TeMA

Journal of
Land Use, Mobility and Environment

This special issue collects a selection of peer-review papers presented at the 8th International Conference INPUT 2014 titled “Smart City: planning for energy, transportation and sustainability of urban systems”, held on 4-6 June in Naples, Italy. The issue includes recent developments on the theme of relationship between innovation and city management and planning.

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Journal of
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This special issue of TeMA collects the papers presented at the 8th International Conference INPUT 2014 which will take place in Naples from 4th to 6th June. The Conference focuses on one of the central topics within the urban studies debate and combines, in a new perspective, researches concerning the relationship between innovation and management of city changing.

TeMA Journal of Land Use, Mobility and Environment

EIGHTH INTERNATIONAL CONFERENCE INPUT 2014

SMART CITY. PLANNING FOR ENERGY, TRANSPORTATION AND SUSTAINABILITY OF THE URBAN SYSTEM

This special issue of TeMA collects the papers presented at the Eighth International Conference INPUT, 2014, titled "Smart City. Planning for energy, transportation and sustainability of the urban system" that takes place in Naples from 4 to 6 of June 2014.

INPUT (Innovation in Urban Planning and Territorial) consists of an informal group/network of academic researchers Italians and foreigners working in several areas related to urban and territorial planning. Starting from the first conference, held in Venice in 1999, INPUT has represented an opportunity to reflect on the use of Information and Communication Technologies (ICTs) as key planning support tools. The theme of the eighth conference focuses on one of the most topical debate of urban studies that combines , in a new perspective, researches concerning the relationship between innovation (technological, methodological, of process etc..) and the management of the changes of the city. The Smart City is also currently the most investigated subject by TeMA that with this number is intended to provide a broad overview of the research activities currently in place in Italy and a number of European countries. Naples, with its tradition of studies in this particular research field, represents the best place to review progress on what is being done and try to identify some structural elements of a planning approach.

Furthermore the conference has represented the ideal space of mind comparison and ideas exchanging about a number of topics like: planning support systems, models to geo-design, qualitative cognitive models and formal ontologies, smart mobility and urban transport, Visualization and spatial perception in urban planning innovative processes for urban regeneration, smart city and smart citizen, the Smart Energy Master project, urban entropy and evaluation in urban planning, etc..

The conference INPUT Naples 2014 were sent 84 papers, through a computerized procedure using the website www.input2014.it . The papers were subjected to a series of monitoring and control operations. The first fundamental phase saw the submission of the papers to reviewers. To enable a blind procedure the papers have been checked in advance, in order to eliminate any reference to the authors. The review was carried out on a form set up by the local scientific committee. The review forms received were sent to the authors who have adapted the papers, in a more or less extensive way, on the base of the received comments. At this point (third stage), the new version of the paper was subjected to control for to standardize the content to the layout required for the publication within TeMA. In parallel, the Local Scientific Committee, along with the Editorial Board of the magazine, has provided to the technical operation on the site TeMA (insertion of data for the indexing and insertion of pdf version of the papers). In the light of the time's shortness and of the high number of contributions the Local Scientific Committee decided to publish the papers by applying some simplifies compared with the normal procedures used by TeMA. Specifically:

- Each paper was equipped with cover, TeMA Editorial Advisory Board, INPUT Scientific Committee, introductory page of INPUT 2014 and summary;
- Summary and sorting of the papers are in alphabetical order, based on the surname of the first author;
- Each paper is indexed with own DOI codex which can be found in the electronic version on TeMA website (www.tema.unina.it). The codex is not present on the pdf version of the papers.

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THE DESIGN OF SIGNALISED INTERSECTIONS AT AREA LEVEL

MODELS AND METHODS

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ABSTRACT

In this paper the results of the PRIN research project named "Guidelines for the urban transportation network analysis and design: methods and models for designing at area level the signalised intersections" are summarised. In the research project, several problems of signal settings optimisation at area level were studied and some methods and model for optimising the signal setting parameters were proposed. All proposed methods were tested on a real-scale case: the road network of Benevento. The results of the research showed that the proposed methods are able to solve the problem in acceptable computing times also on real-scale networks.

KEYWORDS

Network optimisation, Arterial coordination, Traffic-lights, Road traffic

1 INTRODUCTION

A city can be defined a Smart City if ICT and transport infrastructures are conceived and designed so to ensure a sustainable development and a high level of quality of life. The smart mobility is an important dimension of the Smart City, since in urban areas the economics and environmental impacts of the mobility (of people and goods) are very significant. In this context, the design of traffic-lights at area level is an "action" very useful in order to contribute to the smart mobility. Indeed, in congested urban networks a major part of total travel time is spent at intersections and a correct design of them can reduce significantly the total travel time and the (GHG and pollutants) emissions.

The signal settings are usually optimised for an intersection independently of others (isolated intersection) but better results can be obtained optimising signal setting parameters at area level.

In the literature, several techniques and models have been developed for optimising signal settings, and three main problems have emerged: (a) single junction optimisation; (b) arterial optimisation/coordination; (c) multiple junction optimisation (signal network control). Problem (a) regards the isolated junction while problems (b) and (c) regard the optimisation at the area level.

In this paper, we summarise the results obtained during the development of a PRIN (National Relevance Research Project) research project funded by the MIUR (Italian Ministry of Schools and Universities) where the design of signalised intersections at area level have been studied.

In the literature, the arterial optimisation/coordination problem was widely studied. Some important books (ITE, 2009; Roess et al., 2010) report the main solution methods and approaches. Of the many papers, books, handbooks and software programs that have been proposed, some tackle the problem using simulation-based models, while others propose to use analytical models. Examples of simulation-based models are TRANSYT-7F (Robertson, 1968; Wallace et al., 1988) and SIGOP III (Liebermann et al., 1983) while analytical models have been proposed by Gartner et al. (1975) and Liu and Chang (2011). Other papers tackle the bandwidth maximisation problem (Morgan and Little, 1964; Little, 1966; Inose and Amada, 1975) that arises when the coordination regards both directions of the arterial. This problem was studied amongst others by Little et al. (1981), Gartner et al. (1991), Stamadiatis and Gartner (1996), and Papola and Fusco (1998).

The multiple junction optimisation problem can be seen as a particular case of the more general *Equilibrium Network Design Problem* (ENDP), where signal settings assume the role of decision variables; this problem is also known as the *Signal Setting Design Problem* (SSDP) and for solving it two different approaches can be identified (Cascetta et al., 2006): a global approach and a local approach. In the first case, the problem is actually an ENDP, formulated with a (non-linear constrained) optimisation model, and is also known as *Global Optimisation of Signal Settings* (GOSS). In the second case, instead, it is assumed that the signal settings of each junction are designed so as to minimise only the total delay at the same junction according to a specific local control policy. This problem is known also as *Local Optimisation of Signal Settings* (LOSS) and is the focus of this paper. The general problem was studied by Marcotte (1983), Fisk (1984), Cantarella et al. (1991), Cantarella and Sforza (1995), and Cascetta et al. (1999, 2006).

The LOSS problem can be formulated as a fixed/point problem and was studied, amongst others, by Allsop (1977), Smith (1979), Dafermos (1980), Fisk and Nguyen (1982), Florian and Spiess (1982), Gartner (1983), Meneguzzer (1995), Cantarella and Improta (1991), Smith and Van Vuren (1993), Al-Malik and Gartner (1995), Cascetta et al. (1999, 2006), and D'Acierno et al. (2012).

The GOSS problem can be formulated, instead, as a (non-linear) constrained optimisation problem where signal settings assume the role of decision variables and was studied, amongst others, by Sheffi and Powell

(1983), Yang and Yagar (1995), Heydecker (1996), Chiou (1999), Wey (2000), Ziyou and Yifan (2002) and Cascetta et al. (2006).

In this paper, summarising the results obtained during the PRIN research project, we focus on three problems:

1. optimisation of signal settings of two-way coordinated arterials;
2. local optimisation of signal settings problem, known also as "combined assignment-control problem";
3. global optimisation of signal settings.

For all problems, mathematical models will be formulated and solution algorithms will be proposed and tested on a real-scale network.

2 TWO-WAY COORDINATED ARTERIALS

Coordinating the signal settings of an arterial is a control strategy to minimise travel delays on a main road with multiple consecutive intersections. The solution of the single arterial coordination problem is simple if the arterial is one-way: in this case optimal green offsets can be calculated according to distance between intersections and average flow speed, always obtaining the ideal coordination corresponding to the maximum bandwidth (defined as the time interval during which the vehicles are able to travel on the road without any stops at intersections). The same problem is more complex for two-way arterials where the problem is usually approached as one of bandwidth maximisation. However, the latter does not ensure minimum total delay (or total travel time) on the network.

In this section we study the problem of coordinating two-way signalised arterials with a view to minimising total delay, using a microsimulation approach to explore the solution set. In the following we summarise the results reported in D'Acierno et al. (2013), paper produced during the development of the PRIN research project.

2.1 MODEL FORMULATION AND SOLUTION ALGORITHM

We consider a two-way arterial where all intersections are signalised; we assume that the cycle time, C, and the effective green times, g_c and g_{nc}, are calculated as a function of known traffic flows (subscripts c and nc refer respectively to the coordinated and non-coordinated phase), for instance with the well-known Webster (1958) method. The objective is to optimise the total delay on the arterial, td, that is the sum of the delays at all approaches to the arterial's junctions. Obviously, the total delay depends on the offsets of the junction, $\boldsymbol{q}$. The total delay is calculated by a microsimulation model.

The optimisation model can be formulated as follows:

$$\boldsymbol{q}^* = \text{Arg}_{\,\boldsymbol{q}} \min \, td(\boldsymbol{q})$$

$$\text{s.t.:}$$

$$\mathbf{0} \leq \boldsymbol{q} < \boldsymbol{C}$$

$$td\,(\boldsymbol{q}) = MS\,(\boldsymbol{q})$$

where $\boldsymbol{q}$ is the vector of the offsets; $\boldsymbol{q}^*$ is the optimal value for q; $\mathbf{0}$ is the zero vector (a vector with the same dimension of the q vector with all components equal to 0); $\boldsymbol{C}$ is the cycle vector (a vector with the same dimension of the q vector with all components equal to C); $MS(\boldsymbol{q})$ indicates the microsimulation model that is able to estimate the total delay as a function of the offsets.

This is a constrained non-linear optimisation model requiring a microsimulation model to be set up to estimate the value of the objective function; in order to solve it, D'Acierno et al. (2013) proposed and tested two versions of a multi-start Neighbourhood Search (NS) algorithm. The two versions were different according to two different approaches for generating the next solution in the NS algorithm: the *Steepest Descent Method* (SDM) and the *Random Descent Method* (RDM). The necessity of a multi-start procedure is due to the non-convexity of the objective function. For the details about algorithms, refer to the previously quoted paper.

2.2 NUMERICAL RESULTS

The proposed model and algorithm were tested on a real case, namely an arterial in the urban network of Benevento (Italy); Figure 1 reports the arterial and the traffic flows. In this case, we have only two decision variables that are the offsets q_1 and q_2, assuming that the offset of the first intersection is equal to 0. We considered three starting solutions: Solution 0, where the offsets are all equal to 0; Solution A, where the offsets are designed so to be optimal in one of the direction; Solution B, where the offsets are designed so to be optimal in the other direction. Moreover, we performed an exhaustive search, in order to verify the goodness of the results, assuming a discrete step equal to 5 s. In Figure 2(a), the shape of the objective function is reported and in Figure 2(b) the steps of the multi-start neighbourhood serach.

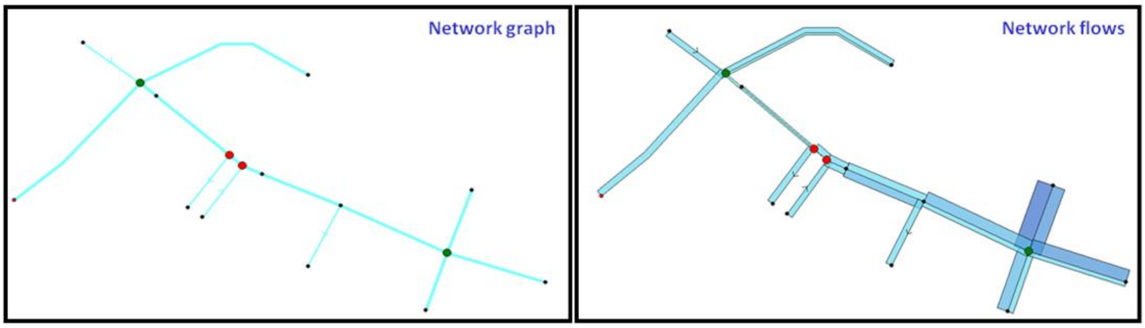

Fig. 1 Two-way coordinated arterial test case

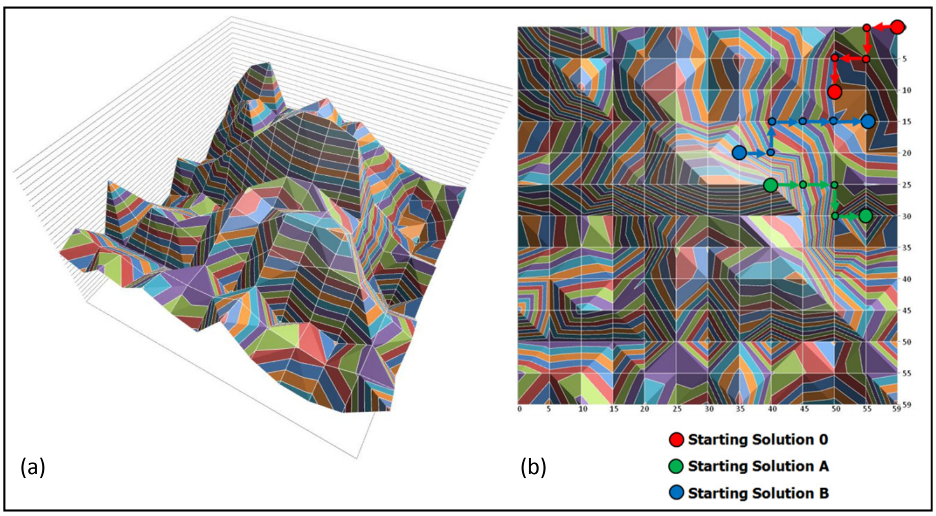

Fig. 2 The shape of the objective function (a) and the steps of the algorithm (b)

On examining the exhaustive search it can be noted that the best solution obtained by the multi-start neighbourhood search method is also the global optimum (Starting solution A). Moreover, the three local optimal solutions have similar values of q_1 (in two cases the value is the same).

An exhaustive search is possible in this particular test case since we have only two offsets to design. In longer arterials where there may be up to 8-10 offsets to design, an exhaustive search is not possible with acceptable computing times. However, the proposed multi-start neighbourhood search is able to produce some local optima with acceptable computing times.

3 LOCAL OPTIMISATION OF SIGNAL SETTINGS

The *Local Optimisation of Signal Settings* (LOSS) problem arises when signal control parameters of an urban road network are locally optimised and have to be consistent with equilibrium traffic flows. This problem can be formulated with an (asymmetric) equilibrium assignment model.

In the following, we summarise the results reported in Gallo et al. (2013), paper produced during the development of the PRIN research project. In particular, we study the LOSS problem, examining the model formulation, proposing some solution algorithms and testing them on a real-scale case.

3.1 MODEL FORMULATION AND SOLUTION ALGORITHMS

For solving the LOSS problem, the following fixed-point mathematical model can be formulated (see also Cascetta et al., 2006):

$$\boldsymbol{f}^* = \boldsymbol{f}(\boldsymbol{c}(\boldsymbol{f}^*, \boldsymbol{g}(\boldsymbol{f}^*)))$$

where $\boldsymbol{f}$ is the link flow vector; $\boldsymbol{f}^*$ is the equilibrium link flow vector; $\boldsymbol{c}$ is the link cost vector and $\boldsymbol{c}(.)$ the vector of link cost functions; $\boldsymbol{g}$ is the vector of signal settings; $\boldsymbol{g}(\boldsymbol{f}^*)$ is the local control policy (for instance, Webster, 1958).

In terms of theoretical properties, the link cost functions are non-separable, since at each intersection the cost of a link depends on the flows of all concurring links (the control policy recalculates signal settings as a function of all flows at the intersection). Therefore, the Jacobian is not positive definite and the uniqueness of the fixed-point solution cannot be stated (Charlesworth, 1977, showed that more than one equilibrium solution can be found). Instead, the existence of a solution is ensured by the continuity of the functions (a condition that is satisfied for stochastic route choice models, continuous cost-flow functions and continuous local control policy functions).

In order to solve the problem, we propose three algorithms based on an MSA framework (Powell and Sheffi, 1982; Sheffi and Powell, 1982). The MSA (Method of Successive Averages) is widely used for solving traffic assignment problems. For solving the traffic assignment problem three MSA algorithms are available: the MSA-FA (Flow Averaging), which is the original version proposed by Sheffi and Powell (1982); the MSA-CA (Cost Averaging), which was proposed by Cantarella (1997); and, the MSA-ACO (Ant Colony Optimisation), which was proposed by D'Acierno et al. (2006). For the details about algorithms, refer to Gallo et al. (2013).

3.2 NUMERICAL RESULTS

The model and algorithms were tested on the urban network of Benevento, a town in the south of Italy with about 61,000 inhabitants. The transportation model (demand and supply) was built during the design of the Urban Traffic Plan of the town. The network graph has 1,577 oriented links, which represents about 216 kms of roads, and 678 nodes. The zoning of the study area is very dense, with 66 internal zones; the cordon sections are 14, so the total centroids are 80 (66 internal and 14 external). Figure 3 shows the graph of the network: different colours for links and nodes indicate different kinds of roads and intersections.

In order to test and compare the algorithms, we generate 35 different scenarios, considering seven different demand levels (ODXX) and five different supply models (SIGXX), increasing the number of signalised intersections.

The three algorithms, MSA-FA, MSA-CA and MSA-ACO, were implemented in Visual Basic code and all tests were conducted using a PC Intel Core i7-2600 (3.40 GHz).

The three algorithms were tested for all 35 scenarios; Table 1 reports the number of iterations and the corresponding computing times. The comparison shows that MSA-ACO and MSA-CA algorithms perform better than MSA-FA for almost all scenarios. Between MSA-ACO and MSA-CA the differences are less substantial, although MSA-ACO seems to work slightly better. The differences between algorithms are very significant when the demand is high (OD18 and, above all, OD20) and when the signalised intersections are numerous. In three scenarios, MSA-FA algorithm does not converge in acceptable computing times: the algorithm is stopped after 100,000 iterations but the convergence test always tends to decrease.

Figure 4 shows the convergence of the algorithms in the scenario SIG48-OD20; in the diagrams only the first 200 iterations are represented.

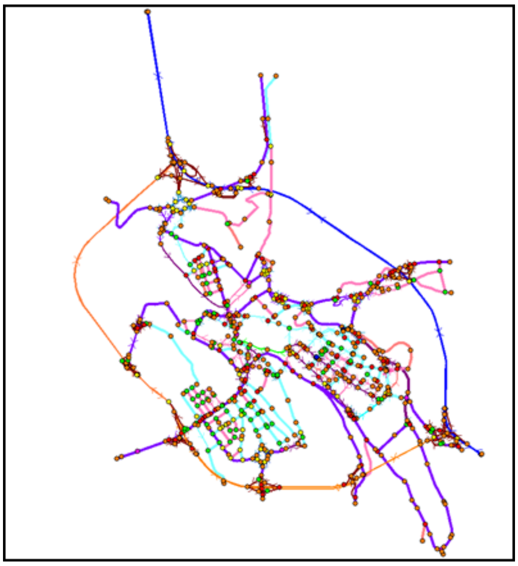

Fig. 3 The graph of the road network of Benevento

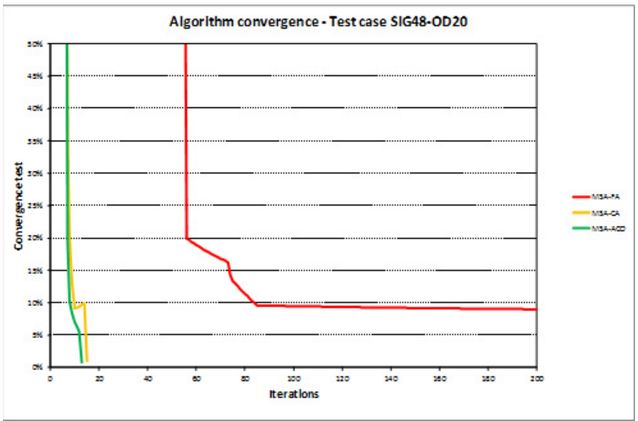

Fig. 4 Convergence of algorithms for the scenario SIG48-OD20

Assuming total travel time as a performance index of the network, we compare, for all 35 scenarios, the solutions obtained by solving the combined assignment-control problem with the solution that can be obtained by applying the local control policy without updating flows and signal settings until convergence. In Table 2 the total travel times on the network are compared; we report only the results obtained with MSA-CA algorithms, since the results obtained with the other MSA algorithms are similar (a slight difference in total travel times is produced by the approximation due to the stop threshold but the final solutions are in practice the same). The results (see Table 2) show that great advantages of applying the methodology are obtained when the network is very congested and the signalised intersections are numerous; in this case, travel time reduction may be as much as 17 %.

					Iterations			
		OD08	**OD10**	**OD12**	**OD14**	**OD16**	**OD18**	**OD20**
MSA-FA	**SIG08**	7	16	31	49	51	110	62
	SIG18	7	16	32	49	51	131	59
	SIG28	7	12	28	46	49	137	>100,000
	SIG38	6	9	28	46	50	137	>100,000
	SIG48	6	9	28	45	50	83	>100,000
MSA-CA	**SIG08**	7	8	7	9	11	14	15
	SIG18	7	8	8	9	11	14	15
	SIG28	7	8	8	9	9	10	13
	SIG38	7	7	7	9	11	10	13
	SIG48	7	7	7	9	11	10	15
MSA-ACO	**SIG08**	4	7	12	11	8	14	13
	SIG18	4	7	12	16	7	15	12
	SIG28	5	7	12	16	11	10	10
	SIG38	5	7	8	9	8	9	10
	SIG48	5	7	8	14	8	14	13
					Computing times (s)			
		OD08	**OD10**	**OD12**	**OD14**	**OD16**	**OD18**	**OD20**
MSA-FA	**SIG08**	12	25	47	72	94	160	87
	SIG18	11	25	48	73	95	191	84
	SIG28	13	19	42	68	91	209	>150,000
	SIG38	14	15	42	68	92	199	>150,000
	SIG48	13	15	42	67	91	121	>150,000
MSA-CA	**SIG08**	11	13	12	14	23	23	23
	SIG18	12	13	13	15	22	22	23
	SIG28	12	14	14	15	19	16	20
	SIG38	16	12	12	15	25	17	21
	SIG48	15	12	12	15	22	17	23
MSA-ACO	**SIG08**	8	13	19	18	13	22	20
	SIG18	8	14	19	25	11	24	19
	SIG28	9	12	19	24	17	16	16
	SIG38	9	12	13	15	13	14	6
	SIG48	9	13	14	21	13	21	21

Tab.1 Comparison among MSA-FA, MSA-CA and MSA-ACO in terms of iterations and computing times

					Total travel time of starting solution (minutes)			
		OD08	**OD10**	**OD12**	**OD14**	**OD16**	**OD18**	**OD20**
MSA-CA	**SIG08**	110,456	158,614	248,457	410,218	662,313	1,023,507	1,521,819
	SIG18	109,412	156,502	242,116	395,744	638,237	984,243	1,468,881
	SIG28	109,412	148,394	226,692	366,471	591,821	919,602	1,385,807
	SIG38	105,518	148,959	228,788	369,840	593,438	915,727	1,377,422
	SIG48	104,681	147,794	226,061	363,210	585,764	907,879	1,362,882
					Total travel time of final solution (minutes)			
		OD08	**OD10**	**OD12**	**OD14**	**OD16**	**OD18**	**OD20**
MSA-CA	**SIG08**	109,968	152,151	224,507	354,985	567,568	876,225	1,301,436
	SIG18	108,943	150,127	219,523	342,824	545,542	838,175	1,247,938
	SIG28	108,943	144,309	206,360	320,056	510,916	790,713	1,189,227
	SIG38	105,517	144,180	206,678	318,313	502,405	770,677	1,159,057
	SIG48	104,707	143,153	204,220	312,260	492,506	755,738	1,134,521
					Percentage variation			
		OD08	**OD10**	**OD12**	**OD14**	**OD16**	**OD18**	**OD20**
MSA-CA	**SIG08**	-0.4%	-4.1%	-9.6%	-13.5%	-14.3%	-14.4%	-14.5%
	SIG18	-0.4%	-4.1%	-9.3%	-13.4%	-14.5%	-14.8%	-15.0%
	SIG28	-0.4%	-2.8%	-9.0%	-12.7%	-13.7%	-14.0%	-14.2%
	SIG38	0.0%	-3.2%	-9.7%	-13.9%	-15.3%	-15.8%	-15.9%
	SIG48	0.0%	-3.1%	-9.7%	-14.0%	-15.9%	-16.8%	-16.8%

Tab.2 Comparison among starting and final solution in terms of total travel times

4 GLOBAL OPTIMISATION OF SIGNAL SETTINGS

The GOSS problem arises when the parameters of all (or some) signalised intersections of a network are jointly optimised so as to minimise the value of an objective function (such as total travel time). This problem can be formulated with a non-linear constrained optimisation model.

In the following, we summarise the results reported in Gallo et al. (2014), paper produced during the development of the PRIN research project. In particular, we study the GOSS problem, examining the model formulation, proposing some solution algorithms and testing them on a real-scale case.

4.1 MODEL FORMULATION AND SOLUTION ALGORITHMS

For solving the GOSS problem we formulate the following optimisation mathematical model:

$$\boldsymbol{g}^{\wedge} = \text{Arg}_{\boldsymbol{g}} \min \, [\boldsymbol{c}(\boldsymbol{g}, \boldsymbol{f^*})]^{\mathrm{T}} \, \boldsymbol{f^*}$$

with:

$$\boldsymbol{g}^{\mathrm{T}} = [g_1^A, g_2^A, \ldots, g_i^A, \ldots, g_n^A]$$

subject to:

$$\boldsymbol{f^*} = \Delta \, \boldsymbol{P}(\Delta^{\mathrm{T}} \boldsymbol{c}(\boldsymbol{g}, \boldsymbol{f^*})) \, \boldsymbol{d}$$

$$g_{min} \leq g_i^A \leq C_i - g_{min} \qquad \forall \, i$$

$$g_i^B = C_i - g_i^A \qquad \forall \, i$$

where $\boldsymbol{g}$ is the signal settings vector; $\boldsymbol{f}$ is the link flow vector; $\boldsymbol{g}^{\wedge}$ is the optimal solution; $\boldsymbol{f}^*$ represents the equilibrium link flow vector (obtained by solving an equilibrium assignment problem on the network); $\boldsymbol{c}(.)$ is the link cost vector; $\boldsymbol{P}(.)$ is the route choice probability matrix; Δ is the link-route incidence matrix; $\boldsymbol{d}$ is the demand vector; g_{min} is the minimum value of effective greens (for instance 15 seconds).

In this formulation of the problem we assume that the cycle lengths are not considered decision variables and all signalised intersections have only two phases; these assumptions allow the number of decision variables to be reduced to one for each signalised intersection.

For solving the optimisation problem we propose to use a multi-start method based on a *Feasible Descent Direction Algorithm* (*FDDA*), as well the *Neighbourhood Search* (NS) cited in Section 2.1; also in this case both approaches based on steepest descent (SDM) and random descent (RDM) methods were adopted. The multi-start approach is necessary since the objective function is not convex, except for simple cases, and looking for more local optimal solutions can improve the final results, even if it requires higher computing times. In particular, in the proposed algorithm we will assume that decision variables (i.e. $\boldsymbol{g}$) are discrete and express the duration in seconds of the effective green times. For the details about algorithms, refer to Gallo et al. (2014).

4.2 NUMERICAL RESULTS

The proposed algorithms were tested on the urban network of Benevento (for details see Section 3.2). We tested the considering the following starting points: (a) all variables g_i^A equal to 50% of the cycle; (b) all variables g_i^A equal to g_{min}; (c) all variables g_i^A equal to $C_i - g_{min}$; (d) all variables g_i^A equal to g_i^A*, where g_i^A* represents the solution of the LOSS problem; (e) random values for all variables g_i^A.

Initial tests were implemented to compare the SDM approach with that of the RDM, by applying all assignment algorithms in the case of the starting point (a). The results summarised in Table 3 show that the RDM almost always requires less computational effort both in terms of calculation times and algorithmic steps. In Table 4 are reported the results obtained adopting the multi-start approach with the RDM approach. The results show the applicability of the proposed methods also on real-scale networks with acceptable computing times.

FDDA approach	Assignment algorithm	Decision variables g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	Optimal objective function value	Algorithm Iterations (AIs)	UNLs	UNLs/AIs	Calculation times [min.]
Initial values: starting point (a)		45	45	45	45	45	45	45	45	45					
SDM	MSA-FA-F0	55	47	55	65	52	58	53	43	45	2863.078	297	10870	36.599	145.62
	MSA-FA-UE	55	45	55	65	50	58	53	43	45	2862.182	299	638	2.134	8.85
	MSA-CA-F0	55	47	55	65	52	58	53	43	45	2864.588	297	2079	7.000	26.30
	MSA-CA-UE	55	49	55	66	50	58	55	42	45	2862.212	282	574	2.035	7.96
	MSA-ACO-F0	55	47	55	65	52	58	53	43	45	2859.963	297	2079	7.000	27.90
	MSA-ACO-UE	45	45	45	45	45	45	45	45	45	2868.986	19	43	2.263	0.61
RDM	MSA-FA-F0	55	47	55	65	51	58	53	43	45	2863.071	290	10668	36.786	133.29
	MSA-FA-UE	55	47	55	65	51	58	53	42	45	2862.165	428	919	2.147	12.31
	MSA-CA-F0	55	47	55	65	51	58	53	43	45	2864.581	232	1624	7.000	21.50
	MSA-CA-UE	51	45	56	65	49	58	49	45	45	2862.216	232	483	2.082	6.53
	MSA-ACO-F0	55	47	55	65	51	58	53	43	45	2859.956	354	2478	7.000	31.29
	MSA-ACO-UE	55	47	55	65	51	58	53	43	45	2862.164	417	854	2.048	10.93

Tab.3 Comparison between SDM and RDM approaches

	Decisional variables g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	Optimal objective function value	Algorithm Iterations (AIs)	UNLs	UNLs/AIs	Calculation times [min.]
Initial values: starting p. (b)	15	15	15	15	15	15	15	15	15					
Algorithm implementation	54	48	55	65	51	58	53	42	45	2862.163	446	1344	3.013	17.58
Initial values: starting p. (c)	75	75	75	75	75	75	75	75	75					
Algorithm implementation	55	47	55	65	51	58	53	42	45	2862.164	578	1211	2.095	15.02
Initial values: starting p. (d)	59	51	50	69	53	59	58	40	59					
Algorithm implementation	56	49	51	66	49	60	56	41	55	2862.165	287	942	3.282	11.57
Initial values #1: starting p. (e)	56	65	54	34	62	44	55	39	73					
Algorithm implementation	56	45	55	65	52	58	53	44	45	2862.180	287	600	2.091	7.87
Initial values #2: starting p. (e)	48	37	36	65	27	16	57	68	35					
Algorithm implementation	54	47	56	65	51	58	53	44	45	2862.157	270	567	2.100	7.44
Initial values #3: starting p. (e)	21	18	46	25	55	38	73	51	24					
Algorithm implementation	56	46	55	65	51	58	53	43	45	2862.158	566	1234	2.180	16.19
Initial values #4: starting p. (e)	28	49	73	61	65	65	50	40	19					
Algorithm implementation	56	47	55	65	50	58	55	43	46	2862.175	309	680	2.201	8.93
Initial values #5: starting p. (e)	44	34	27	49	52	40	44	37	52					
Algorithm implementation	56	47	55	65	51	58	53	43	47	2862.168	559	1154	2.064	15.16

Tab.4 Implementation of the multi-start approach in the case of FDDA-RDM

5 CONCLUSIONS

The Smart Mobility is an important aspect of the Smart City and the optimisation of traffic-lights at area level is an effective action that can be implemented in order to reduce travel time, congestion and environmental impacts of urban traffic. In this paper we proposed models and methods for designing the signal settings at area level. We studied three different problems and proposed for each one some models and methods for solving them. The results showed the applicability of proposed procedures on real-scale cases and the reduction of travel time on the network.

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