# Intelligent Regulation System to Optimize the Service Performance of the Public Transport

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Abstract: The urban public transport systems deal with dynamic environments and evolve over time. Frequently, we dispose of a lot of correlated information that is not well exploited to improve the public transport quality service, especially in perturbation cases where a regulation system should be used in order to maintain the public transport scheduled time table. The quality service should be measured in terms of public transport key performance indicator (KPI) for the wider urban transport system and issues like regularity, punctuality and correspondence criteria. In fact, in the absence of a set of widely accepted performance measures and transferable methodologies, it is very difficult for public transport to objectively assess the effects of specific regulation system and to make use of lessons learned from other public transport systems. Unfortunately, most of the existing traffic regulation systems do not take into consideration part or most of the performance criteria when they propose a regulation maneuver. Therefore, the applicability of these models is restricted only to specific contexts. This paper sets the context of performance measurement in the field of public traffic management and presents the regulation support system of public transportation (RSSPT). The aim of this regulation support system is (i) to detect the traffic perturbation by distinguishing the non-equability of scheduled and the current time table of vehicle passage at the station (ii) and to find the regulation action by optimizing the performance of the service quality of the public transportation. We adopt a multi-agent approach to model the system. The validation of our model is done by simulating two scenarios on Abu Dhabi transport system and shows the efficiency of our system when we want to use many performance indicators to regulate a disturbance situation.

## 1 INTRODUCTION

The study of public transportation systems has changed significantly during recent years in modeling and simulation. In particular, the increasing use of the vehicle and the amplification of the public transport system, make traffic management more complex. This complexity is due to the difficulty of respecting the scheduled timetable of vehicle passage and the emergence of random phenomena that disturbs the network traffic of vehicle. Thus, to improve the quality service of public transport, we have to design and build a regulation support system that detects disturbances and regulates the traffic of public transport. The quality service should be measured in terms of public transport key performance indicators (KPIs).

Against this perspective, modeling and simulating such systems show real problems because there is no clear knowledge of the notion of KPIs and no common framework standard of quality in public transport.

Moreover, the current methods and simulation tools don't combine various KPI measures into a single performance value, potentially covering multiple dimensions or goal categories. Nowadays, several types of research have been carried out in the field of the regulation of public transport; (Newell

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and Potts, 1964) studied for the first time the management of bus disturbances. On the basis of a simplified model, the authors proved the instability of a line by the approximation of the buses without studying the coordination between the vehicles of different lines.

The regulation strategies are usually based on scheduling control and try to reduce the number of buses by adjusting bus schedules. This is based on an analysis of the cause of the disturbance (Moreira-Matias et al., 2012) (Verbich et al., 2016), as well as its impact on calendar-based traffic (Newell, 1977) (Zhao et al., 2006) (Feng and Figliozzi, 2011) investigated the main causes of the disturbance and recommended switching from static regulation based on a scheduled time table (TMT) to a dynamic regulation based on the frequency of buses of the same line. An important problem of this approach is to find a compromise between the regularity and the optimal frequency of the service.

The regulation strategies have become more interesting with the availability of real-time data provided, such as the Automatic Vehicle Locator (AVL) systems. Previous to this, most control methods used decision models that included only bus arrival times at stops. The works of regulation systems made in real-time differ in the techniques and data used. The regulations of this strategy can be divided into two categories: regulation at stations and inter-station regulation.

In the first category, the action is carried out at the station as waiting at a station to regulate only punctuality. Other criteria like regularity or taking account of the transfer time in changing the line for the passenger are neglected. For example, the research by (Gershenson and Pineda, 2009) is based on the static exploitation of time and minimum and maximum waiting time and (Newell, 1974) (Zolfaghari et al., 2004) (Bartholdi and Eisenstein, 2012) which are based on the dynamic exploitation of boarding times and the limitation of downtime (Dwell: time spent by the vehicle at station). Dynamic strategies are advantageous over static strategies. We found that dynamic strategies may require up to 40% less downtime in the schedule (Xuan et al., 2011), which increases the scheduled commercial speed of the trip based on AVL data in real-time.

However, in the second category, the control is done on the links between stations, like the control of the speed of bus (Pilachowski, 2009) (Daganzo and Pilachowski, 2011) (He, 2015), the overtaking of buses or priority mechanisms for traffic signals for public transit (Albright and Figliozzi, 2012) (Bhouri et al., 2011). These approaches do not take into account the real cause of the disturbance.

Based on the above analysis we can conclude that most of the existing traffic regulation systems do not take into consideration part or most of the performance criteria when they propose a regulation maneuver. Therefore, the applicability of these models is restricted only to specific contexts.

This paper sets the context of performance measurement in the field of public traffic management and presents the regulation support system of public transportation (RSSPT). The aim of this regulation support system is to detect the traffic perturbation by verifying the adequacy between the planned and the current performance measures and find the most appropriate regulation action by optimizing the performance of the service quality of the public transportation. We adopt a multi-agent approach to model the system.

This paper is organized as follows. Section 2 introduces and discusses the state of the art of performance measures. Section 3 describes our regulation process and the Multi-Agents System design. Section 4 defines the optimization problem. Section 5 validates our model by providing experimentation and result of two reels scenarios happened in Abu Dhabi transport system. In section 6 we conclude and give some perspectives.

# 2 STATE OF THE ART OF PERFORMANCE MEASURES

## 2.1 Literature Review

The performance of the public transport service is considered one of the main issues influencing the level of passengers' satisfaction. There is abundant literature on various aspects of key performance indicators. This review describes selected papers that focus on the models of passengers' waiting time at the station and the suggested regulation strategies for improving the performance service. Several publications offer quantitative measures of performance in regard to the public transportation service.

(Mark Trompet et al. 2011) evaluates the performance by the excess waiting time (EWT: Excess wait time). This indicator is defined as the difference between the actual waiting time (AWT) and the scheduled waiting time (SWT). Moreover, in (M. Napiah et al., 2015) and (Mark Trompet, 2010), this performance is defined by the average waiting time expected by passengers. This indicator calculates the perceived regularity that measures the average additional waiting time of passengers. In fact, the low EWT means that the performance of the service is fairly regular.

(Oded Cats et al., 2010) defines the performance by the deviations of the time intervals observed between the trips of the same line with respect to the regular frequency of the vehicles during a given period. This indicator is calculated as a standard deviation between the observed frequency and the programmed frequency. In addition, in other specific projects, to give more meaning to the evolution of the performance during abrupt changes in the transport traffic state, (M. Napiah et al., 2015), (Mark Trompet, 2010) and (Oded Cats et al., 2010) provide another complementary definition for performance. This performance is defined as a percentage of deviations that no longer deviate from a quantity in absolute minutes. It represents the coefficient of variation.

(Neila Bhouri et al., 2016) and (Gay H. et al., 1991) describe the Gini index as another indicator by regularity index. Economists and sociologists use the Gini ratio to measure the degree of income inequality within groups of people. By analogy in the field of public transport, the authors measure by this ration the degree of inequality of performance within a group of trips of the same line to quickly detect the abnormal phenomena that disturb the traffic. (S. Carosi a, et al., 2015) describes regularity as an index based on vehicle entries at stations. This indicator is specific to a line. Its formula is expressed as a percentage of unpunctual vehicle entries in relation to the total number of planned entries at the stations.

Other projects define the punctuality as another indicator that determines the performance. (Noorfakhriah Y. and Madzlan N., 2011) defines the punctuality as a comparison of the actual departure times and scheduled departure times at the station. In (Xumei Chen et al., 2009) the authors distinguish three types of punctuality measures: the Punctuality Index based on Routes (PIR), the Deviation Index based on Stops (DIS) and the Evenness Index based on Stops (EIS). The PIR is defined as the probability that a bus will arrive at the terminals during a given period. The DIS is the ability to maintain distances and minimize the typical waiting time of a passenger at the stop, while the EIS is the ability to determine the consistency and balance of the distance between the vehicles. However, in (Vaniyapurackal, 2015), the author considers the punctuality index for a race, $P = 0$ if the bus arrives on time in all the stations of its trip and $P = 1$ if the bus does not arrive on time at all stations. For convenience, the punctuality index, P can be converted to percent for as in $P (\%) = (1 - P) \times 100$ to define the proportion of the trip that was punctual.

In (Saberi, Meead, et al., 2013), three alternative performance measures are proposed: Earliness Index (EI), Width Index (WI), and Second-Order Stochastic Dominance Index (SSD). These indices are used in two forms to capture the characteristics of the unreliability of bus service: (i) the distribution of the time interval deviations of trips for frequent services, (ii) the distribution of delays for non-frequent services.

(Ceder, 2007) adds the transfer time as another indicator. This indicator covers the time spent when the passenger is waiting for the vehicle in changing the line at a connecting station. Other authors add the running time (time needed to change stop by walking in the transfer station) in the calculation of the transfer time.

(Zhenliang, 2013) details and explains the formula of the Headway Buffer Time. This indicator indicates the additional travel time required to allow passengers to arrive on time. It can be used to capture the additional unreliability caused by an incident.

The authors of (Kenneth et al., 2004) (TRT, 2017) and (Levinson, Herbert, 1983) examine another indicator called "Dwell" which is the bus downtime at stations including terminuses. This indicator refers to the time a vehicle, such as a bus or a train, goes to a stop without moving. In general, this time is spent onboarding or on embarking passengers, but it can also be used to wait for traffic to be restored (Vu The Tran et al., 2012) (Cats et al., 2011). For example when the regulator wants to coordinate between trips in the transfer station or to be equal as possible to the scheduled time table.

## 2.2 Discussion

According to the literature review presented above, there is no standard significance of the key performance indicators. The challenge in defining KPIs is to select the right ones that will give a sufficient accepting of overall performance on public transportation. To define KPIs, four strategic themes in the urban traffic management and the Intelligence Transportation System (traffic efficiency, traffic safety, pollution reduction, and social inclusion and land use) are presented in the white papers by the European Commission’s strategy on the future of transport (European Commission, 2011). Also, these indicators are classified according to objectives in (Theuns Henning et al, 2011). For benchmarking purposes, a number of KPIs must be chosen to cover the most critical aspects of public transport from a user's point of view. In the context of this study, we tackle only KPIs of traffic efficiency. The index of traffic efficiency represents three major KPIs: (i) punctuality for the respecting theoretical schedules at stations, (ii) the regularity for the respecting of the scheduled headway, and (iii) the correspondence for the respecting of the scheduled transfer time of the passengers in the transfer station. Consequently, we standardize all performance criteria presented in the literature into three main KPIs: punctuality, regularity, and correspondence. We describe the formulas of these performances in section 4.

Moreover, goals and objectives should be clear, concise, and achievable, in order to model the good performance formula for the regulation process. Indeed, the performance of public transport is an abstract term. In order to include performance considerations in a detailed engineering public transportation design and to evaluate the differences between existing and suggested service alternatives, it is necessary to describe it in mathematical terms. In fact, with a mathematical function, we can apply an optimization approach to the performance formula to reach the target. In addition, the main drawback of possible real-time performance regulation actions is the lack of prudent modeling and software that can activate automatically or semi-automatically these actions. Hence, build a regulation system to optimize the service performance based on key performance indicators in case of perturbation becomes an absolute necessity.

# 3 THE REGULATION SYSTEM OF PUBLIC TRANSPORT

## 3.1 Regulation Process

The below figure 1 describes the regulation process of our system.

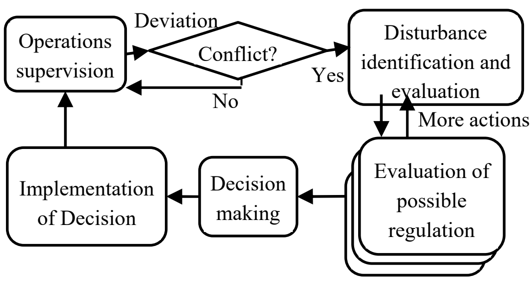


Figure 1: Regulation process in our RSSPT.

This process involves five steps:

- Operations supervision: In this step, races are monitored to see if everything is going as planned. The same thing happens for boarding passengers. the surveillance is done on route and at station after gartering information from (i) the Automatic vehicle location Module (AVLM) that is the GPS vehicle tracking system that continuously records and automatically transmits the geographic location and the speed of a vehicle, and (ii) detectors or loops to provide the properties of roads (length, speed max, density max, and current density) and station (passenger embarking and passenger boarding flow).
- Disturbance identification and evaluation: If an event occurs, for example, if an accident or works take place on a road, a rapid assessment is performed to determine if a regulation action is required. Otherwise, monitoring continues. The detection is based on the impact of the performance variability of the KPIs.
- Evaluation of possible regulation actions: the system selects the possible regulation actions from the existing list by using a classification method. This list is defined and updated by experts. An example of this list can be found in (Froloff et al., 1989).
- Decision making: After filtering out possible solutions, a decision must be made by using an optimization resolution then, the system chooses the adequate action.
- Implementation of Decision: After choosing the decision, it must be applied to the environment with the update of the operational plan.

## 3.2 Multi-agent Design

### 3.2.1 Multi Agents System for Regulation Support System Modeling

Multi-agent modeling can give a suitable solution to public transport network activities where autonomous entities, called agents, interact with each other in a distributed, open, heterogeneous and dynamic environment. We note that multi-agent systems are increasingly present in the field of traffic regulation. The following is a short description of the main characteristics for public transport regulation system:

- Distributed: the information is geographically dispersed over the network requires distributed agents.

- Dynamic: there is a daily change of information, for example, a vehicle can move forward, slow down, accelerate and communicate its passage with other agents like stations. As well, when the operator detects perturbation, a new state should be introduced in the traffic network and derive the bus to another route as regulation action.
- Open: the vehicles can enter or exit the traffic network.
- Heterogeneous: The actors of the system are varied with different natures: vehicle, station, regulator, etc.

These entities can reason, communicate via messages to solve conflicts and reach the best solution. These characteristics demonstrate that the use of the multi-agents system in regulation support system modeling has the advantages of introducing more flexible and efficient representation in the processes that it models.

### 3.2.2 Knowledge Components Modeling

The proposed system provides a baseline modeling to the system knowledge components independently of the performance model. In order to construct the system as a whole, we explore separately each agent with its both interactions “agent-agent” and “agent-environment”; this will also make it easier to define the system’s elements. The proposed multi-agent model is composed of the following agents: vehicle, link, station, criteria, and regulator. We describe the behavior and the interactions of each agent in the following figure (figure 2).

The agents are described as follows:

- Vehicle: Vehicle agent memorizes all its properties such as position, type (bus, metro, and tramway), speed, capacity, number of passengers, line, mission (school bus, special, and passenger), driver, and the properties of the current link. Then, these data are sent to the concerned agents: Station.

- Station: It represents a departure or arrival of one or more links. It must memorize all scheduled and real passage hours of vehicle. It calculates the delayed time for the arrived vehicle. Then it creates the necessaries KPI agents for each coming vehicle and sends to them the calculated delayed time and the waiting passenger number to calculate the key performance criteria value.

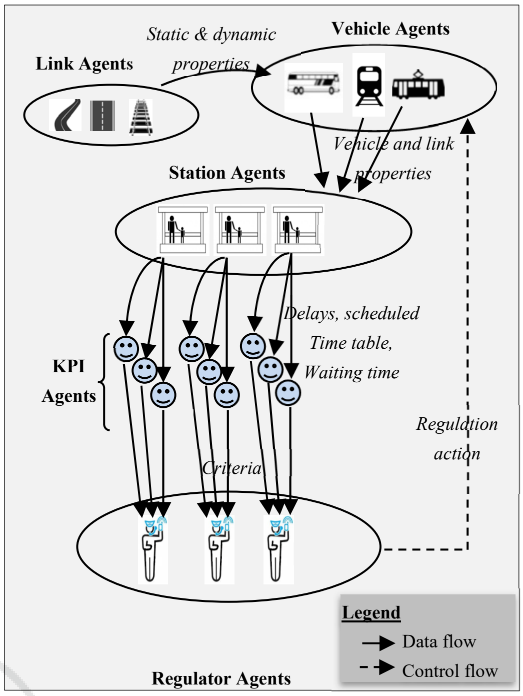


Figure 2: Multi-agent architecture of RSSPT.

- Link: It represents the connection between two consecutive stations. It should be related at least to one line. It memorizes two types of information: static properties (length, speed max, and density max) and dynamic properties (average of vehicle speeds and current density). These data are sent to the Station agent to estimate the needed time of the delayed vehicle to reach the station.

- KPI: It calculates the value of the Key Performance Indicator and sends it to the regulator agent.

- Regulator: Each "regulator" agent is responsible for a geographical area of the network. It receives the KPI values of each disturbed vehicle. Then it defines the perturbation cause (vehicle breakdown, exceed parking time, driver uneasiness, an accident on the road, etc.) and follows an optimization process to find the regulation action. The optimization process is explained in section 5.

A unique characteristic of this model is that the same agents are used to ensure the detection and the regulation process. This makes the model simpler and solves the problem of data duplication. The KPIs used in the regulation process can be adjusted according to the needs of the optimization problem.

# 4 OPTIMIZATION RESOLUTION

## 4.1 Linear Programming Optimization

This section introduces the notion of optimization, using operations research (OR) principles and methods. Optimization usually means finding the best solution to some problem from a set of alternatives respecting constraints. Formally, an optimization problem can be described by a set *U* of potential solutions, a set $L \subset U$ of feasible solutions, and an objective function $F: L \rightarrow IR$. In the regulation problem, we are looking for regulation maneuver $x^* \in L$ that minimizes the value of the objective function *F* overall feasible solutions. There is a list of feasible regulation actions that can be used to handle public transport traffic. This list should respect the constraints of the optimization problem.

In an existing problem, *F* is arbitrary and the question is whether the set of feasible solutions is nonempty. The optimization should take into account all KPIs and constraints fixed by experts of the traffic. We present a method that can be applied to regulate different traffic perturbations. This method is inspired by the work of (Hartani, 1995)

In the RSSPT, a linear program with *n* criteria (KPIs) and *m* constraints is a minimization problem defined on a vector $x=(x_1,...,x_n)$ of real-valued KPIs. The objective function is a linear function *F* of *x*, i.e.

$$F : IR^n \rightarrow IR \text{ with } F(x)=c*x, \quad (1)$$

Where c = ( c1,..., cn ) is called cost vector. It is relative to the importance of different KPIs. E.g. punctuality criteria for buses of low-frequency lines (large headways) is more important than regularity while regularity for buses of high-frequency lines (large headways) is more important than punctuality, against keeping good transfer time criteria is more interesting for lines presented transfer stations with a high passengers' crowding. The variables are constrained by *m* linear constraints of the form:

$$a_i*x \bowtie_i b_i, \text{ Where } \bowtie_i \in \{\leq, \geq, =\},\ a_i = (a_{i1},...,a_{in}) \in IR^n, \text{ and } b_i \in IR \text{ for } i \in 1..m. \quad (2)$$

Consequently, the vector of criteria values of the feasible solutions is given by:

$$L=\{x \in IR^n: \forall i \in 1..m \text{ and } j \in 1..n: x_j \geq 0 \wedge a_i*x \bowtie_i b_i\} \quad (3)$$

## 4.2 Optimization Formulas

### 4.2.1 Formulation of the Optimization Function

We establish the three KPIs related to traffic efficiency: punctuality, regularity, and correspondence for the delayed vehicle. They are based on passengers' waiting time at the station. These measures are applicable essentially when it is assumed that passengers go to the station without expectations of boarding a particular vehicle at a particular time (i. e., those passenger arrivals are Poisson distributed) We formulate the objective function as follows:

$$F = (W_{PUN} . V_{PUN} + W_{REG} . V_{REG} + W_{COR} . V_{COR}) \quad (4)$$

Here, the $W_{PUN}$, $W_{REG}$ and $W_{COR}$ represent the weight (cost) of the criteria in the calculation of the performance value. It is necessary that: $W_{PUN} + W_{REG} + W_{COR} = 1$. To calculate the weights, an experimental method is suggested capable of achieving a twofold objective: (i) to provide a methodology for constructing a measure of performance that can be adapted to any plan or transport program, and (ii) providing a methodology that can be transferred between projects. The technique chosen by the experts is the Delphi method (Linstone HA and Turrof M, 1975) .

*Punctuality criteria:* Punctuality is defined in (Noorfakhriah Y. and Madzlan N., 2011) as a comparison of actual departure times with expected departure times at the station. Its formula is:

$$V_{PUN} = \frac{S_3^2}{\bar{h}^2} \text{ with } S_3^2 = \frac{1}{n}\sum_{i=1}^{n}(t_i - t_t)^2 \quad (5)$$

- n: the number of vehicles of the same line arriving at the station in a defined period.
- $\bar{h}$: $\frac{1}{n-1}\sum_2^{n-1}(t_i - t_{i-1})$ the average headway for n vehicles.
- $t_i$: the actual arrival time of the i-th vehicle.
- $t_t$: the scheduled arrival time of the i-th vehicle.

*Regularity criteria*: It measures the differences in the time intervals observed between successive vehicles of the same line with respect to the scheduled headway. Its formula is:

$$V_{REG} = \frac{S_4^2}{\bar{h}^2} \text{ with } S_4^2 = \frac{1}{n-1}\sum_{i=2}^{n}(h_i - h_t)^2 \quad (6)$$

- *n*: the number of vehicles of the same line arriving at the station in a defined period.
- $h_i$ : $t_i - t_{i-1}$ (i=2,…I), the current headway of the i-th vehicle.
- $h_t$: the scheduled headway of the i-th vehicle.

*Correspondence criteria*: The correspondence criterion signifies the differences between the observed correspondence values with those of the scheduled correspondence. His formula is as follows:

$$V_{COR} = \frac{S_5^2}{\bar{c}^2} \quad with\ S_5^2 = \frac{1}{n}\sum_{i=1}^{n}(c_i - c_t)^2 \tag{7}$$

- $n$: the number of vehicles of the same line arriving at the station in a defined period.
- $c_i$ : the current correspondence of the i-th vehicle.
- $c_t$: the scheduled correspondence of the i-th vehicle.
- $\bar{c}$ : the average of the correspondence for the n vehicles.

The current correspondence value '$c_i$' (or the scheduled '$c_t$') of the i-th vehicle is the sum of the waiting time between the vehicle 'i' and all coming vehicles to the transfer station. It is equal to:

$$C_i = \sum_{j=1}^{n} f_j(\Delta_{ij}) \tag{8}$$

$f_j$ determines the importance factor of the vehicle 'j' which is in connection with the vehicle 'i'. This factor is calculated by experts according to the passengers waiting time of in the connection station for the vehicle in connection "j"[19]. It is necessary that:

$$\sum_{j\epsilon n}^{|n|} f_j = 1 \tag{9}$$

And $\Delta_{ij}$ represents the gap time in relation to the scheduled waiting time of *i*-th connecting vehicle. It is equal to:

$$\Delta_{ij} = t_i - t_j \tag{10}$$

$t_i$ is the current arrival time for the vehicle 'i', while $t_j$ is the current departure time for the vehicle in connection 'j'.

### 4.2.2 Formulation of the Constraints

The following constraints, based on (Ceder, 2007), are accompanied by the following data notations and assumptions.

- $H_{min_i}$: minimum headway in the i station.
- $H_{max_i}$: maximum headway in station i.
- $t_{ij}$ : $t_j - t_i$ time between the departure time $t_j$ of station j and the departure time $t_i$ of station i. i and j represent respectively the two successive stations of the link $l_{ij}$.
- $T_{ci}$: estimated total travel time i.
- $T_{ct}$: scheduled total travel time i.
- $N_i$: number of performed trips in station i.
- $V_{PUN_i}$: punctuality value in station i.
- $V_{PUN_{max}}$: permitted punctuality max value in station i.
- $V_{REG_i}$ : regularity value in station i.
- $V_{REG_{max}}$: permitted regularity max value in station i.

The problem is feasible under the following constraints:

$$I_{REG_i} \le I_{REG_{max}} \tag{11}$$

$$I_{PON_i} \le \min(I_{PON_{max}}, I_{REG_{max}}) \tag{12}$$

$$t_i \le N_i . H_{max_i} \tag{13}$$

$$t_i \ge (N_i - 1). H_{min_i} \tag{14}$$

$$T_{ci} \le T_{cmax} \text{ with } T_{cmax} = T_{ct} + (n * I_{REG_{max}}) \tag{15}$$

These constraints are mandatory in order to verify the following:

- not to exceed the maximum regularity value permissible limit (equation 11).
- the next trip does not catch up with the regulated trip (equation 12).
- the departure time at each station i does not exceed the maximum hour allowed during a regulation (equation 13).
- respect the minimum regularity between the vehicles of the same line (equation 14).
- not to exceed the maximum time allowed for a given trip (equation 15).

As a hypothesis, it is assumed that the first departure for each trip must take place in the interval $[0, I_{REG_{max}}]$ in order to have not a conjunction of two consecutive trips in the starting station.

## 4.3 Regulation Algorithm

The regulation process begins after the detection of perturbation. In the following algorithm, pre-conditions are defined which correspond to the optimization constraints:

Algorithm 1: Regulation.

```
Iutput:
  - Actual status of traffic network,
    scheduled and real timetable of
    public transport.
Output:
  - Regulation action
begin
repeat
```

```
  - Station Agent receives the
    necessaries information from Vehicle
    and link Agents
  - Station Agent calculates the waiting
    time of each coming vehicle
  - Each KPI Agent receives the waiting
    time of its corresponding vehicle
  - Each KPI Agent calculates its
    criteria value
  - Each Regulator Agent receives all
    criteria value of the corresponding
    vehicle
  - Each Regulator Agent calculates the
    performance function "UF" of the
    corresponding vehicle
until "F" falls down in the critical
      area
  - The Regulator Agent fixes the type
    of vehicle with their properties
  - The Regulator Agent fixes the
    incident /*vehicle breakdown,
          congestion, driver malaise*/.
  - Optimization Module
   end
```

We describe the optimization module in the following algorithm:

Algorithm 2: Optimization module.

```
Iutput:
  - Vehicle with their properties and
    incident
Output:
  - Regulation action
begin
switch (Type of vehicle and Incident)
 case
  - The Regulator Agent checks its
    Knowledge Base /* familiar
    perturbation, expressed by Basic
    facts and Basic rules. */
      if (incident exists) then
       ▪ The Regulator Agent extracts
         the list of feasible regulation
         actions // use decision tree
       ▪ The Regulator Agent calculates
         the objective function "F" of
         each regulation action
       ▪ The Regulator Agent chooses the
         optimal regulation maneuver.
      else // new situation
       ▪ the Regulator Agent produces a
         new regulation action using its
         expertise
       ▪ the Regulator Agent updates his
         knowledge base.
      end
 end
end
```

# 5 TESTING AND RESULT

## 5.1 Description

To validate the regulation strategy of our system, we tested our model on a real traffic network of Abu Dhabi. The resolution is expressed by an optimization problem with the objective function *F* using linear programming presented below. We used AnyLogic to simulate traffic scenarios and estimate measures needed to calculate The KPIs values. AnyLogic is a program for computer-aided transport planning, which determines the impacts of existing or planned supply that can encompass public transportation by simulating traffic scenarios (https://www.anylogic.com/). In addition, AnyLogic combines a dynamic simulation engine for animation and analytical tools for optimization. By combining these techniques, it provides models, which allow both to visualize the animation of the model and its logical analysis.

The scheduled data are collected from the department of transport of Abu Dhabi, as well as the map and the observed data are collected from the OpenStreetMap as OSM files to model the public transportation map data like lines, links, stations, and vehicles.

As described above, the regulation process will be activated only when *F* value falls down into a critical zone. The critical zone is defined by experts of public transport according to the treated zone of the network traffic. To prove the efficiency of our system in different situations, we tested results on two scenarios of perturbation.

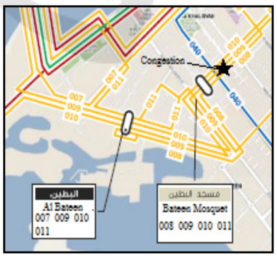


Figure 3: Traffic Network zone of scenario 1.

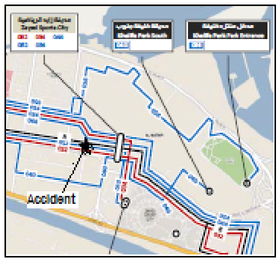


Figure 4: Traffic Network zone of scenario 2.

The first scenario presents perturbation detected in a station without correspondence (no transfer station) and the second one presents perturbation detected in a transfer station. We describe the two scenarios in the sections below:

## 5.2 Scenario 1

Scenario 1 presents traffic congestion in Al Falah Street due to a school entrance: peak hour (see figure 3). The station represents stop for three lines 008, 009 and 010 that have the same next station in the two directions. This means that there is no transfer time to calculate the correspondence KPI. Consequently, $W_{COR} = 0$. In addition, the distribution of criteria weight gives more importance to the punctuality criteria. It is due to the existence of many schools in this area and there is a large main headway (20 min). After calculating the objective function $F$ of the coming bus for each line, the regulator detects, at different times, perturbation for each line 008, 009 and 010 (see table 1).

The system starts its optimization phase by using the initial objective function value $F_{start}$ (see table 2). Each regulator for each coming bus wants to find the optimal regulation action with $F_{opt}$ value. For each bus, the list of the feasible regulation actions was extracted and simulated to let each regulator estimate the objective function of each feasible regulation action of each coming bus.

Table 1: Buses Information at Al Bateen Station.

| Line | Frequency | Theoretical time at Station | Detecting perturbation time | $\Delta_{Rt}$ | $W_{REG}$ | $W_{PUN}$ | $W_{COR}$ |
|---|---|---|---|---|---|---|---|
| 08 | 20 | 07h: 33 am | 07h: 38 am | 8 | 0.25 | 0.75 | 0 |
| 09 | 20 | 07h: 37 am | 07h: 42 am | 10 | 0.25 | 0.75 | 0 |
| 10 | 20 | 07h: 37 am | 07h: 42 am | 10 | 0.25 | 0.75 | 0 |

After optimization, the regulator chooses the derive maneuver for the three later buses of the three lines, and accelerates after departure from the station to reduce the delays and improve the travel time of the busses (see table 2).

Table 2: Result Values in Regulation Process of Scenario 1.

| Line | $V_r$ Detect. | $V_r$ Opt. | $V_p$ Detect. | $V_p$ Opt. | $V_c$ Detect. | $V_c$ Opt. | $F_d$ | $F_{before}$ | $F_{start}$ | $F_{opt}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 08 | 25 | 33 | 5 | 13 | 7 | 7 | 4.25 | 1.25 | 8.26 | 6.15 |
| 09 | 25 | 35 | 5 | 15 | 6.5 | 6.5 | 4.13 | 1.88 | 9.13 | 6.63 |
| 10 | 25 | 35 | 5 | 15 | 7.5 | 22.5 | 4.13 | 1.88 | 9.13 | 6.63 |

In this case, the disturbed bus of line 08 comes 5 minutes earlier with $F_{opt}$=6.15. The $F_{opt}$ return progressively to the target value $F_{before}$ (value corresponding to the theoretical value before perturbation) and the disturbance was fully regulated after 10 bus passages at 10h:27 min. We diagram the regulation process for the bus of line 008 in figure 5.

It presents the three passage times of the bus at Al Bateen station. This diagram shows that the passage time curve after the regulation is closer to the theoretical (scheduled) time passages curve (Bus 08 – before perturbation) than the passage time curve without the use of our regulation (Bus 08 – after perturbation). The same results are obtained for the other lines (009 and 010) of this scenario.

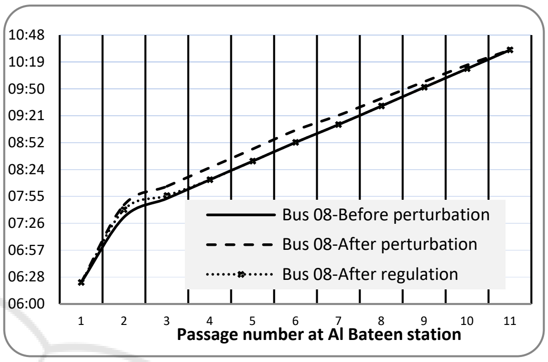


Figure 5: Time of passages for line 08 bus.

## 5.3 Scenario 2

Scenario 2 shows perturbation that was detected after a delay for lines 032 and 052 on Zayed Sports City station. This delay is due to an accident in the embassy area (see Figure 4). Buses information and distributed weights are given in table 3:

Table 3: Buses Information at Zayed Sport City.

| Line | Frequency | Theoretical time at Station | Detecting perturbation time | $\Delta_{Rt}$ | $W_r$ | $W_p$ | $W_c$ |
|---|---|---|---|---|---|---|---|
| 032 | 20 | 05h:42 pm | 05h:47 pm | 22 | 0.4 | 0.4 | 0.2 |
| 052 | 20 | 05h:38 pm | 05h:43 pm | 17 | 0.3 | 0.3 | 0.4 |

In this case, the two lines have at station four correspondences buses for lines 040, 044, 052 and 054. We cite in table 4 all factor values $f_i$ of correspondence buses. We note that when buses have the same direction in the transfer station, the correspondence factor value is zero (see table 4).

Table 4: Distribution of Factor Values.

| Line | Factor Values $f_i$ for lines | | | | | |
|---|---|---|---|---|---|---|
| | 032 | 034 | 040 | 044 | 052 | 054 |
| 032 | | 0.40 | 0.20 | 0.00 | 0.4 | 0.00 |
| 052 | 0.25 | 0.00 | 0.20 | 0.30 | | 0.25 |

After simulation of the different feasible regulation actions, the regulator of each coming bus executes its optimization phase and recommends that the better action is short-turning. Moreover, in order to transport passengers witing in Zayed station to the next one a Short-cut operation is recommended(see table 5 and 6).

Table 5: Decision after Optimization Phase.

| Line | $V_r$ Detect. | Vr Opt. | $V_p$ Detect. | $V_p$ Opt. | $V_c$ Detect. | $V_c$ Opt. | $F_d$ | $F_{before}$ | $F_{start}$ | $F_{opt}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 032 | 25 | 39 | 5 | 24 | 13 | 23 | 4.61 | 2.61 | 17.77 | 14.21 |
| 052 | 25 | 31 | 5 | 11 | 16.3 | 22.5 | 8.03 | 2.52 | 17.13 | 12.23 |

Table 6: Result Values in Regulation Process - Scenario 2.

| Line | U-turn at station | Save |
|---|---|---|
| 032 | 06h: 03 pm | 6 mn |
| 052 | 06h: 00 pm | 11 mn |

The diagram of figure 6 proves the efficiency of our system. The after regulation curve becomes closer to the before perturbation one (scheduled time passages).

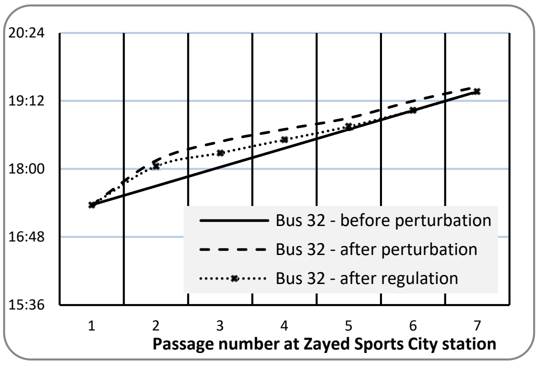


Figure 6: Time of passages for bus of line 32.

The results of the two scenarios show that $F_{opt}$, on which the decision is based improves the service performance of the passenger by minimizing the travel time of disturbed busses.

# 6 CONCLUSION AND PERSPECTIVES

This paper shows that the assessment of the quality of the solution produced by traffic regulation systems should be based on public transport key performance indicators.

The first contribution of this paper has been to provide an overview of the key performance indicators measurement and how to compute these KPIs to regulate perturbation. The second contribution consists in introducing our Support System of Public Transport (RSSPT). This system ensures two phases of regulation: detection of perturbation and optimization resolution to regulate the disturbance. To detect perturbation, the system distinguishes the degradation of the passenger quality service in terms of waiting time at the station for the coming busses. The optimization resolution is based on the performance measures that describe the Key Performance Indicators (KPIs) of the public transportation traffic. Our system is based on a multi-agent approach. It relies on the principle of coordination between different autonomous agents in a dynamic, open and complex environment.

To validate our model, we conducted tests by simulating two perturbation scenarios in a real traffic network. The obtained results show an improvement of the performance of the passenger quality service in perturbation cases.

In perspective, to minimize the development effort in the optimization phase and avoid the knowledge bottleneck of network traffic, we have to improve the system behavior by adding a learning module that would be used in case of new situations like unfamiliar perturbations, new traffic parameter, etc. Therefore, the regulator agent has to use the outcomes and update its knowledge base to deal with future situations.

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