

# Signal setting design on a road network: application of a system of models in evacuation conditions

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## Abstract

This paper presents an application of a system of models and procedures for signal setting design on a road network in evacuation conditions. The system of models, based on a what-to approach, generates signal setting parameters taking into account users behaviour at path choice level. The application has been executed on a real experimental test site with the objectives of validating the system of models and minimizing evacuation times.

*Keywords: signal setting design model, application, evacuation conditions.*

## 1 Introduction

This work is part of research project SICURO, carried out by the Laboratory for Transport Systems Analysis of Mediterranean University of Reggio Calabria (Italy). The general objective is risk reduction in urban areas in terms of exposure through the definition and implementation of evacuation procedures [1, 2]. The results concern the development of models, procedures and guidelines that support transport planning in evacuation conditions. Specific research lines defined in SICURO concern travel demand [3, 4], planning processes and guidelines [5, 6], paths of emergency vehicles [7, 8], pedestrian outflow from buildings [9], transport supply and demand-supply interaction.

As regards the last research line, the specification and calibration of link and node models and an application of a dynamic traffic assignment model are reported in [10] and [11]; they present advancements concerning link and node models calibration through data observed during a real-world evacuation experiment. A selection of decision support systems is compared in [12], testing their response capabilities to help validate procedures in evacuation conditions.



More recently, a system of models and procedures, conceived according to a what-to approach, for signal setting design of road intersections with endogenous estimation of path flows has been proposed in [13].

In the sphere of the research line above described, this paper presents an application of the system of models and procedures proposed in [13]. The application has two main objectives: to validate the system of models through observations executed during a real-world evacuation experiment and through simulation results obtained by means of a what-if modelling approach; to verify the effectiveness of signal setting design on a road network in reducing evacuation times from an urban area.

The paper is articulated in four sections. Section 2 presents a classification of signal setting design models. Section 3 describes the proposed system of models, focusing on the procedure of signal setting parameters generation. Section 4 illustrates the experimental evacuation test site, the defined scenarios and some results of the model application. The last section reports the final remarks.

## 2 Classification

The signal setting problem considers at least one of the following design variables:

- green time on each access and cycle time durations, with exogenous stages;
- green time and schedule (initial instants of green times and green time on each access) and cycle time durations;
- offset between each couple of adjacent intersections.

Signal setting design models may be classified according to two criteria [14]. The first concerns the signal setting strategies (or signal setting design parameters), which may be based on

- flows, with two main objectives
  - minimization of total delay;
  - maximization of capacity factor;
- arrival times.

The second is connected to the intersections which may be: isolated, interacting along an arteria or on a network.

Different combinations of design variables, signal setting strategies and intersections give rise to the classes of models presented in Table 1.

In the sphere of network design problem [23–26], several studies are presented in literature on signal setting design by means of genetic algorithms. Some papers report applications of genetic algorithms with no driver re-routing [27, 28], other papers include driver re-routing [29, 30]. Genetic algorithms are applied in order to optimize traffic signal and transit priority settings in [31].

## 3 Proposed system of models

The proposed system of models for signal setting parameters design (design model) generates and simulates potential solutions in order to optimize an

Table 1: Signal setting design models.

Intersections	Variables	Signal setting strategies		Arrival times
		flows		
		Min delay	Max capacity factor	
Isolated	Green time	SIGSET [15]	Webster [16], SIGCAP [17], SIDRA [18], OSCADY [19]	MOVA
	Green time and schedule	SICCO [20]		—
Arteria	Offset	MAXBAND [21], MULTIBAND	---	—
Network	Green time and offset	TRANSYT [22], SCOOT	As isolated intersections	OPAC, UTOPIA

(source: [14])

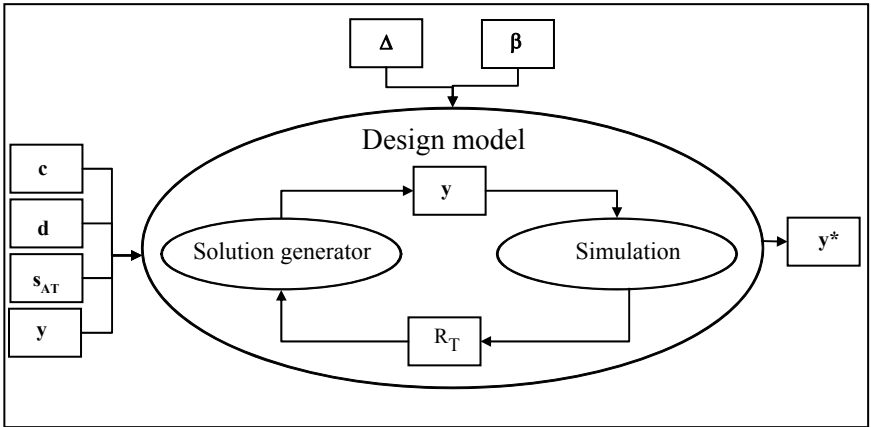


Figure 1: Inputs, parameters and outputs of the design model.

objective function. The design model is schematically presented in figure 1, in terms of elements which feed the model, inputs and parameters, and elements provided by the model, outputs.

Inputs are related to the transport system and, in particular, travel demand (vector of demand flows,  $\mathbf{d}$ ), transport costs (vector of link costs on non-congested network,  $\mathbf{c}$ , and vector of saturation flows on each access,  $\mathbf{s}_{AT}$ ), an initial configuration of signal setting parameters (vector,  $\mathbf{y}$ ).

Parameters are represented by the matrix of network topology,  $\Delta$ , and a vector of transport models parameters,  $\beta$ .

Output is the configuration of the best signal setting parameters (vector of solutions at equilibrium,  $\mathbf{y}^*$ , that optimizes the objective function).

Vector,  $\mathbf{y}$ , is composed by three classes of design parameters:

- cycle duration (assuming that all intersections have a common cycle time or a sub-multiple)
  - common duration of basic cycle for all intersections;
  - sub-multiples of the basic cycle for each intersection;

- phases duration and timing (every couple of the following parameters for each access, assuming that amber time is exogenous)
  - red time;
  - green time in term of initial and final instant of green time;
- offsets
  - number of offsets (both absolute and related to each couple of intersections), which depends on the duration of the basic cycle.

The solution procedure is developed with a genetic algorithm. A population of solutions is tested in each iteration. In the solution population the generic vector  $y$  is indicated with  $y_s$ .

The design procedure operates according to a multi-level structure grouped into two main interacting procedures: current vector of signal setting parameters,  $y_s$ , is generated through a *solution generator* procedure; vectors  $y_s$  are then simulated by means of a *simulation* procedure, which reproduces the response of the transportation system to the current configuration of signal setting parameters, in terms of origin-destination path flows and costs at equilibrium. The response of the transport system, for each solution  $y_s$ , is synthesized in a global network indicator,  $R_T$ , which represents the objective function to be optimized. Therefore, the solutions are compared and evaluated in terms of the values of the objective function.

The solution generator procedure belongs to the category of genetic algorithms (figure 2).

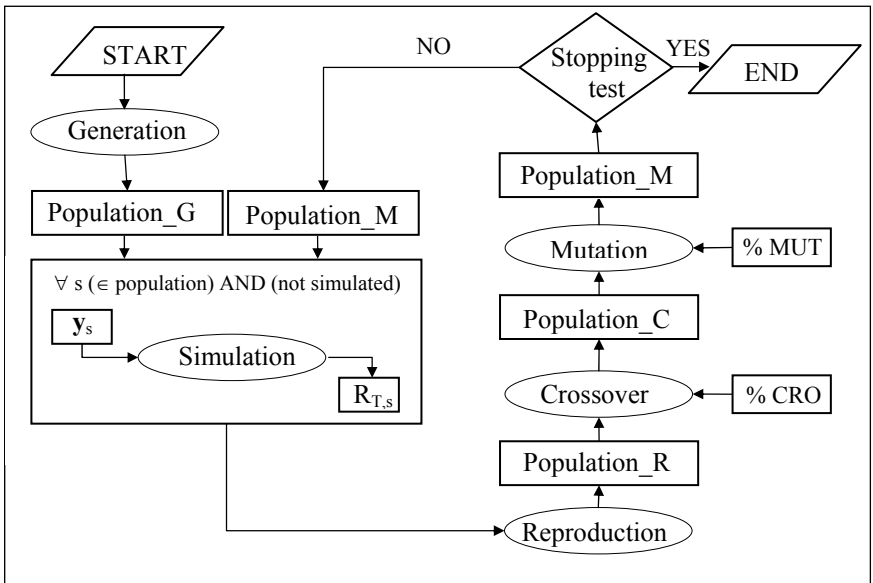


Figure 2: Structure of the solution generator procedure.



The procedure starts with an initial set of solutions, grouped into a randomly generated population (population\_G). Each solution,  $y_s$ , feeds a simulation procedure for the estimation of total delay,  $R_{T,s}$ . Afterwards, population evolves through three operators (or evolution functions), which are sequentially applied. Reproduction consists in selecting a sub-set of solutions from the population, the best should survive and create new offspring (population\_R).

Crossover selects genes from parent chromosomes and creates new offspring (population\_C). Then, the mutation takes place and it changes randomly the new offspring, in order to prevent all solutions in the population falling into the local optimum of solved problems (population\_M).

Once a new set of solutions is generated, a stopping test evaluates whether a new iteration must be performed or not, according to some stopping criteria.

The procedure ends with the identification of vector,  $y^*$ , containing the configuration of signal setting parameters that minimizes the objective function, or the total delay of the vehicles on the network,  $R_T$ .

## 4 Application

An application has been executed on the experimental evacuation test site defined in SICURO, with the objectives to validate the design model, through observed data and results from a what-if modelling approach, and to minimize evacuation times operating on signal setting design of a network of intersections.

### 4.1 Experimental evacuation test site and scenarios definition

The design model has been applied on the transport system of the central area of Melito di Porto Salvo, which is a town in the south of Italy. The municipality has an area of 35.30 km<sup>2</sup>, 10483 inhabitants and 2432 employees.

An incident was reproduced in reality and it concerned an heavy vehicle with leaking hazardous goods inside the urban area during the morning period of an average working-day. As the potential disaster was announced, the evacuation took place in the surrounding area, where public offices (town hall, primary school...), residential and commercial activities were located, and the emergency vehicles started to rescue weak users (see [32–34]). Evacuation operations, executed according the municipal evacuation plan, were monitored and evaluated (see [35–37]).

The road transport system was monitored during the evacuation through videocameras located along selected links and nodes and the application of the proposed system of models required the previous built-up of a network model (see [10–12]) and a travel demand model (see [38–40]). The latter allowed the estimation of origin-destination matrices related to evacuation demand and to travel demand in ordinary conditions.

After the network built-up and travel demand flows estimation, a coordinated network of traffic signals on six selected intersections was introduced in order to regulate the vehicles access to the evacuation area (figure 3). Traffic signals, according to the geometry of the intersections, have signal plans with two stages.

The design model has been applied considering two signal setting scenarios:

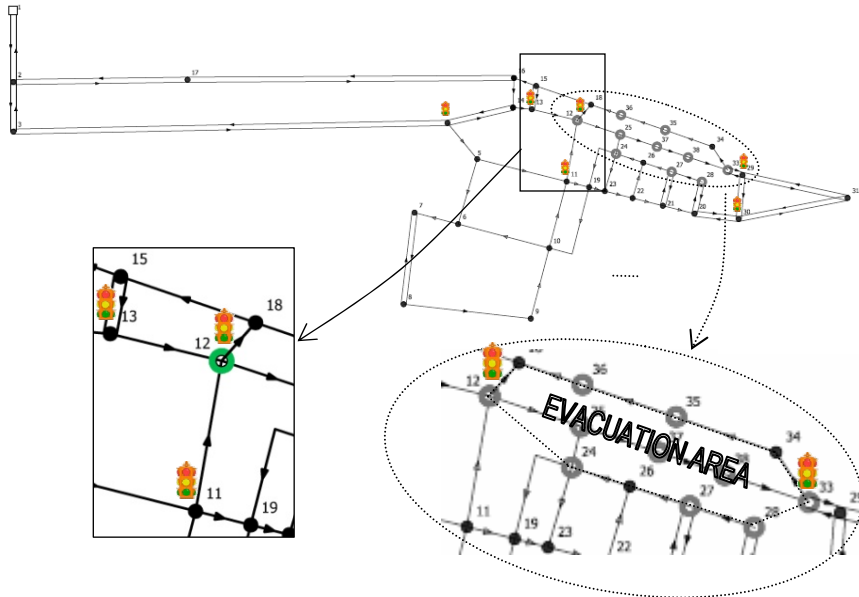


Figure 3: Graph, evacuation area and location of traffic signals.

- (current) scenario, where signal setting parameters were defined in order to reproduce the existing priority rules at the intersections (that are were all not-signalized);
- design scenario, where traffic signals operate with the configuration of signal setting parameters provided as output of the design model,  $y^*$ .

## 4.2 Results

The results obtained running the design model for the two signal setting scenarios are presented and discusses below in terms of a set of indicators belonging to three classes (see [10]):

- demand-supply interaction
  - global delay of vehicles on the network;
  - evacuation time;
- transport system evolution during evacuation
  - number of vehicles approaching the refuge area;
- link and node
  - temporal profiles of vehicular flows on each access of the intersection.

The simulation model, developed in this work and used inside the design model, allowed to estimate a global delay of vehicles on the network of 52312 [vehic h] and an evacuation time of 33 [min] in the current scenario. In the design scenario, the estimated global delay was 18118 [veic h], with a reduction of 71% in relation to current scenario, and the estimated evacuation time was 25 [min], with a reduction of 24% (table 2).

The number of vehicles approaching the refuge area on each five-minutes time slice for the two signal setting scenarios is plotted in figure 4. The plots show that, during the first ten minutes, a larger number of vehicles approached the refuge area in the current scenario than in the design one, due to lower waiting times at nodes. Afterwards, the increasing evacuation demand caused a decay of network performances in the current scenario, due to an increment of congestion levels. In the design scenario, signal settings parameters, optimized according to the increasing vehicular flows, allow to a larger number of vehicles to reach the refuge area, with a subsequent reduction of evacuation time.

In order to show the potentialities of the simulation procedure, which incorporates a dynamic supply-demand interaction model, as an example, the estimated temporal profiles of vehicular flows at node 12 of the network (see figure 3) are plotted in figure 5.

Table 2: Signal setting scenarios: demand-supply interaction indicators.

Scenario	Indicators	
	Global delay [vehic h]	Evacuation time [min]
Current	52312	33
Design	18118	25
$\Delta\%^{(*)}$	- 65%	- 24%

$(*) \Delta\% = (X^{current} - X^{design}) / X^{current}$

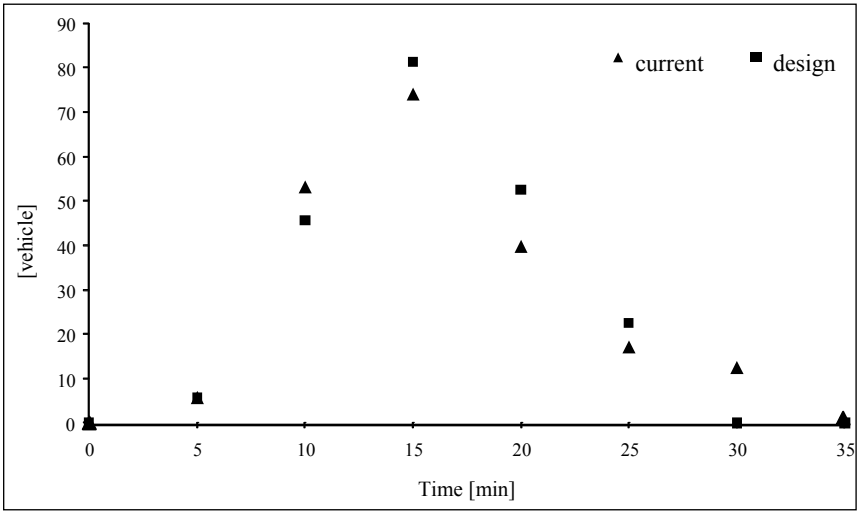


Figure 4: Signal setting scenarios: number of vehicles approaching the refuge area.



The estimated variation of evacuation time between signal setting scenarios was compared with the one estimated between two network topology scenarios, previously defined in SICURO and simulated through a what-if model (see [10–12]). The two network topology scenarios are:

- current scenario, where the network topology was the one operating in ordinary condition, with intersections regulated through priority rules;
- design scenario where network topology was modified in order to prevent historical travel demand from crossing the evacuation area (see [12]).

Evacuation time in the network topology design scenario is reduced of 14%. This reduced variation, compared to the one between signal setting scenarios, indicates that (design) interventions on signal setting parameters could be more effective than interventions on network topology in reducing evacuation time for this specific experimental evacuation test site.

5 Final remarks

A system of models and procedures for signal setting design on a road network has been applied on a real experimental evacuation test site with the objectives to validate the modelling components and to minimize evacuation times.

The simulations showed remarkable reductions in terms of total delay of vehicles on the network and of evacuation time in the signal setting design scenario, emphasized by the small dimensions of the network with few paths alternatives.

The comparison with network topology scenarios indicates that interventions on signal setting parameters could be more effective than interventions on network topology for the examined experimental evacuation test site.

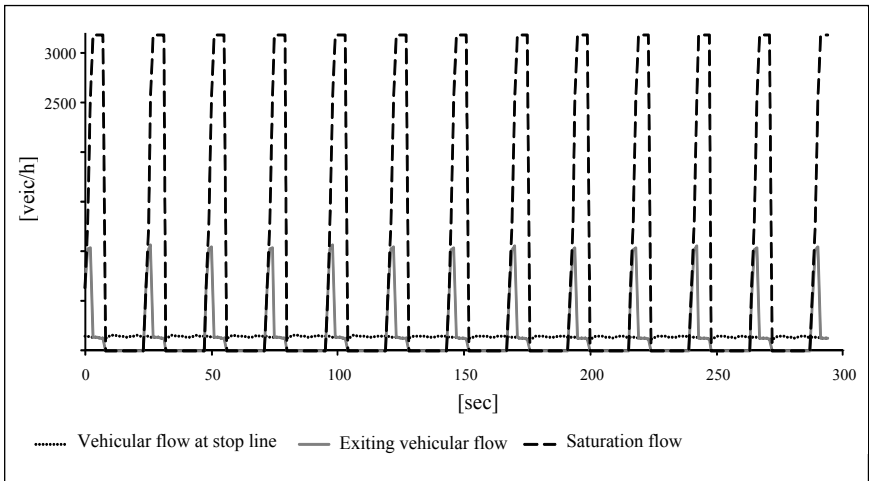


Figure 5: Signal setting scenarios: temporal profiles of vehicular flows at node 12 (see figure 3).





Further research concerns the development of the system of models in order to allow an integrated design of signal setting and network topology parameters and the model validation through the definition of integrated design scenarios on a real test site in evacuation conditions.

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