A CYBERNETIC APPROACH FOR CHANGING VEHICULAR CIRCULATION FROM DIFFICULT TO SMART IN CITIES OF DEVELOPING COUNTRIES

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ABSTRACT

We describe the partial results of a research in systems engineering for a specific socio-technical situation. It addresses the problem of urban circulation in Latin American cities not so technologically advanced. The rating of their circulation performance is very low, when travel times are considered, which produces big ecological, health and economic impacts. The problem is serious and it is still growing. The city traffic system is complex because of the large number of participants and because of the intricacies of their interrelationships. The difficulty of framing this research is observed in that it touches on five known thematic axes: Governance, Economy, Health, Ecology and Technology. The central idea to communicate is that the solution to the problem must be systemic. No feasible solutions will be obtained if the implemented actions are of trial-and-error nature, only technical or only social reductionist approaches, or copied from solutions designed for cities of different locations. The proposal is to gather the main city stakeholders at the systemic academic approach and to guide them consensually to the improvement process with tested and validated effective actions. Some of the difficulties that have been detected so far concern: describing the unstructured problem; setting up the soft systemic model and finding the feasibility conditions for the solution. After looking at the literature on the subject, outstanding scientific advances are found in the topics of the ecological automobile, the autonomous vehicle or the smart city, with proposals based on electromechanical, communications, and computing fields. They are taken into account for the project, but their expectation for been operative does not make them affordable for this case. Nevertheless, many autonomous vehicle details could be useful under a systemic view: what makes it operational is the information exchange with its environment. The synergetic operation of traffic in a congested city requires a proper information usage. In several studied cases, the urban infrastructure does not inform the driver about the restrictions, the driver does not take advantage of information to execute his actions and the traffic regulation does not profit of information to provide corrective actions. Moreover, punitive measures are privileged over preventive ones. Solving the congestion questions of these cities would only be possible if improving actions are also committed to the physical infrastructure, the traffic regulations and the respectful driving subsystems. For this reason, organizational transformation is imperative. Within the project, coordination between soft and hard system models is analyzed, aiming to carry out simulations of identified noteworthy conflict situations. And feasibility will be particularly taken into account before implementation through the agreement of the administrative, technical and social parties, based on the research work conducted at the systemic academic guide. The paper seeks to present the Systems Sciences as a theoretical and practical interdisciplinary science that enable certain solutions of the problematic situation on traffic congestion.

Keywords: Vehicle technology; system performance; cybernetic approach; developing countries; interdisciplinary, consensual, synergetic, punitive, urban circulation.

THE CITY SYSTEM AND ITS CONFLICTIVE CIRCULATION

The network of streets, avenues and rapid ways constitutes the place for citizens to move between two activity points. The city is the space to live, to work and to cultivate body and spirit, as well as to move between the places where those activities are developed. Transport is then necessary, but only as a complement (Merlin, 1992).

As a subject that concerns the great majority of citizens, circulation along the roadways emerged as a natural activity that presented no difficulty. But as the number of users increased, a conflict appeared, when two or more users contended for the same place (such as in queuing theory). Thus, there is a need to assign a right of way. For cities holding thousands of users, the system shows emerging properties of this phenomenon, becoming complex. Hence it is necessary to evolve from an empirical, trial and error, or monodisciplinary vision to an interdisciplinary, technical and human, systems vision.

Nowadays, vehicle circulation becomes an extremely dynamic process, associated with the spatiotemporal behaviour of many particular systems. The traffic complexity is basically due to the nonlinear interactions between the processes of the travel decision, the possible routes in the network and the occurrences of traffic congestion. Formal structures have to be developed, such as the three-phase traffic theory (Kerner, 2009).

Vehicles exist worldwide, but they were conceived mainly in developed countries. So, a difference exist from giving satisfaction to a need than following a trend, even if a similar need could be inferred, as in the other countries. The history of the automobile has gone through well-known stages and now they are omnipresent. A noticeable trend in technology is in actual times oriented toward the autonomous cars, benefiting from advancements in robotics, computing and communications (Poole, 2014).

Its operating framework is cybernetics, where a set of rules should guide the vehicle depending on the variables of the environment. The automobile entity will not work properly if the urban circulation is not taken into account, due to the multiple interactions that occur within the system.

The concept of cybernetics is applied in its sense of interaction between a controlled system and a regulatory system, derived from the concept of control and communication between humans and machines due to Wiener (Durand, 1996). Afterwards, the second-order cybernetics concept, by von Foerster (Heylighen, 2001), came into view as the properties of self-organization, complexity or autonomy, with another potential to consider the relationship between system and observer.

Figure 1 depicts the basic actions, some simultaneous, that a vehicle should carry out in its path for a defined program: forward, backward and stop, keep direction, turn right or left. Without an environment, the work would be simple, as in a test platform. Terrain accidents and road topology adds new constraints. The existence of other user vehicles calls for priority rules. More, meteorological phenomena, mishaps, pedestrians and two-wheeled vehicles and exceptional situations, add complexity to the decision. For this, it is necessary that the control part, according to the law of variety of Ashby, foresees the correct answer before each possible situation.

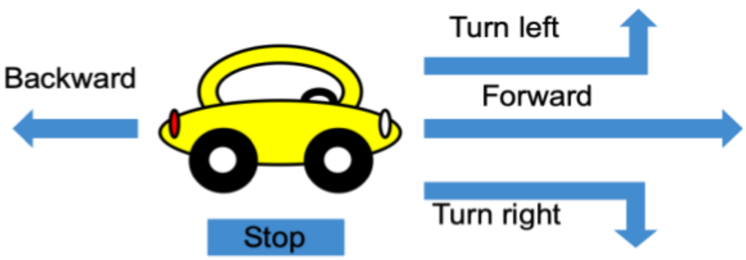

Figure 1. Elementary actions performed by a vehicle.

The processing information, which depends on the initial state of the vehicle and the desired state, as well as the nearby conditions, should result in the set of control signals for forward, turn, brake or reverse, in what appears to be a decision simple. However, the observed picture of reality with human drivers, such as moving despite a stop sign or having to brake for an obstacle when the signal is to circulate at 50 kph, are hardly compatible with the concept of system under cybernetic control.

IMPORTANT PROGRESS TOWARDS A CITY WITHOUT PROBLEMS

With the advent of robotics and automation technologies, automotive mechanics and energetic, internet of things and cloud telecommunication networks, energy savings, reliable sensors, advances in control theory, algorithms and artificial intelligence and efficient computer networks, a trend labelled as unavoidable for the future is that of autonomous vehicles, as one of the significant features of the Smart City (Van den Berg, 2016).

The most widespread development in road circulation performance improvement is referred to technology for the Intelligent Systems (European Commission, 2003) and for the Smart City (Crisostomi, 2016). Derived research work is found in disciplinary fields such as mechanics (Association Française, 2015), electrical (Ducamp, 2012), automation (Baruch, 2016) or computer science (Shladover, 2016). It is also interesting to highlight the visual communications engineering infrastructure supporting the design of the roadways (Gyéjacquot, 2015), including vertical and horizontal signals information standards (CERTU, 2006).

Communications technologies and algorithms make also part of the conditions for vehicular systems to access an intelligence level, giving place to research work in the intelligence fields (Picone, 2015). The tendency to autonomy explores incorporating in vehicles the capacities for communicating and adapting to its environment, as in multi-agent programming to share knowledge (Adam, 2012) (Ksontini,2015).

In terms of the complexity of these systems due to the diversity of the participants, for the realistic study on the subject of road performance, futuristic knowledge has been located in the logical structuring of the design aligned with its correct use (IEEE Global, 2016).

On the other hand, the inclusion of the human actor in transport systems has been widely observed in driver aids (Golias, 2002), the contribution from academia (Gil, 2016), and in human-like characteristics for the automated vehicles in issues as ethics (Deng, 2015), laws (Coca-Vila, 2017), liability (Iozzio, 2016), insurance (Ross, 2016), environmental attitudes, including derision or ignorance (Forward, 2006), as well as resilience face to many unforeseen situations for the driver (Enjalbert, 2011).

ATTEMPT TO LINK SOLUTIONS TO CITIES UNDER STUDY

The whole scenario for the smart city and its circulation considers enough elements from the complex world. Many of these advances are currently being made and others are on the way. The autonomous automobile is expected to be ready to operate by 2040, according to the projection in the countries in which the projects are originated (IEEE News, 2012).

It is noted in media and papers that the described innovations belong mainly to developed cities (Vijayenthiran, 2015) (Hsu, 2015).

However, a contradiction appears when the expected actions are not the same as in the original scenario. In less developed locations the atmosphere is not equally receptive to the new technology. One question to ask is if actual needs are the same. However, their circulation problems continue to increase. For example, in Mexico the pollution indexes have skyrocketed and several administrative actions to cope with it only make it worse.

An accepted congestion index has been proposed by Tomtom (2017), by means of the average travel time it takes a vehicle in a given city with respect to the travel time if no congestion exists. A dramatic 66 percent is accorded to Mexico City in their latest statistics, ranking in the first place. Concerning the security aspect, not only 15.9 deaths per 100,000 inhabitants in 2013 are reported by the Economic Commission for Latin America and the Caribbean (ECLAC, 2015), but the efforts to reduce this rate in the near future do not accomplish the required intensity. Bad indexes coming out from congestion often are connected with economic losses in millions of hour-man losses, but other issues are also important, such as noise, air and soil pollution and traffic accidents (Chías Becerril, 1997) (Steurer, 2016), as well as criminal behaviour and loss of wellbeing. It is difficult to accept that replacing the human driven vehicles by autonomous cars in this context will solve the problem.

A real life test has been undertaken to assess the information exchange between the city and the vehicle to point out this issue. And particularly this is done between the traffic signals and an automobile, supposing it has to interact as if it was autonomous.

First example, an automated vehicle arrives at a crossroad, its speed is low enough to react in security. The situation is shown in Figure 2(a). The responding programmed action for the vehicle must be a function of the detected input traffic signal. Searching in the data base, it would be impossible to emit an action corresponding to a green light, a stop signal and a yield signal, at the same time. Maybe the program indicates to stop, as the safest state, but an associated time loss seeking for an action or remote decision would contribute to lengthen the travel time and to increase congestion states.

(a) (b)

Figure 2. Difficult to follow information for an automated vehicle: (a) to stop or to go; (b) to go left or right.

Second example, continuous or dashed lines limiting road lanes must be of help to maintain autonomous vehicle's direction inside, while permitting or impeaching to change the lane. Figure 2(b) clearly shows that following the ground marking will guide it to an erroneous way or potentially a harmful accident. For sure, human drivers would solve this conflicting situation successfully, but the massive amount of information to learn and to infer by machine behaviour is unnecessary if a more logical infrastructure of signals is provided.

From these real life examples it is easy to see the hardly surmountable difficulties that implementing the autonomous vehicle in countries where the infrastructures and signalizations are not standardized. To support the analysis with formal tools, a series of experiments have been carried out. Three experiments are described, seeking an explanation to what is observed on the streets. Even if more tests have to be executed, these cases illustrate the aspect to outline.

An experiment with speed limit

In a recent case, facing the growing circulation problems, a new regulation was established for Mexico City, comprising speed reduction to improve security, fixing for example a limit to 20 kph near schools and hospitals surroundings. The argument was the relation between CO_2 emissions and traffic speed: the more the speed, the more the pollution. Nevertheless, after this regulation has been applied, pollution increased so much that a contingency has to be declared. Theory explains what happens, but the statement is true only for a segment of the function, as shown in the graph of Figure 3 (Anas, 2009) showing that the effect in CO_2 emissions as a function of traffic speed is more elaborated than a straight line, as for the majority of real life phenomena.

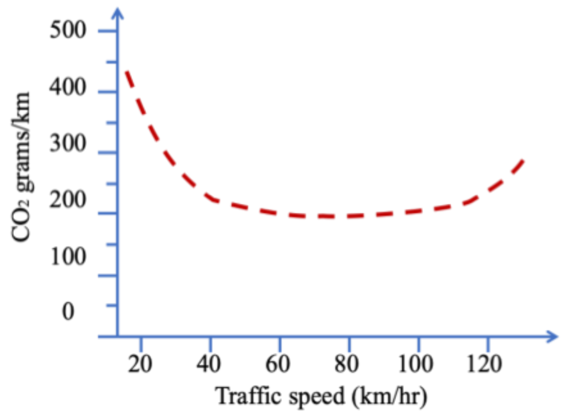

Figure 3. CO_2 emissions as a function of traffic speed.

From this example, it is clear that policies must be designed according to the state of the traffic. Typically, this regulation is sense full if congestions are limited, else congestions provoke the opposite effect.

An experiment on queuing

With queuing theory, it is feasible to visualize that a road modification, such as the lane reduction in an avenue, will have an impact on the congestion, with a numerical basis, as in the following example. Assume a three-lane road (servers) capable of handling 10 vehicles per minute, as well as a user demand (arrivals) of 9.5 vehicles per minute, under Markovian random behaviours. The problem (designated M/M/3) is solved with an analytical technique allowing to obtaining the expected service time in the system and the number of clients also in the system (Chase, 2004).

Table 1 shows the outcome of an experiment, with a system utilization of 0.3167, a time spent at the system (W) of 0.1039 minutes and a number of clients (L) of 0.9871, in expected value.

Table 1. Queuing experiment on the number of lanes

Servers	Arrivals	Utilization	W (min.)	L (units)
3	9.5	0.3167	0.1039	0.9871
2	9.5	0.4750	0.1291	1.2268
1	9.5	0.9500	2.0000	19.0000

In the same table, after running the sensitivity analysis for reductions to 2 lanes and finally a single lane, the waiting time for the last case is raised to 2 minutes, while the number of vehicles in the queue would reach 19. It is evident that this outcome is not achieved by applying only the intuitive assumption. And a completely new situation is reached. Again, conclusion is that situations are more complex than expected, which requires adopting a systemic view of the global congestion problem.

An experiment on changing lanes

Another characteristic in disordered traffic is observed when changing lanes. Lane divisions should guide in choosing the correct one depending on the next direction to take. Figure 4 compares the expected behaviour (left) and the observed behaviour (right) in some cities under study. One could seek for benefits in doing this, and for this reason a model attempting to evaluate the situation is built. The selected formalism is the Petri net (Jensen, 2009) and it models the two lane instance, with the choice of lane changing at two possible stages: the anticipated behaviour or the anytime change behaviour.

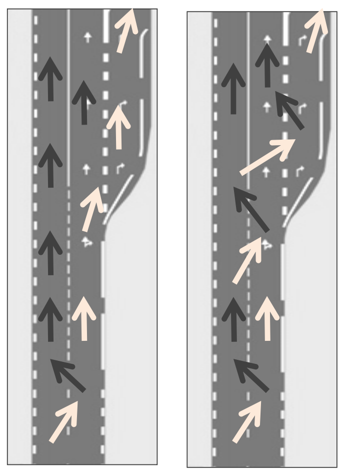

Figure 4. Two situations detected for lane changing.

A Petri net of this situation has been designed and is presented in Figure 5. As seen from here, firing t3 instead of t2 shows the case of anticipated change, while firing t5 could be authorized or not, depending on each of the instances as an alternative to t4 as a case of late decision.

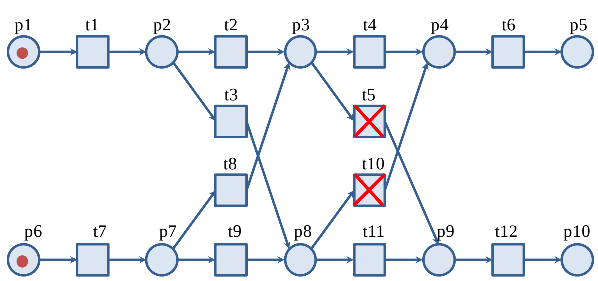

Figure 5. A Petri net represents the options for lane changing.

However, each lane change is time consuming and travel time is to be evaluated. For short, this would be the performance measure, without considering additional effects, as such of psychological category. Table 2 shows the total time compared for the two instances.

Table 2. Outcome of the experiment on changing lane in the two cases

Instance	Travel time	Decision delay	Total time
(a) Ordered	N	0	N
(b) Disordered	N	D, non negligible	N+D

There is a more interesting outcome for the experiment than the numerical results. A conclusion is obvious. Total travel time is always greater in the disordered case (b), because D is non negligible. Then, this will always be a bad decision, which adds seconds or minutes with each vehicle to congestion.

CHANGING TO THE SYSTEMIC VIEWPOINT TO ENSURE THE SOLUTIONS

The method conducting to the solutions by assuming strong assumptions (hard models) in the three analysed cases is wrong. Because of the complexity of the situation, usual theoretical models are far from representing the real world. It is noticeable that the human factors prevailing in developed countries have a dominating effect over the technical factors to attain the expected performance. Then the hypothesis of a technical behaviour does not work. There is a need to adopt a broader, global approach on the considered phenomenon. Systemic and cybernetic should be added to the isolated technical or the empirical analysis so far applied.

The first example previously introduced denotes an obvious misunderstanding of reality when establishing regulations; the second one illustrates an erroneous roadway design, while the third one exhibits the impact of bad driver behaviours. And this is a partial list.

From our point of view, the main urban circulation elements that are to be considered simultaneously are numerous, as illustrated in Figure 6.

Although a final integration must be done, as a start point, the proposal is to explore other research fields than the one focusing exclusively on the vehicle behaviour and control. Typically, the roadway, legal aspects, and the habits of the driving population are some of the other important inputs to the system. The control must be fostered by considering, the management, the regulator and the behavioural domains. The outputs to consider as the performance assessments are of ecological, economic and welfare nature, pointing out their relationship with travel times. And the integrated functioning must be reviewed by the corrective actions given by the cybernetic feedback.

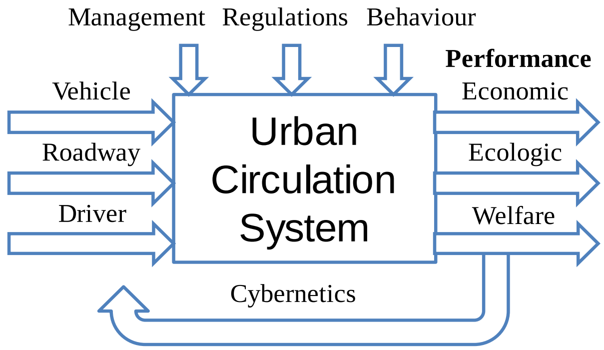

Figure 6. Main descriptive elements of the Urban Circulation System.

Future systemic research work must take into account integration of actions as:

- properly defined system regulations (mainly in according priorities) and avoiding improvisation;
- review of corrective actions;
- for autonomous cars to be a feasible solution, preparatory actions must be started, but the information exchange study is a good starting point;
- effective education actions should be promoted for vehicle drivers, as well as for all the other users of the system, from pedestrians to policemen.

The proposal is to gather the main city stakeholders at the systemic academic approach and to guide them consensually to the improvement process with assessed and validated effective actions.

CONCLUSIONS

In this paper, the limits of existing non-systemic approaches to traffic management have been discussed. The authors foster a more global, systemic approach where all the relevant aspects of traffic must be considered, regarding the infrastructure, the habits of the population, the signalization as well as legal aspects. A clear dichotomy appears between on the one side developed countries, ready to evolve towards traffic management systems of the future, based on the autonomous vehicle and on the other side developing countries where prerequisites must be met before trying to apply similar futuristic systems.

Typically, urban traffic systems in the studied cities have been detected as highly problematic because of their economic, ecologic and welfare issues. A bad circulation conflict understanding generates circulation jams. Every intended solution from individual disciplinary approaches or empirical ones show little impact on the performance. Ambiguous information received by the drivers tends to a loss of time for the reaction time. Hence, a fraction of a second, multiplied many thousands of times, is a cause of traffic congestion.

On the other hand, we have discussed the fact that arguing that the introduction of intelligent vehicles is going to reduce congestion, the panorama is not so convincing. Well programmed to follow instructions, it would not be a strong contribution to the global performance in places where there is a lack of social and technological synergy.

A better proposition is to give the smart attributes not only incorporated in vehicles, but also in the street infrastructure, in drivers' capability and in the traffic control cybernetic feedback.

A description of the complexity involved in conflict generation has been carried out, whose effects are the lengthening of travel times, increased polluting emissions, cost generation and diminishing welfare.

Finally, it is worth commenting that systemic research subjects open up possible future academic work, jointly aimed at improving the realities of vehicular circulation in underdeveloped countries.

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