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Application of the AHP Method for Comparative Analysis of Software Systems in Traffic from the Aspect of Traffic Safety

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ABSTRACT

It is generally known that traffic safety is influenced by humans, vehicles, and roads. Nowadays, when new technologies have taken over a large part of the traffic industry, the selection of relevant software, whose competition is great, presents a big problem for the decision-maker. Intelligent systems, such as Motion, SCOOT, and SCATS, are used for the implementation of a control strategy in order to manage signals on the traffic network, with the goal of increasing efficiency and traffic safety. These systems operate on the demand-responsive principle and have logic for traffic optimization which represents their main difference along with the optimization subject and method of the system functioning. The research included consideration of mentioned differences, software, and hardware architecture that have a significant impact on the system's functionality since the detector's locations themselves depend on the optimization subject. The implementation benefits are considered through the existing world's projects. Based on the obtained data, the criteria used for the comparative analysis of these three systems were defined, from the aspect of traffic safety.

KEYWORDS

traffic safety; information systems; intelligent transportation systems; motion; SCATS; SCOOT.

1. INTRODUCTION

Traffic accidents are a global problem. Worldwide, an estimated 1.2 million people are killed in road crashes each year and as many as 50 million are injured. Road traffic crashes are a leading cause of death in the United States for people aged 1–54, and they are the leading cause of non-natural death for U.S. citizens residing or traveling abroad. Intelligent transportation systems (ITS) were primarily developed to have been developed to reduce the emissions of exhaust gases, cut down travel time, and optimize costs for the user, but their role is also to reduce the number of traffic accidents. Unlike in developed countries, where such systems have been introduced, for the most part, transportation systems in developing countries are yet to find their application. This is the case in Republic of Serbia, where the implementation of such systems has just begun. With this in mind, the Siemens Motion system was introduced and proved to be reliable. There are many other systems in addition to this one, SCATS and SCOOT just to name a few.

The ITS concept is presented in several definitions by well-known world transportation institutions. One of them is given by the Federal Highway Administration – FWHA [1] according to which ITS can be defined as the implementation of progressive information and communication technologies that raise the level of transportation to achieve greater safety and mobility, at the same time reducing the transportation pollution impact. According to the sources provided in the ITS Handbook [2], ITS is a generic term for the integrated application of communications, control and information processing technologies to the transportation system.

This paper provides an overview of ITS systems used in Serbia and presents a model of choice of the ITS system depending on the pre-set criteria applying AHP.

2. OVERVIEW – CITING SOURCES

The traffic control systems can be divided into: (1) systems with *pre-timed* operation, (2) systems with *semi-actuated* operation, and (3) systems with *actuated* operation [3].

According to Vukanović [4], the intelligent traffic control systems, depending on the traffic, can be divided into: (1) Regulation-based systems (semi-automatic, automatic and systems based on control of traffic density) and (2) Model-based systems - adaptable traffic control systems.

The systems with adaptable signal operation use on-line measurement from detectors for optimization of signal time. The control of these systems can be centralized or decentralized [5].

Centralized traffic information systems [6, 7] are systems whose substantial decisions are made at a single, central location, namely Traffic Control Centre. These systems operate based on collecting data which is then analyzed and processed only to be transferred to the end-users to provide information on the situation on the roads. Furthermore, these systems also enable control of the operation of traffic signals.

Decentralized systems [6, 7] are systems in which the decisions are made locally. These are mostly multi-agent systems that collect information from an intersection in real-time and locally, for example, make decisions that would reduce traffic congestion, and give priority to Public Transport vehicles or pedestrians at an intersection. If a certain coordination level is required between the intersections, the process of traffic flow optimization between the intersections is initiated.

Implementation of an Adaptive and Cooperative Traffic Light Agent Module – ACTAM, is one of the options for implementation of decentralized adaptable traffic control.

According to the research by a group of authors [8], hardware components that represent a part of the intersections applying ACTAM, cooperative multi-agent architecture of the traffic signal control system in urban environments are *IIA – Intelligent intersection Agent, SM – Sensor Module and traffic lights*.

Sitraffic Motion (Method for the Optimization of Traffic Signals In On-line controlled Networks) is one of the option modules of Sitraffic Scala developed in Germany, operating on the principle of assessment of the current traffic situation, as well as creating algorithms for the calculation of optimal values of change in signal plans based on collected and measured values. All the tasks pertaining to the traffic network are performed at the central controller level, and since the optimization is performed at the level of both local and central controller, the response of the system is faster and the response to the possible problems thereby more efficient. Furthermore, Sitraffic Motion provides the option of controlling the traffic flows based on creating the "green wave" plan depending on the time of day, namely, traffic density. Internal control strategy [9] enables a quick response to newly created situations in the traffic network that can automatically be identified by setting up internal prerequisites or by manual entry from the control center.

Sitraffic Motion is a software system used for traffic regulation in urban environments. This system is used for the integration of several intersections which allows for easier control, not only of one direction, but optimization of the traffic lights operation for the access roads. Determination of optimum signal plan is facilitated by consideration of the following parameters: minimum waiting time, maximum capacity and optimum coordination.

Motion is [10] a modular system for signal plan optimization in urban environments. It automatically calculates the optimum signal programs within intervals of 5, 10 or 15 minutes on the basis of traffic analysis and transfers it to the local controllers (*Figure 1*). This time interval enables a calculation of all parameters and coordination throughout the entire traffic network. Motion facilitates quality upgrading, operative optimization such as coordination, facing traffic accidents, and minimization of exhaust gases emission caused by traffic.

The three tier architecture of the Sitraffic Motion control system is presented in *Figure 1*.

Motion [11] is set up as a tactical component at the traffic control centers to which signal controllers are linked. It receives data from the installed detectors located on the traffic signal controllers, i.e., traffic lights, and roads, as well as information from the existing traffic control system, and as a result returns the signal plans to the controllers every 15 minutes.

It can be concluded from the *Figure 1* that there are three levels of control:

1) At the strategic level it is possible to monitor the entire system as well as change the light signal plan. The traffic control policy as well as integration with other information systems is also defined, namely, realized at this level.

2) At the tactical level the central control system provides the signal light time plan to the local controllers every 5 to 15 minutes. The traffic situation is identified based on collected data from recording the general traffic state. Furthermore, this level is in charge of synchronizing the sub-networks as well as the broader area of traffic roads covered by this system. The system alone performs the optimization of traffic flows based on collected data and parameters set in the system.
3) At the local level, at which the local controllers are also situated, control of several traffic lights is facilitated by local dependence. At this level, the individual controllers keep the traffic data and operating functions that facilitate control of both private as well as public transportation vehicles. The optimization is performed every second.

In order to avoid frequent minor changes [12] of the signal plan, the changes are made only in case when they lead to a significant improvement of the general goal of optimization. The signal plans are created and implemented depending on the local controller and control methods carried out. In order to avoid serious consequences of the change in traffic signal control plan, incremental introduction of the new plan is applied. The local controllers operate independently until the next change of the traffic light optimization plan, making decisions locally in accordance with the set optimization plan.

According to numerous authors [13], SCATS is an innovative computerized traffic system developed and maintained by the Roads and Maritime Services, namely, Roads and Transport Authority of New South Wales (RTA) in Australia. According to them, the evolution of this system began back in the ‘70s and continued to upgrade in order to enable control of the traffic network in the whole world. SCATS was fist installed in Sidney, and today it is used in over 50 cities around the world.

According to data published by the Roads and Maritime Services [14], SCATS is a system within traffic control, consisting of hardware and software as a unique control philosophy operating in real-time, adjusting the signal timings in response to variations in traffic demands and system capacity at the time they occur.

The system [9] is a part of the central control system that enables other software packages to be a part of the traffic control package. According to a group of authors [15], SCATS has three levels of control: central, regional and local. For each intersection, the system distributes calculations between the regional computer in the operational traffic center and the computer in the field. The central level is controlled by the central computer that communicates simultaneously with the other hierarchy levels and monitors the system. SCATS combines adaptable signal traffic control with the conventional control strategy in order to meet the different operational needs of the users. The control strategy includes adaptable system operation, daily and weekly coordination, as

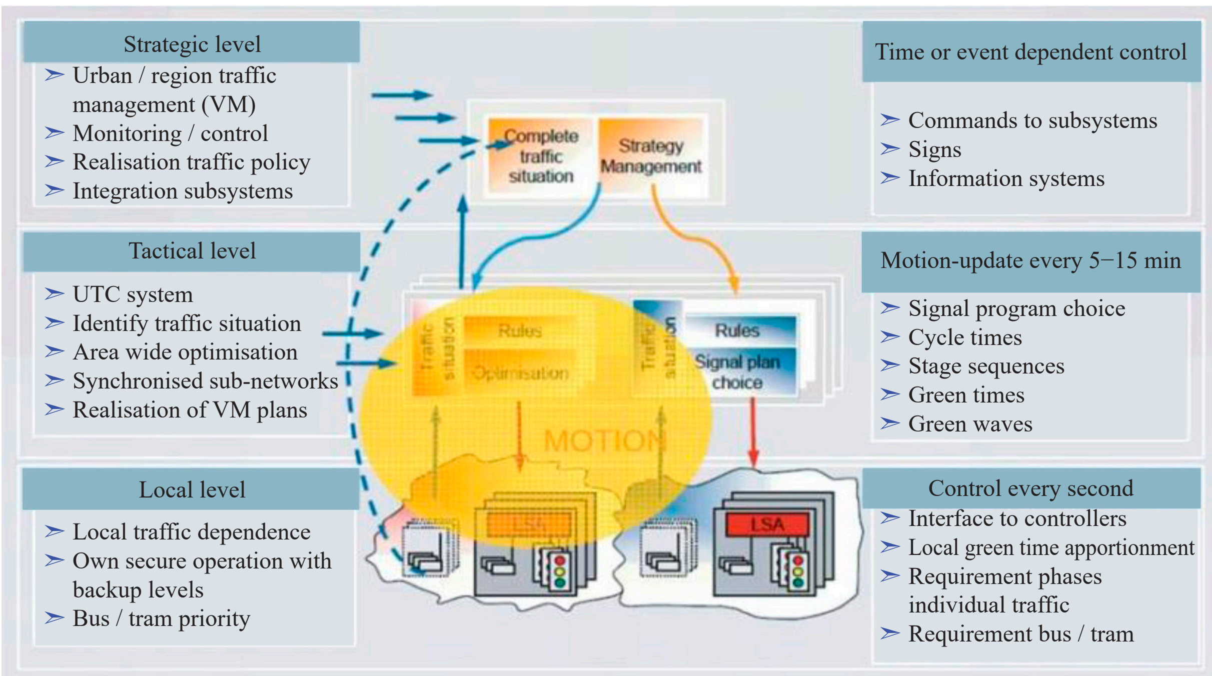

Figure 1 – Three tiers of the management control system [9]

well as isolated operation of the signal lights. With the real-time reporting tools, a traffic engineer can supervise the system operation. Furthermore, with continuous supervision of the intersection, the operators are timely notified of the conditions or breakdown of the equipment.

Traffic control is conducted at two levels [9], strategic and tactical. The strategic level is controlled by regional computers; this way of the system operation is called Masterlink. On the basis of collected flow and occupancy data obtained from detector loops set up at the intersection sidewalk, the area computers determine the optimum cycle time, phase sequencing and appropriate times for the prevailing traffic conditions. Strategic and tactical control levels act jointly in order to provide a powerful but also flexible system operation. Strategic control enables control of the cycle time, phase sequencing and offset of the entire system. Tactical control enables significant flexibility limited by the set strategic control parameters.

Tactical control is carried out at the very intersection by the local traffic light controllers, and it fulfils the cyclic variations of the demand. Tactical control level primarily enables earlier completion of the green light phase, as well as the total omission of phases when required. The local controllers base their tactical decisions on the information obtained from the detector loops at the intersection, of which some may be strategic detectors.

According to the source [14], characteristics of the SCATS system are scalability, sophistication, flexibility, and adaptability.

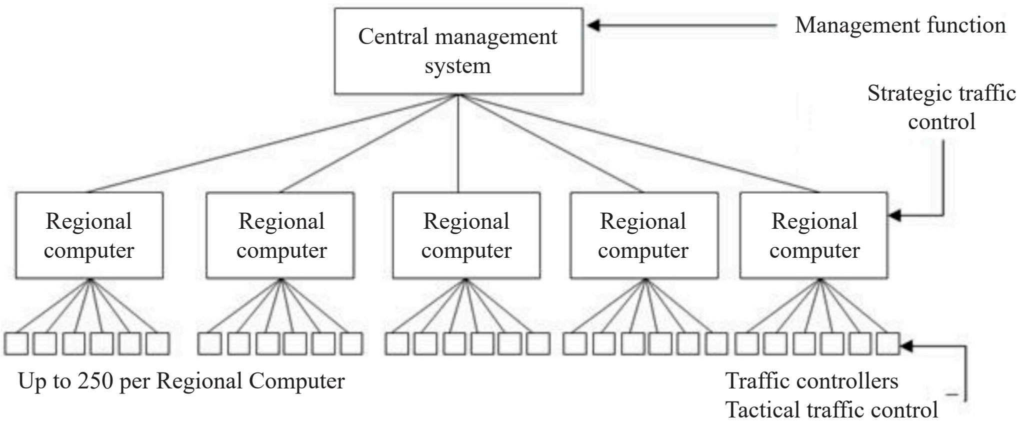

Figure 2 – Typical layout of SCATS [16]

SCOOT system is one of the most wide-spread systems utilized for traffic control; implemented at over 200 locations across the world [15]. In 1973 the British Transport and Road Research Laboratory – TRRL (Now Transport Research Laboratory - TRL) started with the development of the SCOOT system [17].

According to the source [18], SCOOT system is based on centralized control whereby communication with the local intersection controllers is performed every second. No optimization step is performed locally, rather it depends fully on the communication networks and the central control computer.

In order to detect vehicles in advance, detectors are required at every link, usually set up upstream, at the end of the accessible link, using mainly the inductive loops. Information collected from the detector is used as the input data for the calculation of the traffic progression of the SCOOT system, from the detector to the stop-line.

Operation of these optimizers is described by several authors [13, 19].

Split time optimizer considers the traffic situation at each phase change, based on which it decides on the duration of the green/red light, whereas each change may be within an interval of ± 4 seconds.

Offset optimizer considers the current traffic situation at each individual intersection in each cycle, whereas the parameter may change twice during a single cycle. This optimization parameter is activated mainly in the case of identification of traffic congestion.

Cycle time optimizer operates at the regional level and is activated every 5 minutes, and in exceptional situations, when the cycle time changes quickly, even every 2.5 minutes. The optimizer operates on the principle of identification of the most critical intersection in the region with respect to traffic congestion, whereas it will tend to maintain a 90% saturation rate. In a case where the intersection saturation is less than 90%, the cycle time will be reduced and vice versa.

Although numerous methods have been established for traffic (safety) analysis [21, 22], we chose the Analytic Hierarchy Process – AHP as the optimum choice of the ITS solution [20]. This decision-making process is highly suitable when considering the selection of the optimal ITS system, as it enables the integration of subjective position, experience, know-how and intuition. It is highly suitable in the domain of technology control as a support to decision-making, which is the reason it is used most frequently in the evaluation and selection of technological alternatives as well as when needed to consider several criteria. With the differences between the Intelligent Transportation Systems being minimal and the need to consider several criteria, to render a subjective opinion and acquired know-how, the AHP method was selected for the choice of the optimal solution.

Analysis of the selected ITS evaluation will be carried out by the AHP method, hereinafter in the paper, followed by the results of the decision on the choice of the optimum ITS solution. The purpose of applying the AHP method is to select the optimal solution from the perspective of the user of the ITS system, depending on his preferences, and for the purpose of applying the ITS to increase traffic safety.

3. DECIDING METHOD IN THE CHOICE OF ITS

The AHP method basically has a hierarchical structure. At the top of the hierarchy is a goal, whereas at the lower levels are criteria that need to be mutually compared. The same procedure is applied going through the hierarchy downwards. Each criteria needs to be evaluated, namely, given a weighted coefficient with respect to the other criteria. Once the alternatives are evaluated the following matrix is formed:

$$A_{ij} = \left(\frac{W_i}{W_j}\right) = \left(\frac{1}{A_{ij}}\right) i \ a_{ij} = 1 \quad \text{for all } i, j = 1, \ \ldots, \ n \tag{1}$$

Once the matrix of relative significances with respect to the goal is created and the sum of the columns is determined, a matrix is formed whose elements are obtained as column element/column sum. To determine the final priority for the 2nd level, average values of the criteria are ranked as a sum of table rows “column element/column sum” divided by number of set criteria. The same procedure is conducted at lower hierarchy levels. At the end of the procedure, the obtained criteria are multiplied by the obtained weighted coefficient of the superior goal.

At the top of the AHP hierarchical structure, in our case, is the selection of the ITS system, with special reference to traffic safety, at each hierarchical level. As an example, three systems were used: – Motion, SCOOT or SCATS. To decide which optimum ITS solution to select using the AHP method and in order to choose which of the systems to introduce, we decided to apply the following criteria: Interoperability (I), Adaptability (P), Scalability (S), Simplicity of use (JK), Global presence of the system (RS), Supplier’s strength (SD) and Functionality (F). All alternatives were compared from the aspect of traffic safety and other aspects.

4. RESULTS

The procedure of conducting the method of deciding on the choice of the optimum ITS solution as the desired goal is provided in the following tables.

Table 1 – The matrix of relative significance with respect to the goal

	I	P	S	RS	SD	JK	F
I	1	3	0.5	5	4	5	0.1666667
P	0.333333	1	0.3333333	4	3	4	0.1428571
S	2	3	1	5	4	5	0.2
RS	0.2	0.25	0.2	1	0.5	0.3333333	0.1111111
SD	0.25	0.3333333	0.25	2	1	3	0.125
JK	0.2	0.25	0.2	3	0.333333	1	0.1111111
F	6	7	5	9	8	9	1
Σ	9.98333	14.83333	7.48333	29	20.8333	27.33333	1.85675

Table 2 – Column element/column sum

	I	P	S	RS	SD	JK	F	Rows sum - Σ
I	0.100167	0.202247	0.066815	0.172414	0.192000	0.182927	0.089763	1.006332673
P	0.033389	0.067416	0.044543	0.137931	0.144000	0.146341	0.076940	0.650560157
S	0.200334	0.202247	0.133630	0.172414	0.192000	0.182927	0.107715	1.191267317
RS	0.020033	0.016854	0.026726	0.034483	0.024000	0.012195	0.059842	0.194133107
SD	0.025042	0.022472	0.033408	0.068966	0.048000	0.109756	0.067322	0.374964911
JK	0.020033	0.016854	0.026726	0.103448	0.016000	0.036585	0.059842	0.279488868
F	0.601002	0.471910	0.668151	0.310345	0.384000	0.329268	0.538577	3.303252969

Table 3 – Determination the final priority for the II level

	Row sums	Average row values	Final priority for II level:		
I	1.006333	0.1437618	F	0.471893	
P	0.65056	0.0929372	S	0.170181	
S	1.191267	0.170181	I	0.143762	
RS	0.194133	0.0277333	P	0.092937	F-S-I-P-SD-JK-RS
SD	0.374965	0.0535664	SD	0.053566	
JK	0.279489	0.039927	JK	0.039927	
F	3.303253	0.4718933	RS	0.027733	

Interoperability. Motion is a Sitraffic system module using a common basis as a central platform for the operation of all functional modules and enables connection to third party systems. Furthermore, the central system is fully harmonized with the industrial standards and norms thanks to the standard interfaces such as XML and OCIT that enable data exchange with other systems [23].

SCOOT system is also able to collect data from the traffic control system and store it in the ASTRID database in order for these data to be used [24]. The collected and processed data are used by the other systems. Furthermore [25], the system is capable of data exchange using the TCP/IP protocol with any computer connected via Ethernet.

SCATS has an ITS port that enables the exchange of the operative data with other intelligent traffic systems. However, providing a port to the applications of third parties is subject to additional license fee [15].

Table 4 – The matrix of relative significance with respect to criteria „Interoperability“

Interoperability	Motion	SCOOT	SCATS
Motion	1	1	3
SCOOT	1	1	3
SCATS	0.333	0.333	1
Σ	2.333	2.333	7

Table 5 – Column element/column sum for the criteria "Interoperability"

Interoperability	Motion	SCOOT	SCATS
Motion	0.42857	0.428571	0.4285714
SCOOT	0.42857	0.428571	0.4285714
SCATS	0.142857	0.142857	0.1428571

Table 6 – Determination the final priority for the criteria "Interoperability"

Interoperability	Row sums	Average row values	Final priority with respect to criteria I		
Motion	1.285714	0.4285714	Motion	0.429	Motion SCOOT - SCATS
SCOOT	1.285714	0.4285714	SCOOT	0.429	
SCATS	0.428571	0.1428571	SCATS	0.143	

Adaptability. Motion, SCOOT and SCATS are systems for traffic control. These systems are specially created for traffic control purposes, however, Motion and SCOOT are systems that can be extended by additional modules enabling for an easier and a better traffic control. Motion has individual modules for detection of traffic accidents, assessment and choice of the signal plan, as well as its optimization [23]. This is very important from the aspect of traffic safety, due to secondary traffic accidents, which occur due to lack of attention, concentration, extraordinary circumstances, caused by the first traffic accident. Traffic accident detection and traffic organization in the current time is a very important item in the organization of the traffic system and the improvement of traffic safety. The system is adaptable to various control strategies regardless of whether it is control of congestion or increase of traffic capacity. SCOOT system also consists of several functionalities that enable greater adaptability of the system. Some of the functionalities are: giving priority to public transportation vehicles, control of fixed mode of operation of the traffic lights, etc. [9]. SCATS system also has several modes of operation of the system that provide it with better adaptability.

In addition to this, Motion and SCOOT are modular systems that enable upgrading of the system in order to adapt to the new demands. SCATS, on the other hand, has several modes of operation of the system that adapt to the newly created situations.

Table 7 – The matrix of relative significance with respect to criteria „Adaptability"

Adaptability	Scala Motion	SCOOT	SCATS
Scala Motion	1	2	3
SCOOT	0.5	1	2
SCATS	0.3333	0.5	1
Σ	1.8333	3.5	6

Table 8 – Column element/column sum for the criteria „Adaptability"

Adaptability	Motion	SCOOT	SCATS
Scala Motion	0.5454545	0.5714286	0.5
SCOOT	0.2727273	0.2857143	0.33333
SCATS	0.1818182	0.1428571	0.16667

Table 9 – Determination the final priority for the criteria „Adaptability"

Adaptability	Row sums	Average row values	Final priority with respect to criteria P		
Scala Motion	1.616883	0.538961	Scala Motion	0.538961039	Motion SCOOT – SCATS
SCOOT	0.891775	0.2972583	SCOOT	0.297258297	
SCATS	0.491342	0.1637807	SCATS	0.163780664	

Scalability. All three systems have the option of extending the system if needed. For the already existing infrastructure and implemented software, infrastructural extension is possible as well as the extension of the number of system users without the need of acquiring additional software.

Motion can be applied to just one direction (street), but can also be applied to a whole system of main and access roads and traffic routes. Standard traffic control system capacities vary and the control is usually conducted on 50 intersections per zone, and there may also be several zones which form a region. Siemens system has the option of extending all components both with respect to size as well as functionalities. According to the source [26], controllers can manage 48 signal groups, namely, 32 signal groups within a sub-area or an intersection.

SCATS system also enables infrastructural extension of the system where 64 systems can be linked and controlled by a single central management system. An extension of the SCATS system is realized by an addition of a regional computer. The maximum capacity is 250 intersections per regional computer. The system may be controlled by up to 200 users [14]. According to the author, SCOOT system can support up to 255 intersections per region [27]. These aspects of the system are very important for traffic management, due to incident situations.

Table 10 – The matrix of relative significance with respect to criteria „Scalability"

Scalability	Motion	SCOOT	SCATS
Motion	1	3	4
SCOOT	0.333333	1	2
SCATS	0.25	0.5	1
Σ	1.58333	4.5	7

Table 11 – Column element/column sum for the criteria „Scalability"

Scalability	Motion	SCOOT	SCATS
Motion	0.6315789	0.6666667	0.571428571
SCOOT	0.2105263	0.2222222	0.285714286
SCATS	0.1578947	0.1111111	0.142857143

Table 12 – Determination the final priority for the criteria „Scalability"

Scalability	Row sums	Average row values	Final priority with respect to criteria S		
Motion	1.869674	0.6232247	Motion	0.623224728	Motion SCOOT - SCATS
SCOOT	0.718463	0.2394876	SCOOT	0.239487608	
SCATS	0.411863	0.1372877	SCATS	0.137287664	

Simplicity of Use. Motion is a good graphic solution that fully follows the logic of the majority of people for movement through the system. Adjustments and control of traffic signalization is simplified. System users, namely operators are not required to be knowledgeable of the IT technology. SCOOT system has a significantly more inferior interface than the Motion system. Based on the examination of all system interfaces we can notice that the use of the SCOOT application is rather difficult.

SCATS system does not require expert knowledge of computer science, however, the drawback, in our opinion, can be found in the interface for configuration of intersection and programming of the action plan.

Table 13 – The matrix of relative significance with respect to criteria „Simplicity of Use"

Simplicity of Use	Motion	SCOOT	SCATS
Motion	1	4	2
SCOOT	0.25	1	0.3333333
SCATS	0.5	3	1
Σ	1.75	8	3.333333

Table 14 – Column element/column sum for the criteria „Simplicity of Use"

Simplicity of Use	Motion	SCOOT	SCATS
Motion	0.57142857	0.5	0.6
SCOOT	0.142857143	0.125	0.1
SCATS	0.285714286	0.375	0.3

Table 15 – Determination the final priority for the criteria „Simplicity of Use"

Simplicity of Use	Row sums	Average row values	Final priority with respect to criteria JK		
Motion	1.671429	0.5571429	Motion	0.5571429	Motion SCATS - SCOOT
SCOOT	0.36785705	0.12261902	SCATS	0.320238105	
SCATS	0.9607143	0.320238105	SCOOT	0.12261902	

Global Presence of the System. Based on data gathered from the official companies' sites [14], SCATS system is applied in 27 countries throughout the world: Australia, Bangladesh, Brazil, Brunei, Chile, China, Ecuador, Fiji, Indonesia, Iran, Ireland, Jordan, Laos, Malaysia, Mexico, New Zealand, Pakistan, India, Philippines, Poland, Qatar, Saudi Arabia, Singapore, Republic of South Africa, Thailand, USA and Vietnam.

Contrary to the SCATS system, the SCOOT system is implemented in somewhat more than 14 countries around the world [28]: England, Ireland, Wales, Spain, Cyprus, Bahrain, United Arab Emirates, Republic of South Africa, Thailand, Malaysia, China, Brazil, Chile, Colombia, USA and Canada.

According to the Siemens Product Manager and researcher, Jürgen Mück, Motion is the most applied traffic control system in Germany [11]. According to data from various references [29][30], Sitraffic Motion is implemented in 10 countries: United Arab Emirates, Germany, Austria, Denmark, Poland, Greece, Czech Republic, Lithuania, Serbia and Switzerland. It is also necessary to emphasize that a replacement of over 12,000 intersections has begun in New York City, NY, USA that will be controlled by the Motion system [31].

Accordingly, we can say that the SCATS system is currently the most widespread system, however, with respect to the presence of the system in Europe, the Sitraffic Motion takes up most of the market share, thus in our estimate the following significance matrix was created with respect to the criteria World presence of the system. It is very important to collect and analyze this data, from different aspects, and especially to analyze how the systems have contributed to the improvement of traffic safety.

Table 16 – The matrix of relative significance with respect to criteria „Global Presence of the System"

Global Presence of the System	Motion	SCOOT	SCATS
Motion	1	4	2
SCOOT	0.25	1	0.3333
SCATS	0.5	3	1
Σ	1.75	8	3.333

Table 17 – Column element/column sum for the criteria „Global Presence of the System"

Global Presence of the System	Motion	SCOOT	SCATS
Motion	0.5714286	0.5	0.6
SCOOT	0.1428571	0.125	0.1
SCATS	0.2857143	0.375	0.3

Table 18 – Determination the final priority for the criteria „Global Presence of the System"

Global Presence of the System	Row sums	Average row values	Final priority with respect to criteria RS		
Motion	1.671429	0.5571429	Motion	0.557142857	Motion SCATS - SCOOT
SCOOT	0.367857	0.122619	SCATS	0.320238095	
SCATS	0.960714	0.3202381	SCOOT	0.122619048	

Supplier's Strength. There are three main distributors of the SCATS systems: Aldridge traffic controllers (ATC), Tyco Traffic & Transportation and QTC from Australia. Furthermore [32], GeoKat (Poland) is engaged as subcontractor. Siemens (Germany) is in charge of the implementation of the Motion system, whereas Siemens (Great Britain) is in charge of the implementation of the SCOOT system. For a country in transition, this feature of the ITS system is very important.

Table 19 – The matrix of relative significance with respect to criteria "Supplier's Strength"

Supplier's Strength	Motion	SCOOT	SCATS
Motion	1	2	5
SCOOT	0.5	1	4
SCATS	0.2	0.25	1
Σ	1.7	3.25	10

Table 20 – Column element/column sum for the criteria "Supplier's Strength"

Supplier's Strength	Motion	SCOOT	SCATS
Motion	0.5882353	0.6153846	0.5
SCOOT	0.2941176	0.3076923	0.4
SCATS	0.1176471	0.0769231	0.1

Table 21 – Determination the final priority for the criteria „Supplier's Strength"

Supplier's Strength	Row sums	Average row values	Final priority with respect to criteria SD		
Motion	1.70362	0.5678733	Motion	0.567873303	Motion SCOOT - SCATS
SCOOT	1.00181	0.3339367	SCOOT	0.333936652	
SCATS	0.29457	0.09819	SCATS	0.098190045	

Functionality. Another important feature of the ITS system is functionality, which is indirectly related to traffic safety. First of all, through timely response and management of traffic flows. Taking in consideration that all three systems Motion, SCOOT and SCATS, are highly complex systems, in order to determine their functionality, it is necessary to consider several aspects of these systems.

One of these aspects is the time of response of the system to the new traffic situations. The time of response is very difficult to define unequivocally. If, for example, the changes at the strategic level of the cycle are great, e.g., from 120 to 80 seconds, the transition time can last very long. That is why the pace in the change of the duration of the cycle is step by step. If the aim is to reach 90 seconds out of 120 seconds, the system performs several steps in order to reduce the losses and optimize the use of the cycle.

With the Motion system the optimization is performed at the local and central controller level, hence, the system response is faster and thereby the response to the problems or situations more efficient. Optimization consists of three levels: operative, tactical and strategic, with the control logic at the strategic level updated every 5 to 15 minutes, whereas the dependence of the traffic light is controlled locally every second. The system is partially decentralized because the local controllers have the ability to take over certain functions. SCOOT system is a system whose control is performed centrally, and adjustment of the system to the traffic situations is performed every 2.5 to 5 minutes. The SCATS system, is a system whose control logic is performed centrally and from cycle to cycle, but the duration of adjacent cycles cannot change significantly. The duration of the cycle can vary from 6 to 9 seconds with respect to the duration of the previous cycle. The system consists of two control levels: strategic and tactical.

Detection of vehicles is also very important for the functionality of the system. The detectors are set up depending on the achieved control level and depending on what is to be optimized. For example, in case of public transportation vehicles, the detectors are set up so that the vehicles are passed through the intersection without stopping.

Whereas the detectors in the Motion system are set up mostly close to the stop-line, in the SCATS system in most cases they are set up on the very stop-line, and some even close to the stop-line, in the SCOOT systems the detectors are set up upstream from the stop-line. The distance of the detectors from the stop-line in the Motion systems is 10 to 60 meters. For the SCATS system, in case the detectors are located close to the stop--line, it is recommended they be placed at a distance of 3.5 meters. If the detectors are located at an inadequate distance from the stop-line, they will be unable to detect the space between the vehicles. In case of a smaller distance of detectors, and greater density or slower movement of the vehicles, the space between the vehicles will not be observed. The drawback of the SCATS system is the system's inability to respond to congestion. SCOOT system with detectors placed upstream can detect congestion in case of a long queue of vehicles. The function of the Motion detectors is to move the vehicles, whereas a method is used for the prediction of the queue of vehicles, and based on this prediction, the system can calculate the consequences of delay and travel time. The SCOOT system requires many more detectors on the network.

The review of the signal plan optimization in the Motion system is performed through a consideration of parameters of maximum waiting time, maximum capacity and optimum coordination. In order to avoid minor changes, they are performed only when such a change would have a significant impact on the general goal of optimization. Optimization is performed for the parameters: offset, split time, cycle time and phase sequencing. Based on the strategic detectors, Motion makes a prediction and decides on cycle time, split time and offsets, followed by a change of the cycle length at a strategic level. The SCATS makes a pre-calculation of the signal time plan which is adjusted independently to the changes during a specific time period. The optimization is performed for these parameters: offset, split time, and cycle time. SCOOT system uses three key optimizers: offset, split time and cycle time. Although a system does not have an option of phase sequencing optimization, the system with which the SCOOT is implemented can have this option. With the optimizers the system performs continuous adjustment to the demands of the controlled intersections with minimization of unused duration of the green light and reduction of stops and delays due to harmonization of adjacent traffic lights. The goal of the optimization of the Motion system is maximizing the capacity, whereas the SCOOT system tends to minimize the time of travel. Motion as well as the other two systems have the possibility of optimization of public transportation vehicles, pedestrians or just vehicles.

Based on these data, the ranking of the systems according to the listed aspects of functionality is the following:

1) Response time: Motion – SCOOT – SCATS
2) Vehicle detection: Motion – SCATS – SCOOT
3) Signal plans optimization: Motion – SCOOT – SCATS

The following significance matrix was created for such self-assessment with respect to the attribute "Functionality".

Table 22 – The matrix of relative significance with respect to criteria „Functionality"

Functionality	Motion	SCOOT	SCATS
Motion	1	2	3
SCOOT	0.5	1	2
SCATS	0.333333	0.5	1
Σ	1.83333	3.5	6

Table 23 – Column element/column sum for the criteria "Functionality"

Functionality	Motion	SCOOT	SCATS
Motion	0.5882353	0.6153846	0.5
SCOOT	0.2941176	0.3076923	0.4
SCATS	0.1176471	0.0769231	0.1

Table 24 – Determination the final priority for the criteria „Functionality"

Functionality	Row sums	Average row values	Final priority with respect to criteria F		
Motion	1.616883	0.538961	Motion	0.538961039	Motion
SCOOT	0.891775	0.2972583	SCOOT	0.297258297	SCOOT - SCATS
SCATS	0.491342	0.1637807	SCATS	0.163780664	

Overall priority of alternatives regarding to the global objective is:

$$\begin{matrix} W_{Motion} \\ W_{SCOOT} \\ W_{SCATS} \end{matrix} = 0.4719\begin{bmatrix}0.5390\\0.2973\\0.1638\end{bmatrix} + 0.1702\begin{bmatrix}0.6232\\0.2395\\0.1373\end{bmatrix} + 0.1438\begin{bmatrix}0.4286\\0.4286\\0.1429\end{bmatrix} + 0.929\begin{bmatrix}0.5390\\0.2973\\0.1638\end{bmatrix} + 0.0536\begin{bmatrix}0.5679\\0.3339\\0.0982\end{bmatrix} + 0.0339\begin{bmatrix}0.5571\\0.1226\\0.3202\end{bmatrix}$$

$$+0.0277\begin{bmatrix}0.5571\\0.1226\\0.3202\end{bmatrix} = \begin{matrix}0.2544 & 0.1091 & 0.0616 & 0.0501 & 0.0304 & 0.0222 & 0.0154 & 0.5441\\ 0.1402+ & 0.0401+ & 0.0616+ & 0.0276+ & 0.0179+ & 0.0049+ & 0.0034= & 0.2957\\ 0.0773 & 0.0233 & 0.0205 & 0.0152 & 0.0053 & 0.0128 & 0.0089 & 0.1633\end{matrix} \quad (2)$$

Based on the intelligent transportation systems self-assessment, and from the analyzed aspect that also includes traffic safety, results show that the priority should be given to Motion, then the SCOOT system and finally the SCATS system.

5. DISCUSSION

The opinions regarding the implementation of the ITS system are divided and it is difficult to say which is better, but what has been considered are the differences between the systems based on which a conclusion can be reached on the implementation of a specific system, depending on a need. According to the research [33], the difference between the SCOOT and the SCATS system is that the optimization with the SCOOT system takes place at the central level, whereas with the SCATS system it is at the level of the controllers.

Table 25 – Review of benefits of SCOOT and SCATS systems implementation [34]

System	Benefits (Percent change in)			Initial capital cost (per intersection)
	Travel time	Delays	Stops	
SCATS	-20% do 0%	-19% do +3%	-24% do +5%	$25,000 - $30,000
SCOOT	-29% do -5%	-28% do -2%	-32% do -17%	$30,000 - $60,000

The Research of the Transportation Board [9] states that the main difference between the Motion system and the conventional adaptable transportation control systems, such as SCOOT and SCATS, is the separation of levels of the signal groups, performed every second from the adaptable control level. Instead of this, the controllers are used for making operational decisions, whereas the level of adaptable control updates the control logic and conveys to the controllers a new framework plan of control every 5 to 15 minutes. Such results are very important from the aspect of traffic safety, because a timely response to the redistribution of traffic flows due to incident situations (traffic accidents), apart from the benefits of reducing travel time and reducing harmful gas emissions, would also contribute to reducing the probability of secondary traffic accidents [35-38].

6. CONCLUSION

A comparative analysis was performed based on collected information and the calculation of available characteristics of the subject systems, which directly or indirectly have an impact on traffic safety. Since functionality was evaluated as the most essential criterion, additional criteria were considered: system response time as a reaction to the change in the traffic situation, differences in the manner of detecting the vehicles, and optimization logic of the signal plans. Although the price represents an important criterion, it can be considered and compared only in cases where the actual user requirements are known. Some elements that affect the price are software, servers, computers, vehicle detectors, traffic lights, controllers on-site, and other devices whose price depends on the quantity, namely, the number of intersections that are to be covered by the system.

This paper provides an overview of ITS systems used in Serbia and presents a model of choice for the ITS system depending on the pre-set criteria, which have an impact on traffic safety. With the differences between the Intelligent Transportation Systems being minimal and the need to consider several criteria, to render a subjective opinion and acquired know-how, the AHP method was selected for the choice of the optimal solution. Depending on the needs/desires of the entities responsible for the application of ITS systems, from the aspect of traffic safety, the criteria for the optimal solution can also be changed, which can also aim at different tasks, and the primary one is the increase of traffic safety. Analysis of the selected ITS evaluation was carried out by the AHP method, followed by the results of the decision on the choice of the optimum ITS solution.

The results of the analysis indicate Motion as the best solution, followed by SCOOT and finally, the SCATS system. However, the result and the choice of the best solution are prone to change because the compared systems are highly complex, and the difference between them is minimal. Also, the results may differ depending on the setting of goals and criteria. The paper presents an example of the application of the AHP method, for the analysis of the ITS systems, from the aspect of traffic safety. For this reason, it is necessary to determine, first of all, the differences in the functionalities based on which, in certain situations, it would be possible to choose the system that would also meet the requirements. The choice of the solution will also depend on the size of the area to be covered by this system.

The research that could follow after this paper would include:

- Study of additional comparative analysis criteria, making the choice more reliable
- Creating the Terms of Reference that would consider the implementation of these systems in a given area
- Creating a survey that would be conveyed that would target major companies, which would provide their expert opinion on set criteria and make their evaluation.

The subject research would yield an optimum solution, either based on a greater number of criteria, or for an actual case or would yield another researches opinion that would complete this research. In addition to the above, the paper shows a good example of the application of the AHP method for evaluating complex systems in traffic. Also, by changing the aspect from which the selected criteria are viewed, the output result can also be different.

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Primena AHP metode za uporednu analizu softverskih sistema sa aspekta bezbednosti saobraćaja

Apstrakt
Opšte je poznato da na bezbednost saobraćaja utiču osnovni faktori, kao što su čovek, vozilo i put. U današnje vreme, kada su nove tehnologije zavladale velikim delom saobraćajne industrije, izbor relevantnog softvera, čija je konkurencija velika, predstavlja veliki problem za donosioca odluka. Inteligentni transportni sistemi, kao što su Motion, SCOOT, SCATS, koriste se za implementaciju strategije upravljanja saobraćajem, u cilju upravljanja signalima na saobraćajnoj mreži, sa ciljem povećanja efikasnosti i bezbednosti saobraćaja. Istraživanje je obuhvatilo razmatranje pojedinačnih razlika navedenih sistema (softvera i hardvera), koje imaju značajan uticaj na bezbednost i funkcionisanje saobraćaja. Takođe, razmatrani su benefiti implementacije navedenih Sistema kroz postojeća svetska praktična iskustva. Na osnovu dobijenih rezultata definisani su kriterijumi, koji se koriste za uporednu analizu navedena tri sistema, sa aspekta bezbednosti saobraćaja.

Ključne reči
bezbednost saobraćaja; informacioni sistemi; inteligentni transportni sistemi; motion; SCATS; SCOOT.