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A decision-support methodology for priority allocation among road users at signalized junctions

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Abstract

Changing traffic signal programs due to traffic dynamics is an essential step to improve the quality of the city's traffic management. But the large number of players, who are competing for the same resources, complicates the selection of new signal programs. The cars, Public Transport (PT) and pedestrians all coming from different directions create a complex right of way allocation problem. The selection of a new program becomes an especially complex task when PT priority logic is integrated into the signal program planning. This paper suggests a methodology for performing the selection process.
The methodology described in this article for selecting an alternative signal program is based on a definition of Standard Planning Attributes (SPA), which serve as a "data dictionary". The selection criteria, called Integrated Components, takes into account the interdependencies linking the various Signal Groups (SGs) and Standard Planning Attributes and the directivity of the relationship between Planning Attributes (PA) and the performance level of each road user.

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Keywords: traffic management; signal programs; decision support; public transport priority

1. Introduction

Modern traffic management strategies are all traffic responsive in the sense that the green durations, cycle times and offsets are changing within certain boundaries in response to the traffic condition detected in the network. However, the strategies differ from each other both in the characteristics of the control algorithm and in the distribution of responsibility between the central system and the local controllers. On one side of the scale are centralized systems in which all decisions are taken by the central system. On the other side of the scale are distributed systems in which all decisions are taken by each individual controller. Systems such as SCOOT (Robertson and Bretherton, 1991) belong to the family of centralized strategies while TRSP (Montasir, Pesti, Chaudhary & Li, 2008) is an example of a distributed strategy.

Distributed systems are considered more effective when public transport priority is required. In most of the centralized systems PT priority is provided at the local controller's level and is not integrated into the centralized

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optimization algorithm (Aleksandar, 2010). Particularly in Germany, where PT priority is well established, quality standards of prioritization have already been achieved through distributed strategies (Mueck, 2008). The level of performance achieved by distributed traffic management systems relies heavily on the quality of the signal program selection process. A very limited number of studies have addressed the problem of developing a methodology for signal program selection (Montasir et al., 2008). Moreover, the works that have been conducted in this field do not explicitly address signal programs incorporating PT priority.

Under a distributed traffic management strategy, a set of traffic actuated signal programs is implemented according to the time-of-day. The routine follow-up of signal performance should be based on a set of Performance Indicators (PI) assigned to each road user. Whenever the projected PI differs from the measured PI, a more appropriate signal program should be selected and implemented as a solution. The program selection should be made subject to the local transport policy which dictates the relative importance of different road users. This paper proposes a methodology for real-time selection of a new signal program whenever the projected performance level is not satisfied.

2. Performance Indicators and the Signal Selection Process

The three types of road users: PT vehicles, cars and pedestrians, differ in their needs and their requirements. Consequently, the PIs of each of them are of different nature.

- *Performance Indicators associated with PT vehicles* - These PIs should mainly reflect the objective of staying on schedule. Possible PIs are therefore directly related to the arrival times of the PT vehicles at the stations, such as Time Variance between consecutive PT Vehicles or Average Deviation from "On time" Arrivals at the Station
- *Performance Indicators associated with cars* - Car PIs should reflect the objective of avoiding delays, queues, congestion and grid lock.
- *Performance Indicators associated with pedestrians* - Pedestrian PIs reflect the objective of minimizing pedestrian's waiting time. As it is difficult to monitor the arrival time of each pedestrian, the PIs are often based on the duration of red light (red duration) for pedestrians.

Often, the three types of users compete with each other over the same resources, and improving the PIs of one user worsens the situation of another. The expected values of the various PIs are used as thresholds to evaluate the observed performance level of each type of road user. The relative values of the projected PIs reflect the importance and the priority assigned to each road user and their absolute values reflect the expected influence of different traffic levels. The dynamics of traffic conditions call for a different level of projected PI for every type of day and each time-of-day.

Continuous monitoring is required in order to identify situations in which the desired PI values are not obtained. Whenever a deviation is discovered between the observed and projected PI of one of the road users, a new decision should be made regarding the selection of a new signal program. The selection process primarily takes into account the road user who's PIs are not met, but it should also address the effect of the selected signal program on the other road users. To enable the comparison and selection of the most appropriate program the following methodology was developed. For the sake of clarity, the following definitions are made:

- *Signal Group (SG)* – an entity that represents road users of the same type, arriving from the same direction and aiming to cross the junction. The term SGs is used as the plural form of SG.
- *Stage* – A stage is a set of SGs that receives the right-of-way simultaneously for a certain period of time during the cycle.
- *Logic* – the Signal program's logic is a set of rules by which the timing, the sequence and duration of the various stages are determined. Several signal programs can share the same logic.
- *Planning Attributes (PA)* – logical variables representing a constraint that need to be imposed within the signal program logic. The PAs are usually associated with the various stages and SGs.
- *PA Threshold (PAT)* – the threshold values assigned to the various PAs embedded within the logic. These values differ from one signal program to the next.

Figure 1 presents the stages, car SGs, PT SGs and Pedestrian SGs for a certain 4-way junction. The Stages are the squares containing all the SGs and are marked by a capital letter. The PT vehicle SGs are presented by a thick arrow. Car SGs are presented by a narrow arrow and Pedestrian SGs are presented by a striped rectangle. For example in Stage A, the PT SGs are 2 and 6, car SGs are 3 and 7 and pedestrian SGs are a, b & c.

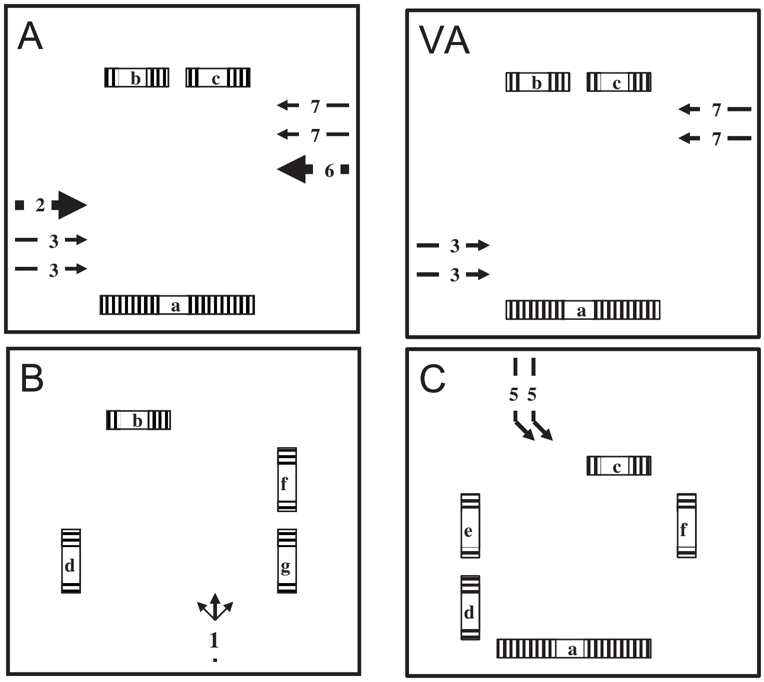

Figure 1 The stages used in the sample signal program's planning process

Typically, the logic of a signal program with PT priority is structured according to the following rule: **Perform the necessary actions in order to allocate the right-of-way to an approaching PT vehicle, subject to satisfying to the rules and the constraints regarding conflicting SGs**. Table 1 presents a selection of PAs which are used in a junction's signal logic. The subscripts refer to the SG of figure 1.

Table 1 The PA used in the junction's planning logic

Planning Attribute's Name	Planning Attribute's Description
ProgCycleTime	Cycle time
$StageMinGreen_A$*	Minimum duration of stage A
$StageMaxGreen_A$*	Maximum duration of stage A
$PedMaxRed_f$	Maximum red duration allowed for SG_f
$PedMaxRed_g$	Maximum red duration allowed for SG_g
$VehMaxRed_1$	Maximum red duration allowed for SG_1
$ReqCumDuration_1$	Cumulative green duration required for SG_1 as a compensation for truncating its green duration due to the arrival of a PT vehicle.
$ReqCumDuration_5$	Cumulative green duration required for SG_5 as a compensation for truncating its green duration due to the arrival of a PT vehicle.
$PTDirectionPriority_2$	Relative priority given to SG_2 compare to the other PT SG
$PTDirectionPriority_6$	Relative priority given to SG_2 compare to the other PT SG

* A similar Planning Attribute exists for all other stages (VA, B,C)

The logic is actually a set of rules composed of conditions and actions. The content of the conditions describe the current status of certain characteristics at the junction. Each condition is compared to a PAT. As a result of this comparison, a certain action is processed. A typical rule can be formulated as following:

IF {*condition* n_1} $\leq / = / \geq$ {PAT $_{i1}$}
AND {*condition* n_2} $\leq / = / \geq$ {PAT $_{i2}$}
AND {*condition* n_1} $\leq / = / \geq$ {PAT $_{i3}$}
THEN {*action* $_i$}

There can be three types of conditions:

- Conditions referring to Stage Current Green Duration – such conditions compare the current green duration of the active stage to minimum and maximum duration thresholds.
- Conditions referring to the SGs' recent green/red allocation – such conditions refer to the durations of green and red lights currently allocated to the various SGs or the cumulative durations that were allocated to the SGs in the recent cycles.
- Conditions referring to the SG status at the junction – such conditions refer to the situation in the network, typically identified by the detectors, representing the demand of the various SGs for the allocation of green light.

There can be two types of actions:

- Prolonging the active stage, hence effecting stage duration.
- Halting the active stage and performing a transition to a different stage, hence effecting stage sequence.

Each intersection has its own characteristic regarding the nature of each SG, the conflicts between the various SGs and the priority policy required. Therefore, the signal planning logic and the PA embedded into it are tailor-made for each junction. However, this versatility increases the difficulty of developing a general methodology for comparing alternative signal programs and selecting the most appropriate one for the prevailing conditions.

3. Comparing the Signal Programs

Signal programs at the same junctions share the same logic structure expressed by a set of rules. The differences between the programs are reflected only by the different threshold values of the different PAs. In other words, the set of PAs has a one to one relationship (injective relationship) with the set of signal programs. To facilitate the reference to the PA list, a set of Standard PAs (SPA) is defined and can be considered a data dictionary of the signal programs. The SPAs that constitute the data dictionary represent the most common conditions and constraints typically integrated into the planning logic of signal programs which incorporate PT priority. The composition of the data dictionary should reflect two types of considerations:

- The SPA data dictionary should be broad enough to reflect the versatility between junctions, and consequently preserve the ability to accommodate the planning logic to the junction's characteristics.
- Still, the SPA data dictionary should be compact enough to serve as a basis for the formulation of the signal program comparison process that can be used for various junctions.

Each SPA was assigned with a predefined name and meaning, thus, enabling the development of a general process for comparing between signal programs. Four types of SPA were defined (the PA names are defined in Table 1):

- Stage-related PA - Stage-related PAs usually refer to the minimum and maximum duration of each stage. Hence, PAs such as StageMinDuration and StageMaxDuration were defined as in the standard.
- PT-related PA - PAs associated with PT SGs are usually used for controlling the priority regime between conflicting PT directions and for avoiding preemption in situations in which the PT vehicle is ahead of schedule.
- Private vehicle-related PA - PAs associated with cars are used for ensuring sufficient flow conditions for cars. As the fundamental PT priority strategy aims to provide the right-of-way for an approaching PT vehicle, it is often required to truncate the green duration given to a conflicting private vehicle SG. If the arrival frequency of PT vehicles is high, a common PA represents the required compensation due to the specific private vehicle.
- Pedestrian-related PA - PAs associated with pedestrians are used for limiting the waiting time of pedestrians at sidewalks. Such PAs enable the implementation of a strategy in which priority is given to the PT vehicle only if the red duration of a pedestrian does not exceed a certain value.

Some of the PAs typically affect stage duration while others typically affect stage sequence. For example, a PA representing the maximum duration of a stage determines stage duration and a PA representing the maximum red duration of a pedestrian or a private vehicle typically affects the stage sequence. Selecting the appropriate SPA for each junction and incorporating them into the signal program logic, enables an understanding of the principles of the signal program logic while avoiding the need to know its specific details.

Given the SPA as the basis for selecting the most appropriate signal program, the selection process steps can be listed as follows:

- Perform constant monitoring of each road user's PI.
- When a deviation between the actual and the expected PI value is observed for one of the road users, identify the SG to which this road user belongs and mark as "SG needed consideration".
- Compare the expected priority given to the "SG needed consideration" in each alternative signal program relative to its priority in the currently active signal program. The comparison should be performed on the basis of the type of PA implemented within the signal program logic and the PAT assigned for each signal program.

Given the "SG needed consideration", it is clear that the treatment should refer to the PA directly associated with it. However, other PA used by the signal program and their thresholds should also be taken into account. The reason for this is demonstrated by the following three examples, which refer to a situation where the cars' SG_1 is the "SG needed consideration":

- The influence of a PA on another SG belonging to the same stage – An increase in the threshold of a stage's minimum green duration (StageMinGreenA) is expected to have a positive effect on the queues accumulating at the SG belonging to the same stage.
- The influence of a PA on another SG belonging to the same stage – A decrease in the threshold of maximum red light time for a pedestrian crossing (PedMaxRedg) is expected to have a positive effect on the accumulating queues of SG1 during the red light interval, as SG1 will benefit from the shorter red duration allocated to SGg.
- The influence of a PA associated with SGj on a conflicting SGi – An increase in the threshold of the cumulative green duration required for SG5 as compensation for truncating its green duration due to the arrival of a PT vehicle (ReqCumDuration2) is expected to have a negative effect on the queues accumulating at SG1, as these SGs are in conflict with one another, and an increase in the green allocated to SG5 will probably be at the expense of the green allocated to SG1.

The above examples clarify the need to formalize the mutual relationships between the various stages and SGs.

4. Formulation of sets of SGs and the relationships between them

Signal Group Sets (SGS) are defined in order to formalize the dependencies between the various SGs. The SGSs are defined by the ability of different SGs to obtain the right-of-way simultaneously, given the stage composition. Notice that SGSs is used as the plural form of SGS. The rules by which SGSs are built are:

- All SGs are divided into sets based on the stage composition.
- Each SG belongs to a single SGS.
- SG_r and SG_h belong to the same Signal Group Set (SGS) if, and only if, SG_r appears in every stage in which SG_h appears.
- If SG_r belongs to SGS_g then all the stages in which SG_r appears also belong to SGS_g.
- Each stage belongs to at least one SGS.

Figure 2 depicts examples of various SGSs.

After all SGSs are built, the relationships between them can be determined according to the following rules:

- SGS_g CONTAINS SGS_k if all the stages that belong to SGS_k also belong to SGS_g.
- If SGS_g CONTAINS SGS_k then SGS_k is a SUBSET of SGS_g.
- SGS_g and SGS_k are DISJOINT if none of the stages that belong to SGS_k also belong to SGS_g, and none of the stages that belong to SGS_g also belong to SGS_k.

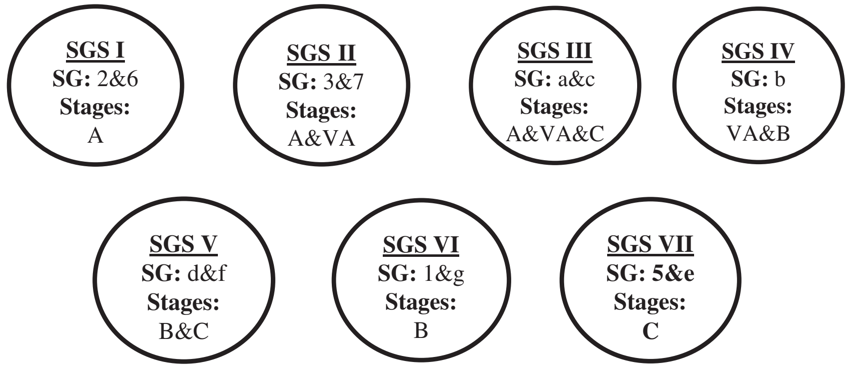

Figure 2 The SGS derived from the stages presented in Figure 1

The relationships between SGs are inherited from the relationships between the SGS they belong to. Based on this definition process the following rules hold (as demonstrated in Table2):

IF SG_r belongs to SGS_g
AND SG_h belongs to SGS_k
AND SGS_g and SGS_k are **DISJOINT**
THEN SG_h and SG_r will never get the right-of-way simultaneously

IF SG_r belongs to SGS_g
AND SG_h belongs to SGS_k
AND SGS_g is a **SUBSET** of SGS_k
THEN SG_h gets the right-of-way whenever SG_r gets the right-of-way

Table 2 Examples of relationships between the SGS

SGS ID	OPERATOR	SGS ID	OPERATOR	SGS ID
I	SUBSET	II, III	DISJOINT	IV, V, VI, VII
VII	SUBSET	V	DISJOINT	I, II, IV, VI

5. Construction of Integrated Components on the basis of the SGS and type of road users

Further refinement of the SGS is required in order to include considerations regarding the type of the road user. This demand is vital for the process owing to the difference in the nature of the PI and PA of each type of road user. Three types of Integrated Components were defined:

- PT Integrated Component – As PT vehicles tend to have "competing" relationships even when belonging to the same SGS, then each PT SG in the junction is defined as a separate Integrated Component.
- Vehicle Integrated Component – All cars SGs which belong to the same SGS constitute an Integrated Component.
- Pedestrian Integrated Component – All pedestrian SGs which belong to the same SGS constitute an Integrated Component.

Integrated Components provide an aggregation of the SG so that if the comparison process between signal programs would have been made with respect to any of the SGs constituting the Integrated Component, the results would have been identical. Therefore, Integrated Components simplifies the signal program comparison process without any loss of information as the "SG needed consideration" is actually a "needed consideration Integrated Component".

6. The Impact of the PAT on the Priority Given to SG

Once the dependencies between the stages and the SG are formalized, quantifying the improvement of the expected PI of the "SG needed consideration" as a function of the difference in the PAT between the currently active signal program and an alternative one is required. The number of factors influencing the priority given to a particular SG, and the interdependencies among them makes it impractical to quantify this impact. However, it is possible to predict the directivity of impact of some of the PATs on the various types of SGs. A positive directivity between a PA and a specific type of SG is defined when an increase in the PAT is NOT expected to harm the performance level of this SG.

An analysis of the directivity of the impact reveals three main phenomena:

- The directivity of the impact of PAs on the SG directly associated with them is relatively straight forward.
- The directivity of the impact of PAs on the SG they are not associated with is sometimes non-conclusive.
- The directivity of the impact of PAs both on the SG they are directly associated with and on the SG they are not associated with should sometimes be considered in conjunction with other PAs.

Table 3 demonstrates some examples for the directivity of relationships between specific PAs assigned to a particular SG and the PI of the same SG.

Table 3 Examples of the directivity of relationships between specific PAs assigned to an associated SG and the PI of the same SG

Planning Attribute	Type of SG it is associated with	Directivity of the impact of the PA on the SG it is associated with
$PTDirectionPriority_2$	PT	Positive
$PedMaxRed_f$	Pedestrian	Negative
$ReqCumDuration_1$	Private Vehicle	Positive

In some cases it is also relatively straight forward to determine the directivity of the impact of PAs on the SGs they are not directly associated with. Table 4 demonstrates some examples for the directivity of relationships between a specific PA assigned to a certain SG and the PI of a different SG.

Table 4 Examples of the directivity of relationships between specific PAs assigned to a particular SG and the PI of another SG

Planning Attribute	Type and name of SG it is associated with	Type and name of influenced SG	The relationship between the two SGs	Directivity of the impact of the PA on the influenced SG
$PedMaxRed_g$	Pedestrian SG_g	PT SG_2	DISJOINT	Positive
$PedMaxRed_g$	Pedestrian SG_g	Pedestrian SG_f	SG_g is a SUBSET of SG_f	Negative

However, in some cases, the directivity of the impact of PAs on various SGs is non conclusive. The following example demonstrates such a case. PT SG2 belongs to stage A (see Figure 1). If the threshold of PA StageMaxGreenA is increased, and consequently the green duration of stage A increases, it is unclear if the performance level of SG2 will be improved. Such extension of the green light is beneficiary for SG2 only in cycles in which a PT vehicle from this direction is approaching within the extension of stage A. However, this extension might limit the ability to give priority to SG2 if the PT vehicle is detected later on in the cycle, as while prolonging stage A the conflicting SGs are waiting and the constraints associated with them might become binding.

Determining the directivity of the impact of a specific PA on a specific type of SG while avoiding other PAs might sometimes be misleading. The following example demonstrates this phenomenon. Assume the PT SG_2 is the "SG needed consideration". The threshold of $ReqCumDuration_1$ has a negative impact on SG_2. The threshold of $ReqCumDuration_5$ also has a negative impact on SG_2. If the threshold of $ReqCumDuration_1$ is higher in the alternative signal program compared to the one that is currently active, and the threshold of $ReqCumDuration_5$ is lower, then the cumulative impact of both PAs might seem inconclusive. However, the sum of $ReqCumDuration_5$ and $ReqCumDuration_1$ has a clear negative impact on SG_2.

Two main conclusions can be derived from the above examples:

- Only part of the impact of the PA Thresholds on the "SG needed consideration" can be predicted.
- A new element integrating the impact of the conjunction of several PAs on the "SG needed consideration" should be formulated as a basis for comparing between signal programs.

7. The Formulation of Integrated Attributes

Integrated Attributes are formulated in order to formalize the relationships between the various PAs and the relationships among the SGs with which they are associated. Each Integrated Attribute is associated with one type of Integrated Component. The calculation rules of different Integrated Attributes can take on different forms, according to the nature of the PA involved and the dependencies between the SGs. The directivity of the impact of each Integrated Attribute on the Integrated Component it is associated with is defined. This relationship holds for all SGs composing the Integrated Component. Some examples of calculation rules are demonstrated in Table 5.

Table 5 Examples of Integrated Attributes and their calculation rules

Integrated Component type with which the Integrated Attribute is associated	Integrated Attribute Name	Integrated Attribute's calculation rule	Directivity of the relationship with the PI associated IC
PT IC_p	ConfMaxRed	$MIN\{PedMax\,\mathrm{Re}\,d_f, VehMax\,\mathrm{Re}\,d_v\}$ $ForAll\ (f\ DISJOIT\ p)\ AND\ (v\ DISJOIT\ p)$	Positive
Vehicle $IC_v \in SGS_x$	StageMinGreen	$\sum_s \{StageMinGreen_s\}\quad ForAll\ (s \in SGS_x)$	Positive
PT IC_p	ConfCumDuration	$\sum_v \{Cum\,\mathrm{Re}\,qDuration_v\}\ ForAll\ (v\ DISJOINT\ p)$	Negative

The value of the Integrated Attributes associated with each Integrated Component is calculated for each of the signal programs. This calculation is done as part of the process of storing the signal program's PA in the Traffic Management System. Once a selection of an alternative signal program is required, the values of the Integrated Attributes the "SG needed consideration" of the current signal program are compared to those of an alternative one. If those values are in favour of the "SG needed consideration", then the alternative signal program is implemented.

8. Example

The following example demonstrates the implementation of the described methodology for selecting an alternative signal program. The example refers to a situation in which PT SG_2 is the "SG needed consideration", meaning that the program selection process aims to improve the level of priority given to SG_2. The Integrated Attributes associated with SG_2 are:

- *ConfMaxRed* – This Integrated Attribute is calculated on the basis of the minimum of PedMaxRedf, PedMaxRedg and VehMaxRed1, all conflicting with SG_2. This value represents the binding constraint on the priority given to SG_2 as a result of limiting the waiting times of the conflicting SG. Higher values of this attribute are in favor of the priority level implemented for SG_2, as this constraint is looser.
- *ConfCumDuration* - This Integrated Attribute is calculated on the basis of the sum of ReqCumDuration related with to SG_1 and SG_5, both conflicting with SG_2. This value represents the binding constraint on the priority given to SG_2 as a result of compensating the conflicting SG for truncating their green duration due to the arrival of a PT vehicle. Lower values of this attribute are in favor of the priority level implemented for SG_2, as this constraint is looser.
- *ConfStageMinGreen* - This Integrated Attribute is calculated on the basis of the sum of StageMinDuration of stages B and C, to which SG_2 does not belong. This value represents the binding constraint on the priority given to SG_2 as a result of mandatory green duration allocated to other SG through the stages to which they belong.

Lower values of this attribute represent higher flexibility in the allocation of the right-of-way to SG_2 and are therefore in favor of its priority level.

The values of these Integrated Attributes for each alternative signal program are compared to their values for the signal program currently implemented. In order to simplify the comparison, relative values are calculated, and transformation is applied on the basis of the directivity of the relationship between the Integrated Attribute and the priority level of SG_2. As a result, a positive relative value of an Integrated Attribute indicates that if this alternative signal program is selected, the priority level of SG_2 if not expected to deteriorates, and has a potential to increase. Figure 3 demonstrates the result of the comparison between 7 alternative signal programs (No. 2 to No. 8) and the one currently implemented. Signal programs No. 2 and No. 7 are clearly inferior, as the relative values of all Integrated Attribute is non positive. Signal programs No. 3 and No. 8 are non conclusive, as some of the Integrated Attribute are in favor of the level of priority assigned to SG_2, and some are opposing it. Signal programs No. 4, No. 5 and No. 6 hold potential to improve the priority level of SG_2.

The relative value of the Integrated Attribute ConfStageMinGreen in Signal program No. 5 is very small, therefore the potential of this program to improve the priority level of SG_2 might not be sufficient. Signal program No. 6 might result in a decrease of the level of priority achieved for SG_f and/or SG_g and/or SG_1. As the pedestrian SGs are usually considered as important as the PT SGs, it is often undesired to increase the level of priority of the PT on the expense on the pedestrians. Signal program No. 4 might result in a decrease of the level of priority achieved for SG_1 and/or SG_5. In this case, it seems like the most reasonable choice for reaching the goal of improving the level of priority of the PT.

A micro-simulation model was built for the junction. Figure 4 demonstrates the improvement achieved with regards to the level of priority of the PT SG in terms of the % occurrences in which PT vehicle stopped at the stop line. The improvement for SG_2, which was original the "SG under consideration" was more substantial than the one achieved for SG_6. Figure 5 demonstrates the phenomena of deterioration in the level of priority obtained for SG_1 and SG_5 in terms of average queue length. The fact that effect on SG_1 was more substantial from the effect on SG_5 indicates that the compensation for SG_1 was the binding constraint that harmed the level of priority of SG_2.

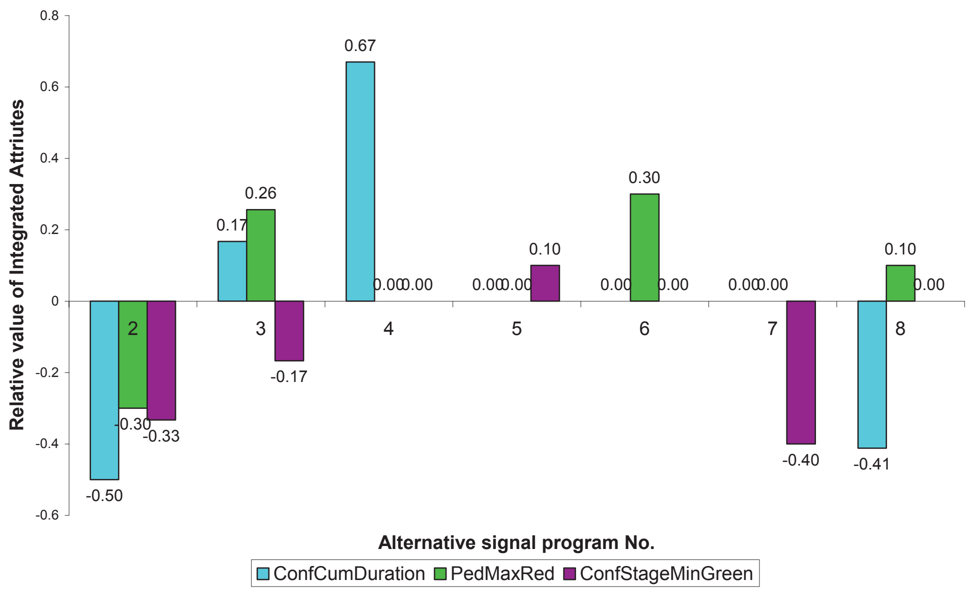

Figure 3 Comparing between alternative signal programs on the basis of the relative values of Integrated Components

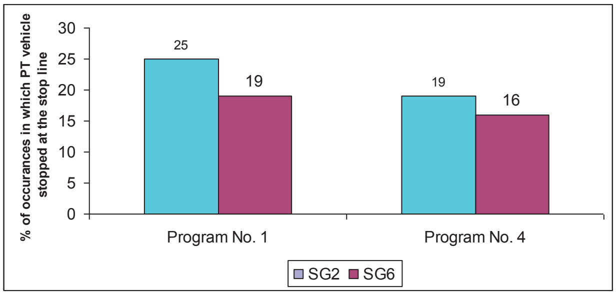

Figure 4 Occurrences in which PT vehicle stopped at the stop line in [%]

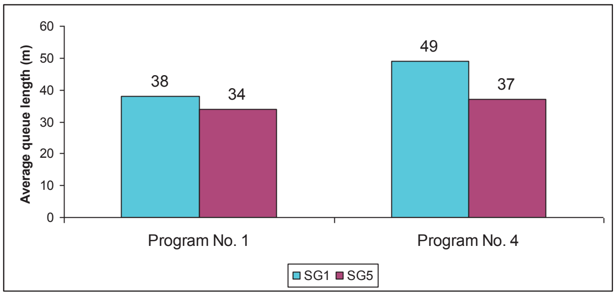

Figure 5 Average queue length at private vehicle SGs

9. Summary and Discussion

Distributes traffic management strategies must rely on a methodology for selecting an alternative signal program as an essential component for improving the quality of the city's traffic management. However, the large number of road users who are competing for the same resources complicates the selection process. The cars, PT and pedestrians all coming from different directions create a complex right of way allocation problem.

Signal programs with PT priority are complex in nature because of the many possible situations that the programs are intended to respond to. This "tailor-made" planning approach aims to obtain a high level of operational efficiency, while accommodating the individual characteristics of each junction. Yet, this approach also impedes development of a general methodology for comparing alternative signal-programs.

The methodology described in this article for selecting signal programs is based on a definition of standard PAs, which serve as a model "data dictionary". The threshold values assigned to the PAs differentiate between the various signal programs. The PAs and their thresholds constitute the basis for comparing signal programs in conjunction with the interdependencies linking the various SGs. The proposed methodology logically formalizes the directivity of the affect of aggregated PAs on the different types of road users.

Clearly, if the signal program library is sparse, then the outcome of the selection process will likely be that there is no possible remedy for the situation. However, an analysis of the content of the signal program library on the basis of the variety of PATs incorporated in the signal programs should be a complementary measure for the effective use of the proposed methodology.

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