# Paraconsistent Logic Applied Public Transportation System

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*Abstract:* - Intelligent Transportation Systems make use of communication and information technology with the objective of improving the performance of public transport, reducing time and thus saving resources. Sensors enabled the development of new computational solutions, as well as different algorithms have been studied and applied in this area. A literature review process has also proven to be an appropriate tool to manage and organize the growing number of article and periodical databases, allowing the identification of relevant contributions.
A total of 170 articles were selected and categorized in the study of the algorithms applied in the Public Transport System with the Internet of Things. It is presented the Para-Analyzer algorithm, based on the Paraconsistent Logic, which provides the analysis of an uncertain and contradictory environment facilitating decision making. Finally, it is proposed an application of the Para-Analyzer algorithm in public transport using sensors to detect obstacles.

*Key-Words:* - Paraconsistent Logic, Public Transportation Systems, Intelligent Transportation Systems, IoT, Sensing Systems,

## 1 Introduction

Public Transportation Systems (PTS) play an important role in modern societies, there are an essential and dynamic part of our lifestyle and space-economy [1]. However, urban expansion in the last 70 years [2] changed the pattern of mobility in cities motivated by socioeconomic growth and driven by the automobile industry, there was an increase in the demand for private transportation, due to the lack of investment in public transportation [3] [4] [5] in developing countries. Therefore, congestion increased, reaching up to 90 hours per 240 days per person on weekdays in big metropolises. The cost of traffic congestion is an average of £1.168 per driver in the UK [6] [7].

On the other hand, a developed country such as Japan has a long history in improving public transportation and monitoring systems [8] promoting cooperation of government with industrial and academic sectors, resulting in better services for all stakeholders, with efficient transportation for users, maximizing the financial profits of the industry.

Nowadays the most critical challenges of the PTS include creating a sustainable system, saving fuel and resources, providing economic opportunities and reducing the environmental impacts [9]. Therefore, Intelligent Transportation Systems (ITS) are expected to enable improvements in the quality and efficiency of PTS with the monitoring and management of transport infrastructure, transforming the PTS into the new mobility standard. Technological advances, along with cost reduction, have enabled the development of applications that capture data from physical devices (sensors, controllers, actuators etc.) by sending web services, which provide information to different stakeholders such as public organizations, transport companies and users of the PTS.

Public transport requires more control and, consequently, more data and information on the services so that it can have a good systemic performance. Data collection is carried out using the Internet of Things (IoT) and context-aware computing, then communication devices send data to the Advanced Traffic Management System (ATMS) [10].

This work aims to identify the algorithms applied in the monitoring system within the bus in the PTS, allowing us to verify their evolution, through the compilation of recent algorithms, providing support for future studies in this field, as well as proposing the application of paraconsistent logic in this area.

## 2 Intelligent Transport System

Intelligent Transport System (ITS) is a road monitoring and control system used to solve transport-related problems such as traffic accidents, traffic congestion, environmental measures, etc., which receive and transmit information between people, roads and vehicles, constantly using state-of-the-art technologies for communication and control of information such as transportation monitoring systems and fee payment mechanisms as illustrated in Figure 1. Different technologies are used to improve the convenience and performance of the public transport service, such as satellite communication systems, Global Position System (GPS), or radio frequency cellular phones, vehicle embedded systems, Advanced Traffic Management System with web services, web servers, cloud computing, and the most recent approach, fog computing approach.

Monitoring System in Public Transportation is a set of systems that exchange information with each other. The purpose of it is to maximize the safety, reliability, and efficiency of all modes of the transportation system, improve operational performance, reducing long-term costs and saving time [11], providing information to users, as highlighted in red in Fig. 1. Furthermore, the main purpose is to allow the better management of their vehicles. To achieve this goal is necessary a collection of resources as systems, vehicles, infrastructure, and devices. Systems collect data about events on the route, weather conditions, traffic conditions, about users and onboard sensors and systems.

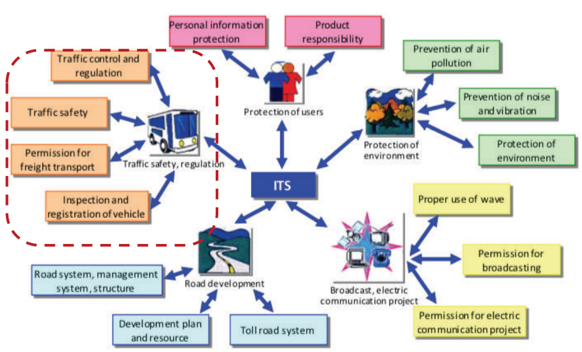


*Fig. 1 - Intelligent Transport Systems [2]*

In addition, there is an information processing system that processes the data provided by the infrastructure, defines and prioritizes the information that needs to be provided to the information infrastructure, and processes the content of the information to be provided. Moreover, the information provision systems provide information for different entities as commuter, road users, and control center [2].

### 2.1 First Systems

The first route guidance systems emerged in the 1960s in Europe, the U.S. and Japan, which improved in the following decade with the goal of establishing digital communication between devices and vehicles. In this same period the U.S. Department of Transportation developed an automatic bus service monitoring [12]

In the 1980s, Japan started to develop a set of traffic control systems, and in the 1990s two of them were unified, resulting in a functional system in 1996. These systems were called Intelligent Transport System. (Koide, 2015). In this same period, Canada initiated the use of a location system with communication by message exchange using satellite [13]. Europe and U.S. also implemented and employed various systems in this decade.

ITS became indispensable in the following decades, with the proliferation of systems, sensors, controllers to integrate with cellular telephony, GSM and GPS, IoT and a distributed system sharing sensor data from vehicles to vehicles or even the vehicle sending and receiving infrastructure in order to reduce accidents [14].

## 3 Materials and Methods

A study was conducted to identify the systems and use of bus monitoring systems (BMS) in PTS with the main focus on algorithms. The search was carried out in two phases and the first one consisted of two steps (see

Fig. 2 for illustration) described below: preliminary survey – journals and scientific papers were searched to identify studies about transportation in the area of computer science and engineering and data crossing of papers about the main theme.

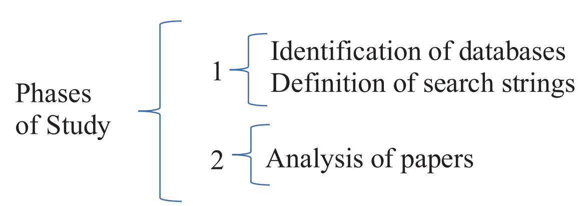


*Fig. 2 - Structuring the study*

All searches were performed electronically, as shown in Table 1. This study has not defined a time limit for the searches, since ITS and bus monitoring systems is a field that has been renewed with IoT.

*Table 1* - Electronic databases

| |
|---|
| ACM |
| IEEE |
| International Journal of Transportation Science and Technology Journal (IJT) |
| Transportation Research Part C: Emerging Technologies Journal (TRC) |

The search strings were defined so that only relevant studies were included in the search, as illustrated in Table 2. The term ITS was not used in the search because it is a broad definition, possibly not used as a keyword, title or abstract.

*Table 2- Strings used to search databases*

| | |
|---|---|
| ((“BUS ROUTE MONITOR”) OR | (BRM) |
| (“BUS ROUTE TRACK”) OR | (BRT) |
| (“BUS” AND “IOT” AND “ALGORITHM”) ) AND | (BIA) |
| (“PUBLIC TRANSPORTATION SYSTEM”) | (PTS) |

The second phase consisted of verifying that the titles and abstracts of the articles were in fact related to PTS and BMS, discarding them if they did not meet this criterion. Afterwards, the full text analysis was performed to analyze the algorithms and classify them.

# 4 Results and discussion

The searches were carried out electronically from March to April 2018, resulting in 170 articles. Although some articles met the search criteria, many were discarded because they were solutions without the use of internal devices in the vehicle. Others were discarded because they presented only initial prototypes or because they presented works on school transport.

Systems were developed and are being developed to meet the need for new applications and data processing with IoT.

Due to the different types of solutions and equipment used within the vehicle and given the heterogeneous nature of the information that needs to be combined, different algorithms are used in data processing. These techniques were absorbed from other areas, including artificial intelligence, pattern recognition, statistical estimation and others. ITS benefits from existing literature ranging from a simple arithmetic mean to more complex approaches such as machine learning.

All the following solutions use some internal equipment in the vehicle, from a simple GPS or just a cell phone with SMS, to equipment developed specifically to be used inside a bus, with sensors that collect data on temperature; location with GPS or even exchanging data with sensors at specific points; control of payments among others [21].

The algorithms can be divided into practical applications, used inside the vehicle for internal control and for external communication, and those that are used in simulations. This study will not differentiate between these two modes of use of them.

The algorithms are classified into 4 types: Statistical approach, Probabilistic approach, Artificial Intelligence approach and others. Older studies used simpler solutions, such as arithmetic or weighted averages, using external processing to the vehicle with SMS envoy or even from the geolocation captured with the GPS. These solutions were implemented because they are inexpensive. Priority queue was used to warn the driver about the presence of passengers with mobility problems. ticket counter is used to count the total number of passengers using the transport system.

Statistical approaches: weighted combination, multi-epoch trajectory determination is based on multi-epoch observations, makes use of the past observations for current equation solution. Combinatorial Optimization Matching rules of Driver-Bus-Route. Algorithm of proximity with simple mobile media that uses the average of times spent by the last bus.

Probabilistic approach with Viterbi algorithm to find the sequence of hidden states, since a route may not be fully monitored due to lack of access to the service. Hidden Markov models is used to identifying vehicle trajectories from the sequences of noisy geospatial-temporal datasets or inaccurate. Stochastics approach was applied to improve results in route planning

Artificial intelligence: decision tree, genetic algorithms and neural networks. The evolutionary algorithm searches combinations of number of private/public transportation users, capacity of buses, and time interval between bus departures minimizing traffic density, travel time and fuel consumption simultaneously. Fuzzy logic was used to count the passengers that are inside the bus, transmitting the data to a service center can predict the demand for buses. Supervised Learning with Least Squares Support Vector Machine was applied to detect bus bunching with the predicted headway pattern.

# 5 Paraconsistent Logic Eτ

Paraconsistent Annotated Evidential Logic (logic Eτ) is a logic that can be used as the basis for inconsistent but non-trivial theories. A theory is called paraconsistent if its underlying logic is a paraconsistent logic. Newton C.A. da Costa (1929- ), the Brazilian logician, built paraconsistent propositional calculi Ci, $1 \leq i \leq \omega$, of paraconsistent first-order predicate calculi (with and without equality), of paraconsistent description calculi, and paraconsistent higher-order logics [15].

The atomic formulas of the logic Eτ are of the type $p(\mu, \lambda)$, where $(\mu, \lambda) \in [0, 1]2$ and $[0, 1]$ are the real unitary intervals (p denotes a propositional variable). $p(\mu, \lambda)$ can be intuitively read: "It is assumed that p's favorable evidence is $\mu$ and contrary evidence is $\lambda$." The Favorable Evidence Degree is a value between 0 and 1 that represents the favorable evidence in which the sentence is true. The Contrary Evidence Degree is a value between 0 and 1 that represents the contrary evidence in which the sentence is untrue. Through the Uncertainty degree: $G_{un}(\mu, \lambda) = \mu + \lambda - 1$ $(0 \leq \mu, \lambda \leq 1)$ and Certainty degree: $G_{ce}(\mu, \lambda) = \mu - \lambda$ $(0 \leq \mu, \lambda \leq 1)$ it is possible to represent the four extreme logic states.

Uncertainty and certainty degrees follow 12 regions of output: extreme states that are, False, True, Inconsistent and Paracomplete, and non-extreme states. All the states are represented in the lattice of the next figure: such lattice τ can be represented by the usual Cartesian system.

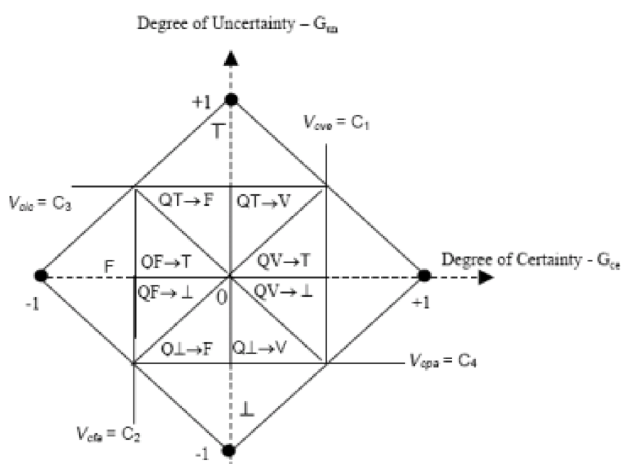


*Fig. 3 - Extreme and non-extreme states [15]*

## 5.1 Max and Min Operators

The operator Max indicates the operation of maximizing real numbers with the ordinary order. Given two values from different sources $(\mu1, \lambda1)$ and $(\mu2, \lambda2) \in \tau$. $(\mu1, \lambda1)$ OR $(\mu2, \lambda2) = (\text{Max}\{\mu1, \mu2\}, \text{Min}\{\lambda1, \lambda2\})$. The operator Min indicates the operation of minimization of real numbers with the ordinary order. Given two values from different sources $(\mu1, \lambda1)$ and $(\mu2, \lambda2) \in \tau$. $(\mu1, \lambda1)$ AND $(\mu2, \lambda2) = (\text{Min}\{\mu1, \mu2\}, \text{Max}\{\lambda1, \lambda2\})$.

The operators maximizing (OR) and minimization (AND) from Logic Eτ are applied for a group of experts for each one of the strategic topics. The rule of maximizing the intra-group favorable evidence is applied so that the connective (OR) is used in the favorable evidence and the connective (AND) in contrary evidence within each group, and the rule of minimizing favorable evidence between the groups is applied using the connective (AND) for favorable evidence and the connective (OR) for contrary evidence for the results obtained at both groups (between groups), clustered according.

# 6 Proposed PTS and Paraconsistent Logic

Sensors play a key role in connecting the physical world (presence, luminosity) with the digital world. Data from sensors allows for improved solutions in the Public Transportation Monitoring System, because a sensor is a set of electronic components responsible for capturing data from the environment, to send to software analysis and, finally, make a decision about this interaction.

But systems with different devices may conflict with one another for a variety of reasons, such as conflicting inputs in dynamic contexts, for example, one device may have more recent or more complete information than the others, and differences in device knowledge may generate conflicting knowledge. Inconsistency with inaccurate data, because the source does not send accurate data, and paracompleteness, which is a dual concept of inconsistency.

This work proposes the application of Paraconsistent Logic, specifically the Para-Analyzer, in a system able to handle data from sensors, manipulating data through the favorable and contrary evidences, degrees of certainty and uncertainty, plus control values. The purpose of this application is to increase internal security in the Transport Systems.

First, the proposition must be defined to be processed by the Para-analyzer. The origin of the data may be from different sensors, and should be at least from two different sources, as shown in Fig. 4

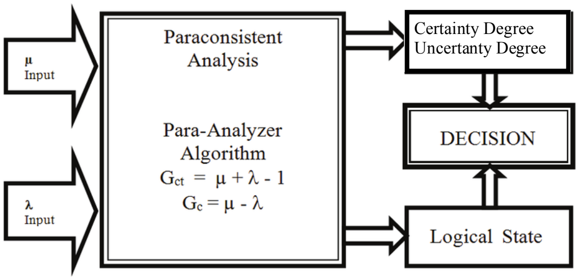


*Fig. 4 - Para_Analyzer [15]*

Different sources can be treated with the same principle, but the Para-analyzer works only with the values of μ for favorable evidence and λ for contrary evidence.

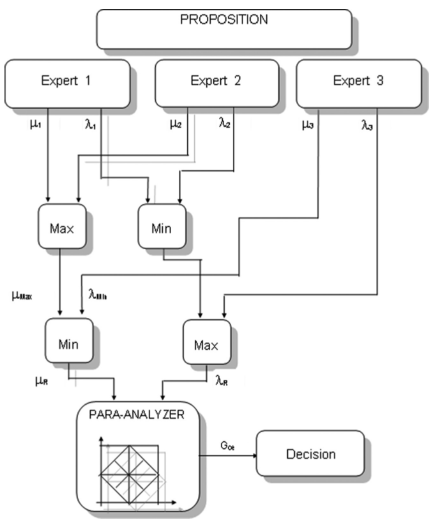


*Fig. 5 - Scheme of an expert system based on logic Et and para-analyzer algorithm [16]*

All relevant parameters (factors, characteristics, etc.) are considered in the analysis. A set of devices capable of sending data on such parameters expressed as favorable evidence and contrary evidence, in addition to external data, is defined.

These devices are combined together, which can be in two subgroups, using the operators Max and Min to analyze two inputs, resulting in unique value. The example of Figure 4 shows the analysis of the favorable evidence with Max operator of expert 1 and expert 2 in the first level and use of the Min operated in the Second level receiving favorable evidence. The same is done with the contrary evidence. Thus, the para-analyzer processes the values of μ and λ, presenting as degrees of certainty and uncertainty for decision-making.

## 7 Conclusion

This article shows at least in general terms the different algorithms used in PTS and IoT, presenting the Paraconsistent Logic, which is a formal and adequate tool to deal with inaccuracies, inconsistencies and paracompleteness.

A new IoT based public transport monitoring system was also proposed to collect external data, using Paraconsistent Logic, which offers new solutions for the treatment of paracompleteness and inconsistency, not only to monitor the vehicle in its route, but also to capture data from the outside, transforming them into information for internal control, improving comfort and safety of transportation.

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