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28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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GENETIC ALGORITHMS TO OPTIMAL DEFINITION OF PEDESTRIAN TERMINAL LAYOUT

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Abstract

In the recent years is observed a growing interest in the analysis of pedestrian dynamics. Nowadays architecture design must aim to identify constraints and requirements to satisfy pedestrian flows inside nodal infrastructure – such as train stations, subways, airports – as well as into any civil complex that may gather notable pedestrian flows – city malls, theatres, meeting rooms, skyscrapers – and in urban elements such as shopping streets, main important squares, pedestrian flows in case of exceptional events, etc. In order to create an instrument to support technicians into pedestrian terminal projects and optimum layout definition according transport needs, an interesting approach was developed. Starting from analytical background for facilities dimensional range definition, through pedestrian dynamics modelling and cost objective function definition the application of genetic algorithm combined with social force models allows to identify a domain of optimum solutions compatible with pedestrian needs.

Keywords: pedestrians, terminals, design, optimization, genetic algorithm

1 Introduction

Nowadays, it is given major attention to pedestrian dynamics. Day by day, millions of pedestrians move in the world with different purposes and behaviors. Various disciplines and research activities are dealing with these items. Pedestrian behavior, reason of their movement, path selection and the necessity to model them, crowded phenomena, emergency situations etc, are very active sectors in transport engineering, in psychology, in economy as well as in computer vision techniques, biology etc. The complexity of pedestrian dynamics increases according to the intensification of the flow and, consequently, of the density. Interaction among pedestrians and their reaction to the objects present in the environment where they move are the motivation of numerous theories. The results are not only statistical data and qualitative considerations, but also models both analytical and simulative. Pedestrian dynamics conveys in area where interaction can increase and decrease rapidly as for example in urban environment, – squares, pedestrian zone, commercial streets – pedestrian infrastructure as well as complex and large buildings – skyscrapers, directional and recreational buildings, cinemas, theatres, city malls – stadium etc. Engineering, architecture and specialized techniques work every day very closely to project the works above mentioned. Terminal, such as airport, subway station, railway station, bus station, cruise terminal etc, is a place where lots of pedestrians move inside for different purposes and in different ways, where interaction are relevant and where crowded phenomena and emergency possibility are ordinary items. While the goals of functionality and flexibility have a primary importance, the planner must also consider ways of creating a building layout and environment that supports the highest levels of passenger services and facilities in balance with the size of the building envelope and available budget. After a deepen and careful analysis of literature appears clearly that there is a great lack about the concept of optimum terminal layout definition, while deepen study were carried out to analyze single facilities like escalators, elevators, walkways, doors performance, stairs etc.

2 Methodology developed

The methodology developed allows to the user to arrive at the definition of the best layout configuration according input desired in some consecutive steps. First of all, it must be selected the case where the process must to be applied: e.g. if the objective is the identification of the best terminal layout for an underground terminal, the user will define a basis layout of the same terminal with the boundaries and the identification of the point where it will be inserted characteristic elements. In a pedestrian terminal will be defined as characteristic elements all the elements that generate consequences into pedestrian flow and dynamics as for example platforms, stairs, escalators, elevators, walkways, doors etc. Secondly, it must be defined the Level of Service – L.O.S. – desired that can be a single value or a range. This must be defined for every single characteristic element according to H.C.M. – Highway Capacity Manual – approach. In order to identify the volume of pedestrian that will move during the life useful of the terminal is required the quantification of the flow for dynamics that will be generated inside. Selected the above inputs, through an analytical model based into H.C.M. and T.C.Q.S.M. – Transit Capacity and Quality Service Manual – the dimensional range of every single characteristic elements is defined. The further application of an analytical model defines the travel time for pedestrian in usual condition, comfort condition as well as into emergency situation, increasing the flexibility of the approach. To evaluate the behavior of the terminal, according previous inputs, in terms of infrastructure costs and pedestrian costs, an objective function was elaborated. This aim to correlate the variation of terminal sizing with pedestrian travel time. Consequently, SOBOL methodology was used to generate the population for the next genetic algorithm application. This is possible through the application of the analytical models above described that provide results for objective function. Starting from SOBOL results, the research of the objective, best terminal layout configuration through the minimization of objective function, is pursued with M.O.G.A. – Multi Objective Genetic Algorithm. This led to identify a Pareto front with optimum solutions domain. At this point, the necessity to determinate the final performances of the terminal and consequently select the best solution led to apply the social force algorithm. This allows to obtain qualitative and quantitative measurements that led to final selection.

3 Analytical Tool

The issues concerning pedestrian flows have begun to have some relevance only in the last 40-50 years. In a first approximation, the studies concerning the analysis of the characteristics of pedestrian traffic can be divided into two broad categories (May, 1990): macroscopic and microscopic analysis. The first studies were based on direct observation and on the use of photographic material or shooting with cameras in slow motion. These studies gave rise to the first macroscopic models: they consisted in the development of the concept of “Level of Service” (Fruin, 1971), in deducing design rules for optimal pedestrian infrastructure, or in the development of guidelines for planning and design of transport systems (HCM, 1985). Moreover, these models took into account the traffic flows in the aggregate, without taking into account the inevitable interactions that are established between individual pedestrians, and that influence their behavior. Therefore, a further step forward was the introduction of so-called microscopic models: mathematical models of simulation of pedestrian behavior, both in normal and emergency conditions. One among the first and most important of these models assumed for the movement of pedestrians a behavior similar to that of the gases or fluids (Henderson, 1974): this model was born first as macroscopic model, then adapted to take into account the interactions between the different entities (Helbing, 1992). Later were further developed mathematical models, such as models of the "Code" (Yuhaski, Macgregor Smith, 1989), models in the transition matrix (Garbrecht, 1973), stochastic models (Ashford, O'Leary, McGinity, 1976). In recent years have emerged models that currently constitute the most used tools in the analysis in the field of pedestrian models: model with cellular automata (Blue and Adler, 2000; Muramatsu et al., 1999) and the model of social forces (Helbing, 1991) which, together with models based on artificial intelligence and research models of the path (way-finding algorithms), form the basis of modern simulation tools of pedestrian traffic. A terminal can be defined as a sequence of characteristic elements through which pedestrian flow move. A good equilibrium in terms of capacity/potentiality of these elements imply a good or bad performance of the terminal in terms of L.O.S. subjected to a data demand. Starting from these general considerations, the need to identify dimensional range for facilities inside which test pedestrian behavior in relationship to their paths and interaction, pursued to develop an analytical tool easy to be used based into main confirmed approach as H.C.M and T.C.Q.S.M.

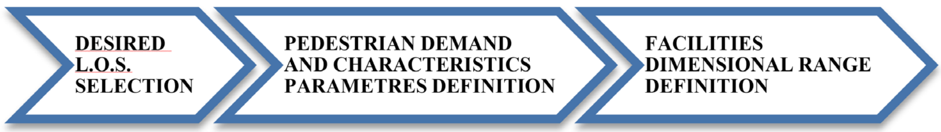

Figure 1 Facilities dimensional range definition

Defined a L.O.S. – Level of Service – desired, identified the demand and particular environmental conditions, as for a platform can be surface not available for pedestrian movement, space reserved for disabled etc. the methodology allows to the user to obtain a dimensional range for every single characteristic element of the terminal. This domain of possible acceptable solutions, will be the starting point for the best solution identification. In order to understand the behavior of pedestrian trough the terminal, an analytical model was used to get users travel time inside infrastructure. This imply the possibility to evaluate as every single facilities satisfy the flow and how the flow move through them. Incorrect dimension led the pedestrian to have delay into facilities passage increasing the total travel time from origin to destination. This objective was carry out with the approach developed from V.M. Predtechenskii A.I. Milinskii [1] and in a next moment reviewed and applied from DDr. U. Schneider [2] for evacuation dynamic. Even if this model principally is used to evaluate evacuation process, through speed conversion is possible to consider dynamics also under comfort and usual conditions.

Figure 2 Pedestrian dynamics modellization through analytical model

4 Genetic Algorithm

Defined dimensional range of characteristic elements and identify pedestrian travel time inside terminals, an objective function finalized to minimize the sum of terminal construction cost and pedestrian travel time cost was developed. This function allows to apply the genetic algorithm. Genetic algorithms belong to the larger class of evolutionary algorithms (EA). Evolutionary algorithms (EAs) are population-based meta heuristic optimization algorithms that use biology-inspired mechanisms like mutation, crossover, natural selection, and survival of the fittest in order to refine a set of solution candidates iteratively. [3-6] Genetic algorithms (GAs) generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. GA are a subclass of evolutionary algorithms where the elements of the search space G are binary strings (G = B*) or arrays of other elementary types. The genotypes are used in the reproduction operations whereas the values of the objective functions f € F are computed on basis of the phenotypes in the problem space X which are obtained via the genotype-phenotype mapping. [7,8,9]. The evolution usually starts from a population of randomly generated individuals, and is an iterative process, with the population in each iteration called a generation. In each generation, the fitness of every individual in the population is evaluated; the fitness is usually the value of the objective function in the optimization problem being solved. The more fit individuals are stochastically selected from the current population, and each individual's genome is modified (recombined and possibly randomly mutated) to form a new generation. The new generation of candidate solutions is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.

5 Application and results

Let to consider a portion of an underground station. During a traditional path, pedestrians move from trains to exit and vice versa. Defined the layout boundary and the characteristic elements through which flow moves, as for example into a path from train to exit could be platform, walkways, escalators, turnstiles etc, with H.C.M. and T.C.Q.S.M. approach above described the dimensional range of every single characteristic element is obtained, in respect of the flow and L.O.S. required. Being the characteristic element sizing allowed inside the range above identified, several combination of terminal layout can be generated. For every one of these the travel time for pedestrian can be evaluated as well as terminal performances. The application of Sobol Design of Experiments generates different layout configurations, each of them with a specific dimension of characteristic elements. This imply that for every single configuration a surface is determinated and the consequence travel time for pedestrian is obtained. Sobol methodology allows to generate population – possible terminal layout configurations – in order to apply M.O.G.A. Algorithm, Multi Objective Genetic Algorithm, for optimization process, according objective function minimization. The M.O.G.A. is applied to the objective function that considers the infrastructure cost, function of infrastructure surface, generated from combination of characteristic elements, and pedestrian cost, function of travel time. The minimization of objective function allows to obtain a Pareto front with the optimum solution identification.
In most real-life optimization situations, however, the cost function is multidimensional. Consequently, there is no unique optimal solution but rather a set of efficient solutions, also known as Pareto solutions, characterized by the fact that their cost cannot be improved in one dimension without being worsened in another. The set of all Pareto solutions, the Pareto front, represents the problem trade-offs, and being able to sample this set in a representative manner is a very useful aid in decision making, [10].
In the following picture the result obtained for a case of study done are plotted. Required a level of service D-E, Sobol and consequently M.O.G.A. allows to obtain different terminal configurations that minimize objective function. The point in the following graphic are the possible terminal layout configurations, the green point represent the Pareto Front, optimal solutions.

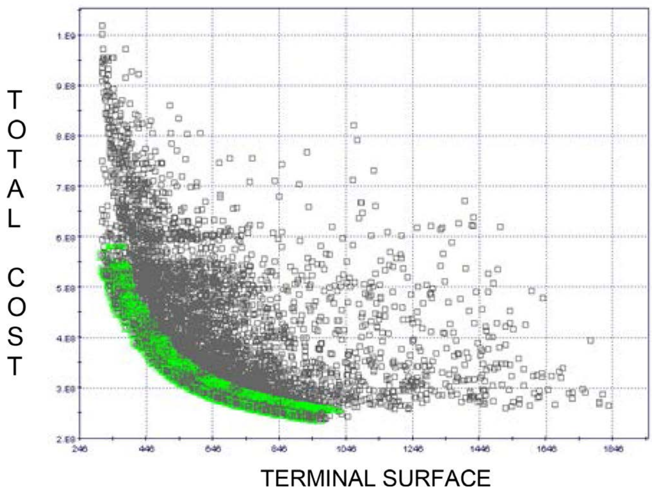

Figure 3 Pareto front obtained with strict range values for input variables

Even if all the solutions, taking into account the way in which dimensional range for D.O.E. were set up, are compatible with LOS that the terminal should have considering its pedestrian flow, is clear that the decision of the best solution cannot be taken only according cost values or pedestrian travel time.

Identified the optimum solutions, an analysis about the performance of the terminal was carry out with Social Force Algortihm. Run the simulations for every optimal scenario a lot of information can be obtain to evaluate the terminal performances.

The analysis, helpful to evaluate alternatives, are qualitative analysis as paths and trajectories, and quantitative analysis as travel time, average speed, speed los, distance walked from every single pedestrian, average minimum and maximum density and counters.

Divided the layout into potential cell of equal size is obtained the number of cell with the same LOS, during simulation windows time. The surface obtained is a good indication about the general performances of the layout that helps technicians to select the best layout configuration.

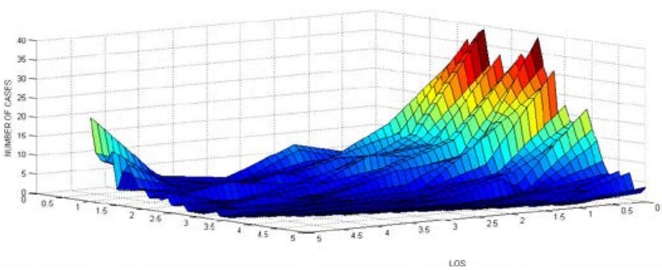

Figure 4 LOS representation for a possible scenario

In the following figures some outputs are shown. Into the fugures on the right the reader can see the results for a layout generated from the experience, while into the figures on the left are plotted the same result for an optimal solution that allow to minimize surface assuring an acceptable travel time for pedestrian according the required L.O.S. and flow.

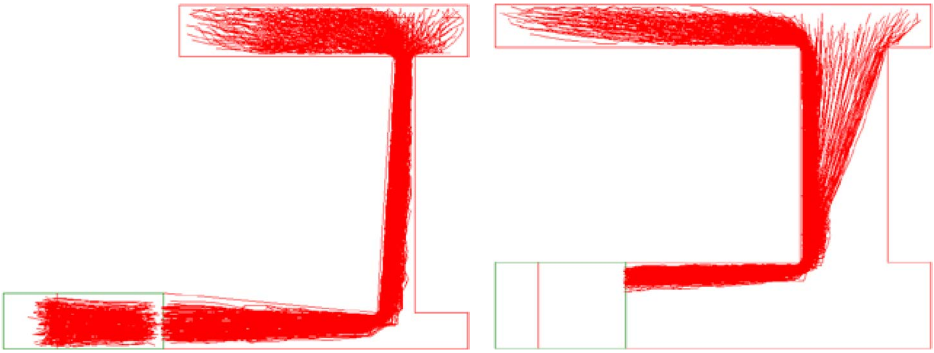

Figure 5 Trajectories into optimal scenario – left – and standard scenario – right

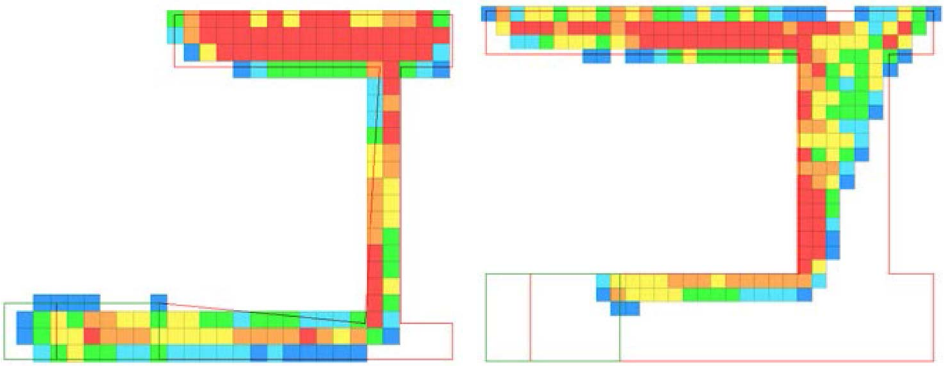

Figure 6 Max density into optimal scenario – left – and standard scenario – right

6 Conclusion

The major attention for pedestrian dynamics requires more reliable and useful techniques to find solution at daily problems. Congestion situations, delays, spaces undersized etc. are frequent in different scenarios. Starting from H.C.M. and T.C.Q.S.M. approaches, it was defined a tool able to identify the dimensional range of characteristic elements inside terminal layout according to Level of Service required and pedestrian flow prevision. Represented the pedestrian dynamics through an analytical model that allows to define the travel time for pedestrian in usual conditions as well as into emergency and comfort situations, it was defined an objective function finalized to identify the right trade off between infrastructure and pedestrian costs. The behavior of the function was tested through Sobol approach, necessary to generate population for next genetic algorithm M.O.G.A. application.
The domain of possible optimal solutions was evaluated through social force algorithm, that allows to obtain qualitative and quantitative indicators for an objective terminal performances evaluation. The methodology developed allows to approach terminal project definition, its analysis and renovation process, from another point of view, thanks to the application of genetic algorithm applied into the objective function defined on analytical basis. The process led to obtain optimal solutions about layout configuration according Level of Service desired and flow prevision, sometimes also unexpected and difficult to be predicted. Every solution rising from analytical background through the Sobol and M.O.G.A application is tested and evaluated with Social Force algorithm simulative approach. The outputs obtained are very

useful to evaluate terminal performances in an objective way, through numerical indicators based into H.C.M. and T.C.Q.S.M. approach. The test done in the case of study examined shows that the methodology is able to provide sizing requirements to be adopted in terminal layout configuration, finalized into the satisfaction of the demand required, researching the right trade off among the magnitudes involved into phenomena.

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