Assessment of Transportation System Resilience

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Abstract

A transportation system like tramway or train is a system in which the functions of the human and the machine are interrelated and necessary for the operation of the whole system according to Human-Machine System (HMS) definition. Both human and machines are sources of system reliability and causes of accident occurrences. Considering the human behaviour contribution to HMS resilience, resilience can only be diagnosed if the human actions improve the system performances and help to recover from instability. Therefore, system resilience is the ability for a HMS to ensure performances and system stability whatever the context, i.e. after the occurrence of regular, unexpected or unprecedented disturbances. The COR&GEST platform is a railway simulation platform developed in the LAMIH in Valenciennes which involves a miniature railway structure. In order to study the human behaviour during the train driving activities with or without any technical failure occurrences, an experimental protocol was built with several inexperienced human operators. In railway transportation systems, traffic safety is the main performance criterion to take into account. Based on this criterion, authors propose to evaluate an instantaneous resilience indicator in order to assess the "local resilience" of HMS. As others performance criteria must be aggregated to reflect the whole studied HMS performance, the "global resilience" of HMS will be defined.

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Introduction

Resilience is a relatively new field of research although the concept has been first use in physics for Charpy impact test in the early XX^{th}. Resilience was related to the ability of a material to recover from a shock or disturbance. The concept of resilience was next developed in the field of ecology and characterizes natural systems that tend to maintain their integrity when subject to disturbances (Ludwig et al., 1997). It has generated much interest in different communities and has been applied to sociology, economy, informatics (Chen et al., 2007; Luo and Yang, 2007) and:

- In psychology or psychiatry, the concept is linked to the invulnerability theory i.e. the positive capacity of people to cope with trauma and to bounce back.
- In biology, resilience is developed in the theory of viability i.e. ability for an organism to survive after disruption (Orwin and Wardle, 2004; Pérez-España and Sánchez, 2001).
- In industrial systems and automatic, resilience is related to the concept of robustness which is related to error-resistant and error-tolerant systems.
- In organisational and safety management, resilience is the capacity of a system to survive, adapt and grow face to unforeseen changes, even catastrophic incidents (Zieba et al., 2007).

The analysis of the positive contribution to the system control relates to the concept of resilience. Hollnagel and Woods define the concept of resilience engineering as the *“intrinsic ability of an organization (system) to keep or recover a stable state allowing it to continue operations after a major mishap or in presence of a continuous stress”* (Hollnagel and Woods, 2006). This approach, which incorporates all components of HMS (machines, human, and organization) and their interactions, can be adopted as a definition for further developments.

Indicators to assess resilience

Human related performance, machine related performance or organisation related performance can be used to assess the human machine system performance. They can focus on the measurement of the occurrence or the consequence of the events that may affect this system performance. When a measure of the event occurrence is combined with a measure of their consequences, the risk of system performance is assessed. Several criteria can then be evaluated considering the human behaviour contribution to HMS resilience.

Several performance shaping factors are factors that may affect human performance. They are taking into account the internal physical, psychological and physiological state of the human operators or are based on the requirements or the impact of external events (Swain and Guttmann, 1983, Polet et al., 2002). External factors relates to events such as the demands of the tasks to be achieved, the interaction with other operators or with the technical systems, etc. Internal human state concerns for example personal motivation, trust, self-confidence, individual experience, workload, stress, etc.

Sometimes a limited number of factors can be assessed because of the correlations or the dependencies with other factors. For instance, some factors that may affect human performance can also maintain an optimal level of performance. Therefore, human factors such as stress, workload or task demand can generate positive or negative stimuli when controlling a given system (Wiener et al., 1984; Schonpflug, 1985). A low or a high level of stress, workload or task demand may lead to a degradation of the human performance, vigilance or attention whereas a medium level may maintain an acceptable level of performance, vigilance or attention. This hypothetical view also considers temporal and functional factors integrating the control of particular situations such as emergent or complex ones. Each of these factors can be assessed qualitatively or quantitatively by subjective or objective approaches. For instance, the human mental workload may be subjectively assessed by TLX or SWAT methods that assess the workload by taking into account factors such as the temporal, the cognitive or the physical requirements of the human tasks (Pichon et al., 2010). Objective methods can also be useful to calculate on-line the human workload related to the tasks demands assessment. There are methods such as the assessment of the functional task demand to identify the complexity level of controlled current situation or of the temporal task demand to identify the saturation of the human resource (Vanderhaegen, 1999).

Other factors aim at assessing the erroneous behaviours and their consequences. For instance, there are interpreted in terms of the number of human errors per time unit or the number of human errors upon the total solicitations of the same task. Some human error assessment methods integrate several performances shaping factor that facilitate the occurrence of human errors (Vanderhaegen, 2001).

In transportation systems, several performance criteria are assessed:

- The traffic safety in terms of barriers non violation, i.e. signals and speed limits respect,
- The departure quality related to the respect of trains departure time from stations,
- The arrival quality related to the respect of trains arrival time at stations,
- The human workload linked to the number of interactions between drivers and technical driving support systems.

Due to the importance of safety for railway transportation systems, the evolution of system safety under disturbances must be selected as the main indicator for HMS resilience.

System resilience classification

Several measurements of resilience based on the evolution of performances considered as indicators have been proposed in literature. In order to present these measurements, an example of evolution of system safety under a disturbance is presented in Figure 1. The baseline in the figure presents the totally safe condition and the minimum acceptable threshold indicates an acceptable safety level for designers. E_{max} is the maximum amplitude of the effect of disturbance on safety and E_j is the amplitude of the effect of disturbance on safety at time T_j.

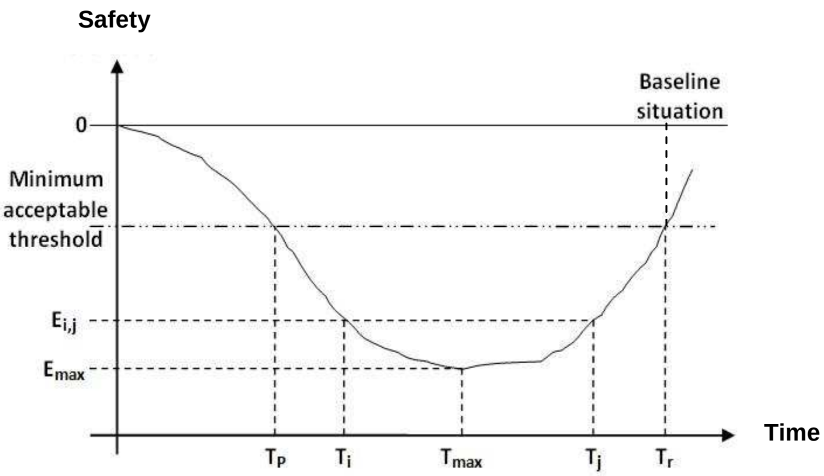

Figure 1: Resilience measurement in literature.

Resilience can be evaluated by the maximum intensity of an absorbable force by the system without perturbing its functioning. The measurement of the instantaneous resilience can also be linked with the speed of recovery from a disturbance. As these measurements do not consider on the same time disturbance period and effect, and recovery speed, another method will be proposed.

System resilience assessment requires the evaluation of two classes of indicators:

- The stability indicator of performances on a given time interval, i.e. the time period during which the performance improvement occurs or remains.
- The performance indicators of HMS related to the consequences of human actions in order to compare performance levels between two dates, i.e. the current one and a past one (sampling period).

Supposed that optimal performance level exists (initial and nominal HMS state, i.e. baseline situation), after any disturbance (intrinsic, like human or technical failure, or external, like environmental event), performances of the HMS will be degraded and several scenarios can be considered:

- If the HMS is capable to return to the initial nominal performance (known disturbances situation), the system can be defined as resistant;
- If the HMS is capable to recover from a perturbation and to stabilize to another acceptable performance level (not optimal, unknown situations, e.g. unexpected or unprecedented disturbances), the system can be defined as resilient;
- Else, If the HMS is not capable to recover from perturbation (out of acceptable performance domain) or to stabilize itself, the system is nor resistant nor resilient.

HMS capable to recover from a perturbation and to stabilize to another acceptable performance level will be studied in next section in order to assess their resilience.

Application to transportation system

The COR&GEST (French acronym for Railway Driving and Traffic Management) platform is used to simulate railway driving systems. System safety, in order to assess the system resilience, is determined by the sum of effect of factors which can affect the system safety like speed, braking distance, driver awareness, etc. (Gu et al., 2009). For instance, resilience can be assessed between times *tb* (beginning of disturbance effect, i.e. safety indicator below minimum acceptable threshold) and *te* (end of unacceptable performance) in Figure 2.

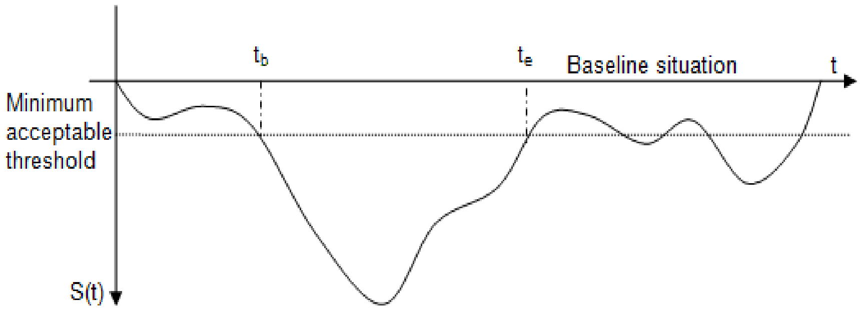

Figure 2: Evolution of safety indicator for resilience assessment.

Based on this safety indicator, "local resilience" evaluation is proposed in Equation 1:

$$local\,resilience = \frac{dS(t)}{dt} \qquad (1)$$

The "local resilience" is an instantaneous measurement of resilience and its value depends on the effect of disturbance on the system. It can be negative if the performance decreases or positive if the system recovers from the disturbance. The "total resilience" is the sum of "local resilience" during a sampling period as presented in Equation 2:

$$total\,resilience = \int_{tb}^{te} local\,resilience = \int_{tb}^{te} \frac{dS(t)}{dt} \qquad (2)$$

The table 1 presents results that can be obtained for times t_i (during safety performance decrement), t_{max} (maximum effect of disturbance) and t_j (during safety performance recovery):

Table 1: resilience assessment results.

	t_b	t_i	t_{max}	t_j	t_e
local resilience	$S'(t_b)$	$S'(t_i)$	0	$S'(t_j)$	$S'(t_e)$
total resilience	0	$\int_{tb}^{ti} S'(t)$	$\int_{tb}^{t\max} S'(t)$	$\int_{tb}^{tj} S'(t)$	$\int_{tb}^{te} S'(t)$

Results from ITERATE European project experiments will be used in order to evaluate the proposed resilience assessment.

Conclusion

In this paper, indicators of human behaviour contribution to assess resilience in Human Machine System have been discussed. Then, a system resilience classification based on literature review of measurement methods is proposed. It has been applied on railway simulation platform and will be validated on ITERATE European project data.

Future works will deal with "global resilience" which can be evaluated as the merging of different indicators of "total resilience" such as workload or quality of service. Moreover, learning algorithm to achieve the selection of the most appropriate alternative for driving (Ouedraogo et al., 2010) and to define a new action plan, with its associated consequences, applicable to HMS in order to evaluate its effect in terms of resilience.

Acknowledgment

The research leading to these results has received funding from the European Commission Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 218496 Project ITERATE.

The present research work has also been supported by:

- CISIT (International Campus on Safety and Intermodality in Transportation),
- The Nord-Pas-de-Calais Region,
- The European Community,
- The Regional Delegation for Research and Technology,
- The Ministry of Higher Education and Research,
- And the National Center for Scientific Research.

The authors gratefully acknowledge the support of these institutions.

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