, the person waits for a free place for a certain amount of time, after which, if he has not found any parking slot, he goes to another store, causing a loss of customers for the supermarket. On the contrary, if there are free places, the customer remains in the store for his purchases for a certain time, depending on the sales area and on the people flow inside the store (including service times and queues at the counters). After that, the customer comes back home, travelling the reverse path – according to the road directions – and finding a particular traffic flow depending on the particular daytime. Once arrived near home, he has to look for a car park available in the road and the cycle stops. Figure 3 shows the developed architecture; as it can be seen the simulator is directly interfaced with the local database and with the GIS.

3 Simulation results

The model here above described has been simulated for a period of time of one day and a time step of one minute. The major system outputs are shown in Figure 4, 5 and 6.
4 Conclusion

In conclusion, the research here described aims to highlight the efficiency of the System Dynamics approach for a Decision Support System devoted to analyze the impacts on the traffic flow of a particular area after the opening of a new supermarket.

This tool, perfectly integrated with the Via Michelin GIS System, is useful for two stakeholders categories:

- the Supermarket managers, which have to evaluate the impact in terms of traffic deriving from the opening of a new supermarket, with the final goal of deciding where to place a new store;
- Public Administrations and municipalities, which are in charge of managing a town road network; so, when there is a specific need (as it can be the case of this particular issue), they can decide to modify the road layout or to change the road traffic directions.

As seen in the previous section, even if Powersim Studio™ software is the only one that allows optimization, no enhancement of the objective functions is required, because the model is a tool devoted to check the preliminary feasibility of the store location.

Further research will be devoted to refine the model and to analyze more in detail different aspects of the problem.

References:
