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Abstract: The work presented in this paper concerns the control and the efficient assessment of transport systems of a city by studying the impact of climate change, energy supply or human behaviour on different modalities of mobility. Concepts from Human Machine Systems and from green, eco, sustainable, and smart cities, aggregated on resilient city concept, should be an inspiration to develop model for urban transport control systems. A state-of-the-art is proposed to discuss about these concepts and try to determine criteria which should be selected in such process. A first framework based on cooperation and learning concepts is then presented and still must be improved.

Keywords: Smart city, Urban transport control system, Design, modelling and analysis of Human Machine Systems, Resilience of Human Machine Systems

1. INTRODUCTION

Projected climate change for the upcoming decades represents a major challenge to be faced by humanity in the twenty-first century and climate changes expose cities to sea levels rising, changes in the frequency and intensity of storms, increased precipitation and ocean temperatures, among other negative impacts. Each of these factors poses risks to the human population. Today, more than half of the world's population (3.6 billion) lives in cities and by 2050, the urban population is expected to grow to 5.6-7.1 billion, or 64-69% of world population The increasing of people in cities implies the design of infrastructures and supports capable to prevent, recover or mitigate the occurrence or the consequence of economic, social or environmental obstacles, aggressions or perturbations. To do so, different concepts as green city, sustainable city, smart city, or resilient city are developed in order to face social, economic and environmental impact of such phenomena or other disorders. One of the main challenging aspects for city resilience is the facilitation of the mobility of people whatever the conditions of use. This paper proposes a way to design such a support dedicated to the smart control of urban transport system based on constraints such as human and consumption factors. The sections 2 and 3 of the paper present definitions and concepts about Human Machine Systems (HMS) resilience and city resilience respectively. Section 4 introduces the proposed architecture for a smart urban transport control system based on electrical energy and human driver constraints. An example illustrating the feasibility of the proposal is considered.

2. CONCEPTS ABOUT HUMAN MACHINE SYSTEMS RESILIENCE

Resilience relates to the ability of a system or a human to avoid any loss of auto-control or self-control despite the occurrence of whatever disturbances (Vanderhaegen (2017)). It is linked with different kinds of ability and criterion given in Table 1. On ecology or biology viewpoints, it relates to the survival of species when they undergo attacks or aggression (Holling (1973); Orwin and Wardle (2004); Watanabe et al. (2004); Pérez-España and Arreguin-Sánchez (2001)). On psychology or medicine domains, it depends on individual ability to recover from a physical or psychological shock or trauma (Engle et al. (1996); Goussé (2008)). From an engineering point of view, it is the ability to manage any unstable system face to any events by recovering it as quickly as possible (Hollnagel et al. (2006); Wreathall (2017)). Other engineering approaches consider that a resilient system can prevent, absorb, recover or mitigate any disorder (Vanderhaegen (1999); Ruault et al. (2012)), can successfully control unprecedented situations (Ouedraogo et al. (2013); Enjalbert and Vanderhaegen (2017)), or can successfully self-organize interconnected system components to react to any breakdown (Martinson (2017)). Finally, in a more general viewpoint, the resilience of isolated or interconnected systems relates to the acceptable control of their stability or instability by taking into account a single reference or several references of acceptability (Vanderhaegen (2012, 2016, 2017)). A sustainably stable system state can be an obstacle to react efficiently to unknown disturbances due to hypovigilance for instance. On the other hand, the regular occurrence of unstable states can train the system to control this event, and to go back to a previous stable state, to discover new stable states or new strategies to accept and manage sustained instability.

This requires resilience ability properties to achieve such goals. Criteria of stability aim at detecting an instantaneous or sustained state of system stability or instability, and the acceptability ones to determine if it is an acceptable or unacceptable state regarding factors as safety, performance, workload, attention or comfort for instance. Criteria about plasticity related to the ability to adapt to changes and transform the system structure to maintain the achievement of its functions entirely or partially. Plasticity gathers then criteria as:

- ability to perform these goals (i.e., performability),
- ability to recover from a perturbation (i.e., recovery),
- ability to discover and control dissonance when conflicts between contradictory viewpoints about acceptability occur.
- ability to cooperate (i.e., co-operability) in order to share a problem-solving due to a perturbation and find a joint optimal solution
- ability to learn (learnability) to handle human-systems knowledge.

These abilities and criteria about system resilience can be applied for city resilience. The next section focuses on the existing concepts around the city resilience achievement.

3. CONCEPTS ABOUT CITY RESILIENCE

Contributions on city resilience can take into account criteria about resilience engineering and related to green city, sustainable city, smart city or resilient city in Table 2. They concern different dimensions about infrastructures, services, environment, or health. Green cities or eco-cities focus on ecological dimensions related to environmental factors and their impacts on human life quality, health and pollution (Busch (2012)). Sustainable cities take mainly into account the sustainable social, environmental and economic impact of city services and infrastructures (Ibrahim et al. (2015); Batten and Edwards (2016). Smart cities include smart city components to guarantee mobility, services, security, safety and autonomy (Gaur et al. (2015); De Wijs et al. (2017)). They aim at designing connected city that use technologies of communication and information to produce data, to analyze them, and to improve city efficiency in terms of criteria as quality, performance, interaction between urban services, reduction of economic costs and of resource consumption, increasing of interaction between citizens with the city administrative services. Resilient cities usually gather the dimensions of the other concepts, but integrate additional ones related to city management or city governance for instance (Da Silva and Morera (2014); Sugahara and Bermont (2016); Zheng et al. (2018)). They are cities that have the ability to absorb, recover and prepare for future economic, environmental, social and institutional disorders.

When considering the resilience of cities, account should be taken on the increased climate risks as the suppression of ecosystems, triggered by urban growth. This is one of the main factors reducing the resilience of cities, making them more vulnerable to current and future problems, which may be accentuated by rising heat islands, air pollution and flooding. Thus, climate variations may exacerbate pressures already existing. The often already chaotic urban traffic tends to become even worse. Impacts on transport infrastructure are also expected due to sea level rise, temperature variations, precipitation and the occurrence of extreme weather events (including heavy rainfall), which may accelerate the deterioration of structures, increase the risk of interruptions traffic and accidents, with consequent impact on the economy of cities. These episodes are often accompanied by flooding, whose urban drainage system cannot contain, and which result in blockage from urban roads and property damage, among other disorders. All of these potential risks to the proper functioning of urban transport systems must be considered when designing a smart control system that aims to make the city more resilient. All the city resilience based concepts propose dimensions related to urban transportation systems and imply sustainability based criteria. The urban transport sustainability depends on factors such as transport system usability, ecological impact, economic impact, traffic flow, passenger comfort, system safety, passenger accessibility, or quality services.
In section 4, contributions to city resilience based on a framework including Human-Machine Systems concepts depicted in section 2 will be proposed.

4. A FRAMEWORK FOR SMART URBAN TRANSPORT CONTROLLING SYSTEMS FOR CITY RESILIENCE

The design of smart urban transport systems requires high level of adaptability by taking into account static and dynamic constraints such as road, rail, maritime or pedestrian infrastructures, mobility needs, or services availability. The proposed smart urban transport system takes into account ecological and economic criteria by assisting mobility to optimize energy consumption related to current human behaviours. Some obstacles to the design of smart real-time infrastructure control systems are for instance the lack of instrumentation on infrastructure, the lack of efficient automation and control supports, lack of autonomy on vital supplies, the lack of efficient shareable data model due to the design of closed systems, the lack of relevant reporting without adapted focus on trustworthiness, the lack of real-time data optimized for different classes of user or the inability to simulate, model and anticipate the effects of change.
Several models exist for such designing smart urban transport control systems by taking into account resilience criteria, as shown in Table 3. Mechanical engineering approaches simulate traffic flow by making analogies with fluid or gas-kinetic characteristics (Catalin et al. (2012); Utama et al. (2016); Tampère et al. (2002); Ngoduy (2012)). Bio-inspired models aim at modelling the behaviours of species as ants or birds to avoid collision and maintain movement (Kammoun et al. (2011); Jabbarpour et al. (2014); Li and Huang (2019); Antoniou et al. (2009)). Human-machine approaches are automation-supported human based approaches (La Delfa et al. (2016)) or human-supported automation based ones (Vanderhaegen (2019)).

Resilience criteria can be controlled alone or by interacting with other connected components of transport systems. Their smartability supposes that they have the requi-

Table 1. Abilities and criteria about resilience

Global resilient system abilities	Literature resilience criteria	References
Survival ability from an aggression or an attack	Ecology, Economy, Survivability, Acceptability, Stability	Holling (1973); Orwin and Wardle (2004); Watanabe et al. (2004); Pérez-España and Arreguin-Sánchez (2001)
Recovery ability of a personal psychological or physical shock, or a trauma	Recovery, Absorption	Engle et al. (1996); Goussé (2008)
Management ability of any unstable system state whatever events	Prevention, Recovery, Stability	Hollnagel et al. (2006); Wreathall (2017)
Prevention, recovery, containment and protection ability to any perturbations	Prevention, Recovery, Containment, Protection, Reactivity, Co-operability	Vanderhaegen (1999); Ruault et al. (2012)
Successful control ability of unprecedented situations	Prevention, Learnability, Performance	Ouedraogo et al. (2013); Enjalbert and Vanderhaegen (2017)
Flexibility ability between interconnected systems to react to any breakdown	Reactivity	Martinson (2017)
Acceptable control ability of system stability or instability	Acceptability, Stability, Sustainability, Plasticity	Vanderhaegen (2012, 2016, 2017)

red resources to solve a problem and manage alone resilience criteria such as decongestion, efficiency, comfort, safety, flexibility, ecology or economy. However, components from a given transport mode are sometimes insufficient to achieve resilience criteria and require the support of other components from other transport modes. To do so, interaction supports are required to perform activities as co-learning or cooperation (Vanderhaegen (2012)). Cooperation activities between systems imply three main prerequisites: the required knowledge to solve any problem, the availability of the required technical and human resources to apply this knowledge, and the possibility to act by these resources (Vanderhaegen (2017)). Learnability and co-operability are then the minimum requirements for smart urban transport system in term of city RC Resilience Criteria. The controlled of these criteria can be done locally or globally by a given TM Transport Mode or by interacting with OTM Other Transport Modes in Figure 1. Each component of a TM or OTM has its C Competency, its A Availability and its P Possibility to act regarding its prescriptions and its available interaction supports.

As these prerequisites are dynamic, future smart transport system models have to be designed by applying the human-systems inclusion concept (Vanderhaegen (2019)). This approach considers both the automation-supported human and human-supported automation processes to take advantage of both human and machine abilities to treat normal and abnormal events. Transport system component should be able to learn alone (*i.e.*, self-learning or auto-learning abilities), from the other or with the other connected components. When unknown, uncertain or unprecedented situations occur, behaviours as trial-and-error or wait-and-see can be implemented in the system learning process (Vanderhaegen and Caulier (2011)). To do so, different learning strategies can be applied in order to merge feedback data about controlled situations or to create new ones (Polet et al. (2012); Vanderhaegen and Zieba (2014); Enjalbert and Vanderhaegen (2017)). Such learning process is not devoid of possible dissonances when conflicts on knowledge exist between human and machine components of the system (Vanderhaegen (2014, 2016, 2017)). Therefore, the knowledge of each component has to be dynamic in order to recover any possible inconsistency or to take into account knowledge discover. The management of resilience criteria includes several classes of dynamic constraints as human factor based constraints, energy consumption constraints or climate effect based constraints. Smart urban transport system models have then to be able to support human decision to optimize energy consumption, to sustain mobility services despite strong climate effects, or to learn from human behaviours in two ways: 1) when the human drivers do not respect the initial advices, obliging the decision support tools to reassess new advices, and 2) when the support systems can improve their knowledge taking into account feedback from human behaviours.

5. CONCLUSION

In this paper, the authors try to develop a framework for modelling a smart urban control system. The presented model should be improved taking into account energy and human constraints, and also to be able to learn form unexpected whatever the conditions of use of city transports. City and Human Machine Systems resilience concepts seem promising to be used to develop such a new resilient city model regarding transport control systems. This work should to be led during PhD collaboration between french and Brazilian universities and is expected to be started as soon as possible to face acceleration of climate change events and growing of city population.

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Table 2. Concepts about resilient city

Concepts	Main associated dimensions	Associated transport dimensions	Resilient transport criteria	References
Green city, eco-city	CO2 emissions, energy, buildings, land use, transport, water and sanitation, waste management, air quality, environmental governance	Use of non-car transport, size of non-car transport, green transport promotion, congestion reduction policies	Usability, Ecology, Decongestion	Busch (2012)
Sustainable city	Population, housing, economy, utility and infrastructure, public facilities, environment, sociology and social impact, land use, tourism and heritage, transportation, management and finance	Control of safety, comfort, efficiency in terms of economy and power usage of transport system, minimize the environmental pollution of transport system	Safety, Comfort, Efficiency, Economy, Ecology	Ibrahim et al. (2015)
	People, planet, profit	Transport infrastructure, performance measurements, transport energy consumption, air pollution of transport	Performance, Ecology	Batten and Edwards (2016)
	Environmental, social, economic, livable, viable, equitable	Users of mass transit, average distance in km/per capita/year traveled for all means of transport combined, rate of death and injuries caused by traffic accidents per 1000 inhabitants	Performance, Ecology, Economy	Tanguay et al. (2010)
	Transport: environmental, economic, social	pollution, energy consumption, land consumption, cost for government, direct trip cost for user, indirect trip cost for user, safety, accessibility, variety	Target relevance, data availability and measurability, validity, sensitivity, transparency, independent, standardized	Haghshenas and Vaziri (2012); Haghshenas et al. (2015)
Smart city	Economy, people, governance, mobility, environment, living	Transport accessibility, sustainable, innovative and safe transport systems	Accessibility, Sustainability, Innovation, Safety	De Wijs et al. (2017)
	Environment, transports, industries, administration, office and residential building, security and energy	Smart traffic control, Intelligent drive, smart transport infrastructure	Smartability, Sustainability	Gaur et al. (2015); Girardi and Temporelli (2017)
	Transport	Noise and vibrations, Accidents, air pollution, soil and water pollution, impcats on land, Non-renewable resource use and waste handling, Greenhouse effect	Representation, Operation, Policy application	Joumard et al. (2011)
Resilient city	Economy, society, ecology, infrastructure	Traffic congestion, Urban transport risk management	Decongestion, Safety, Performance	Zheng et al. (2018)
	Governance, society, environment, economy	Sustainable urban transport development, adequate and reliable transport infrastructure	Sustainability, Reliability	Sugahara and Bermont (2016)
	Leadership & strategies, health & well-being, infrastructure & ecosystems, economy & society	Diverse and affordable transport network, effective transport operation and maintenance for quality and safety	Flexibility, Operationability, Maintainability, Quality, Safety	Da Silva and Morera (2014)

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Table 3. Examples of models for smart urban transport control system

Model	Principe	Resilience criteria	References
Mechanical engineering approaches	Fluid flow modeling	Decongestion, Efficiency	Catalin et al. (2012); Utama et al. (2016)
	Gaz-kinetic flow modeling	Decongestion, Safety	Tampère et al. (2002); Ngoduy (2012)
Bio-inspired approaches	Ant flow modelling	Decongestion, Safety, Flexibility	Kammoun et al. (2011); Jabbarpour et al. (2014); Li and Huang (2019)
	Bird flock modelling	Decongestion, Safety	Antoniou et al. (2009)
Human-machine approaches	Automation-supported human	Ecology, Economy, Safety, Comfort, Efficiency	La Delfa et al. (2016)
	Human-supported automation	Learnability, Safety, Comfort, Efficiency	Vanderhaegen (2019)

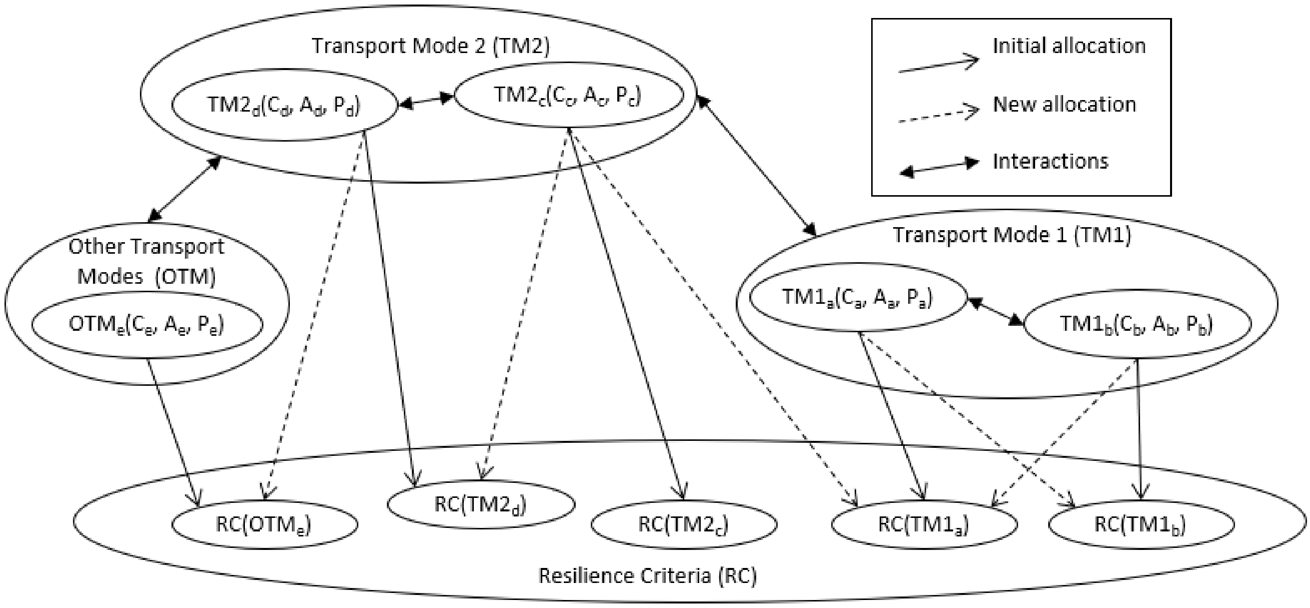

Fig. 1. Co-operability and learnability of smart urban transport systems

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