Automation for improve of mental workload of the systems engineer.

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Abstract: This paper is a feedback of an original approach to standardize the work of electric traction of railway transportation. This work was developed within an industrial thesis, financed by the SNCF (French acronym for National Society of French Railways) in association with the CReSTIC (Research Centre in Information and Communication Science and Technologies). Thanks to Systems Engineering approach around standardization and safety programs, the systems engineers' concentration on cognitive task has been improved. After 2 years of implementation, some results are analysed.

Keywords: control, task-based design, mental workload, standardization process, safety-critical systems, railway transport.

1. INTRODUCTION

The competition of the European rail transportation due to the opening of the market imposes to the National Society of French Railways (SNCF) to set up innovative solutions improving the productivity. These solutions must not be to the detriment of the safety of installations and persons from which the engineering of the SNCF infrastructure is a guarantor. Moreover, the work of systems engineers evolve and their workload around automation tools too (Young and Stanton, 2008).

In SNCF, the electric traction engineering department (called IGTE) is in charge of the specification of the equipment of telecontrol, automation and Low Voltage (LV) protections of the Power Supply Equipment of the Electric Lines (PSEEL) market. The PSEEL are the electrical supply points of the electrified lines, called catenary. The role of the PSEEL is to transform, to supply, even to rectifier in the case of DC supply, the tension of the High-Voltage (HV) network into compatible tension with traction units (1500 V DC, 25 kV AC or 2x25kV AC). A traction substation is an electrical substation that converts electric power from the form provided by the electrical power industry to an appropriate voltage, current type and frequency to supply railways with traction current (Fig. 1). A traction substation has (very) High-Voltage devices as switches, circuit breakers, protection and control equipment, to ensure safety (EN 50126) in case of electrical danger to persons and properties (Fig. 2).

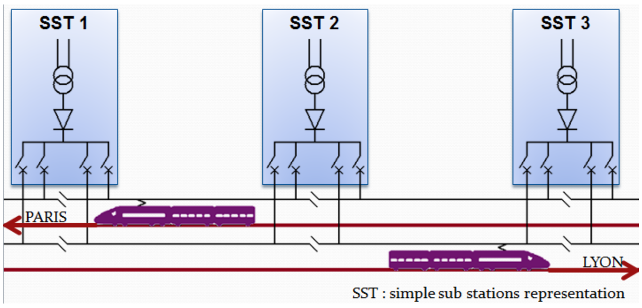

Fig. 1. Traction Substation System.

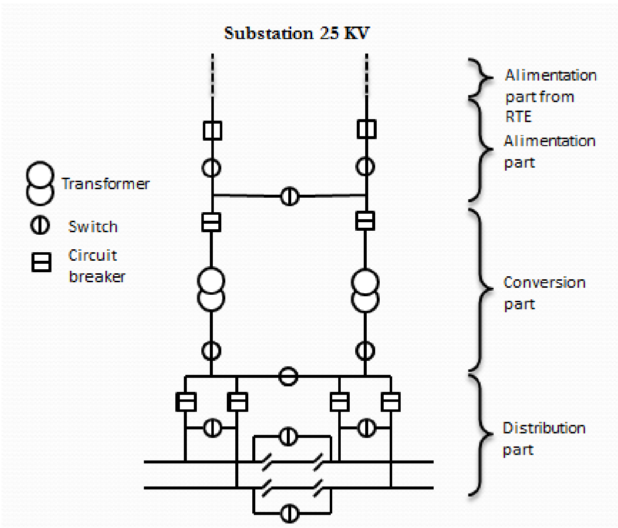

Fig. 2. Traction Substation Devices.

The PSEEL are distributed automated systems among which control-command can be done locally but also remotely, in a centralized control station (Gilmore et al., 1989) called Central Sub-Stations (CSS). The human supervisors can activate HV devices (switches, circuit-breakers…) since this control room. They are responsible for ensuring the supply of

PSEEL under nominal and degraded modes (maintenance of catenary voltage) to ensure safety when working on PSEEL or catenary under national regulations (UTE C 18510) or specific and emergency shutdown in case of electrical danger to persons and properties (Fig. 3).

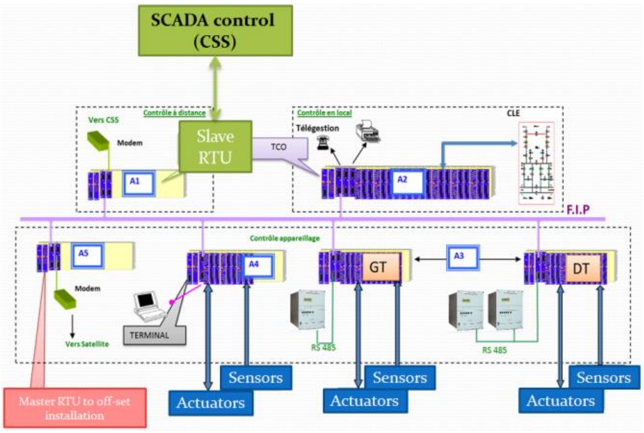

Fig. 3. Distributed Control.

To increase competition, the electric traction engineering department of the SNCF has prospected around two axes of improvement. The first one is the standardization, in order to improve the homogeneity of deliverables made by the technical studies. Standardization can also integrate the generation of deliverables (documents, schema...). The deliverables generation allows optimizing the working time of the systems engineers by avoiding them to enter redundant data. The improvement of the working conditions involves a regulation of their mental workload by avoiding the errors consecutive to the mental underload and to the peaks of overload. The second one is the implementation of a robust filter based on safety constraints (Riera et al., 2012) to ensure the safety of persons and PSEEL whatever is the functional control implemented in Programmable Logic Controller (PLC). The program must respect standard language (IEC 61131-3). This control safety filtering should be used to prevent control errors that may be sent from CSS.

In a previous work (Coupat et al., 2013), we have presented the theoretical influence of these two axes on performance and mental workload of the systems engineer (Fig. 4). In 2013, it was not possible to measure the effect of the proposed approach on the life cycle of the PSEEL. To bring these results, it was necessary to wait to have an experience feedback over a significant duration to be able to compare with existing systems.

This paper is a feedback of 2 years of results and exploitation. Section 2 reminds the methodology to improve engineer work. Firstly by the use of a software tool for standardization, and secondly by the application of a robust filter. Section 3 talks about the mental workload results in project workflow of a systems engineer. It is described each phase of a project and the impact of standardization and use of robust filter. Conclusion and future works are in section 4.

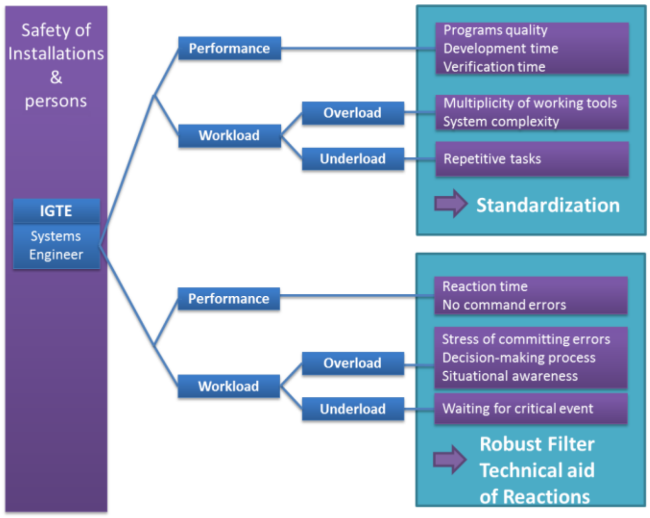

Fig. 4. Representation of the solutions proposed to increase performance and mental workload.

2. METHODOLOGY TO IMPROVE ELECTRIFICATION PROJECT OF PSEEL

Firstly, the solution is based on the principle of unique data entering, this allows optimizing the workload. The description of the PSEEL in this unique software environment should allow generating all deliverables (documents, programs, wiring diagrams ...). This software solution is a part of a process of work standardization. Secondly, the implementation of a robust filter based on safety constraints (Riera et al., 2012) to ensure the safety of persons and PSEEL whatever is the functional control implemented in Programmable Logic Controller (PLC). This control safety filtering should be used to prevent control errors that may be sent from CSS (Fig. 5).

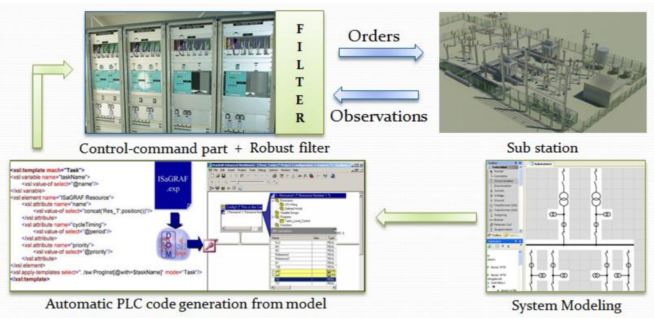

Fig. 5. Application of standardization and robust filter.

2.1 Software for standardization

Standardization of a job is a process requiring the domain know-how and having a global vision (job expert). It is therefore natural that the first phase of this approach is a study of all the principles used by the job to understand the know-how. Indeed, the workflow methodology followed by the systems engineers is composed of steps shown in Figure 6.

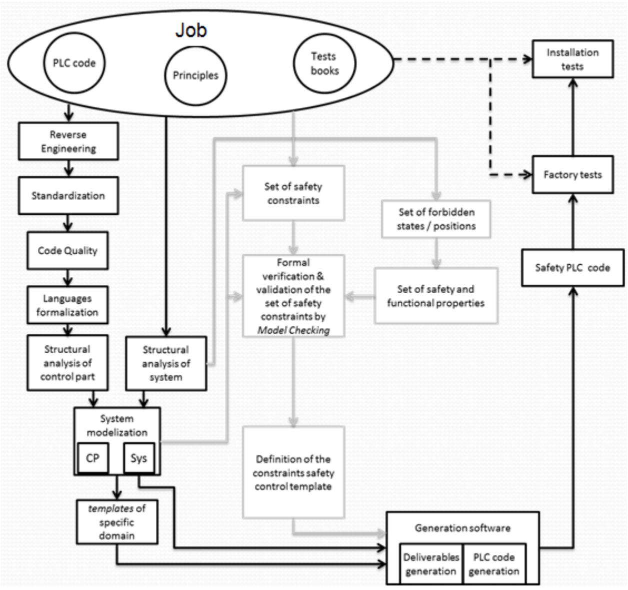

Fig. 6. Methodology for the standardization axis.

The methodology is based on standardization and begins by studying the "job", these principles and existing documents and programs. Through these input documents, and by reverse-engineering of PLC programs, it is possible to define standards. For this it is necessary to standardize the programming principles and ensure that the existing PLC code presents no default. Indeed, the automatic generation based on the creation of templates, which consists from rules to enrich or adapt prototypes predefined code. Qualimetric step of analyzing the existing PLC code is therefore essential to confirm or improve the prototype code. A structural analysis allows the system decomposition, and building models of plant (Sys) and architecture of controller part (CP). It is from these models (which are domain specific "job") that we propose to define templates. The modeling of the hardware architecture of controller is necessary to establish program distribution rules into the PLC. The templates must be integrated into a software environment with a single input of data. This should allow to automatically generate deliverables, through a Human Machine Interface (HMI) adapted to the engineer language (Fig. 7).

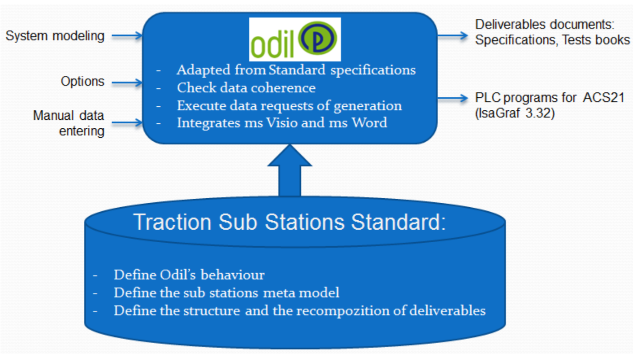

Fig. 7. Standardization software.

It results a tool called Odil GREMLINS (GénéRateur Evolutif du Modèle et des LIvrables des Nouvelles Sous-stations) developped with the collaboration of the society Prosyst (www.prosyst.fr). Details can be found in (Coupat, 2014).

2.2 Robust Filter

In the approach described in Fig. 8, system safety is ensured by the robust filter regardless of the implemented control-command. Indeed, ensuring a formal safety to automated systems is a scientific challenge that issues important industrial stakes. The interest of the robust filter is to insure systems engineer that he/she will not interfere with system and human safety. So he/she can be serene and it avoids a state of stress which can lead to a mental overload.

A methodology has been described by (Marangé et al., 2010) to get a robust filter formed by a set of safety constraints formally verified from a Failure Modes and Effects Analysis (FMEA) of the system. This check is done through the model-checker UPPAAL (Behrmann et al., 2002), allowing the system modeling then the formal verification of system properties and proposed logical constraints. Safety constraints are expressed as a monomial (product of logical variables, Π form) which is a logical function of the inputs / outputs of the PLC and any possible observers (function of inputs) to compensate the lack of observability of the system.

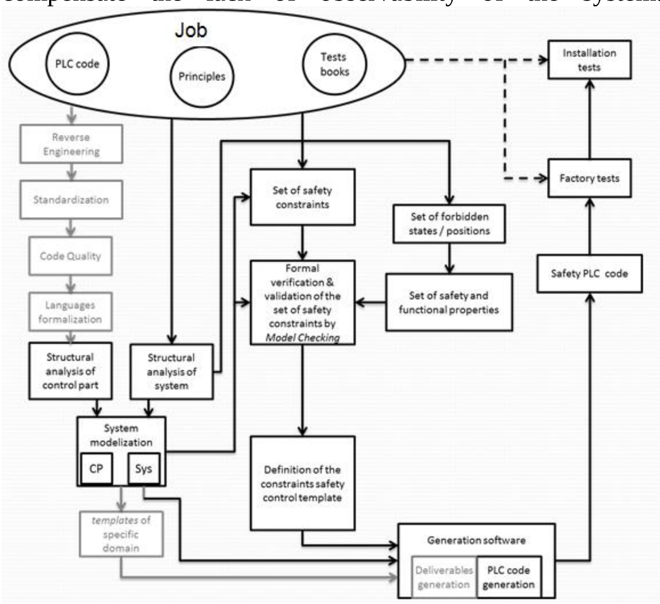

Fig. 8. Methodology for the robust filter.

The robust filter is implemented at the end of the control-command program in the PLC. It is then possible to verify formally if the set of safety constraint is necessary and enough to ensure the system safety thanks to UPPAAL. Although this formal approach requires the intervention of an expert of the system, combined with the standardization process, it allows to strengthen the safety of the elements of the system without complicating the work of systems engineers (Coupat, 2014). This work of elementary decomposition of the safety constraints must not evolve. Only the functional part of elements may need to be modified. The safety part must be the same in anytime. That is why the interest to insure the safety of each component and of the global system, thanks to the formal filter, whatever is the implemented command in the PLC seems obvious (Fig. 9).

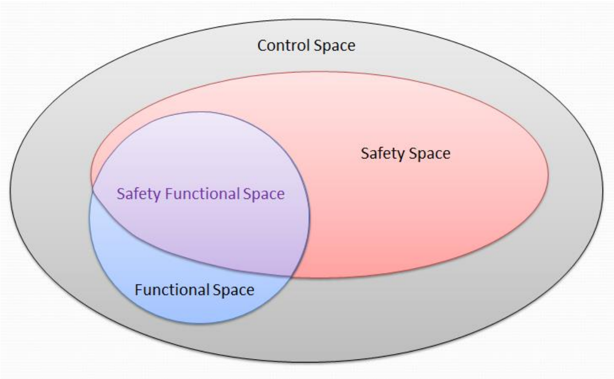

Fig. 9. Safety Command Filter Integration.

3. RESULTS AND IMPACT

The mental workload (ISO 10075) in the automation field is a major concern since a few years. This persistent notion has never been completely surrounded and is a part of the social debate related to work intensification (Askenazy and Caroli, 2003). It is defined as the quantitative or qualitative measure of the level of activity required to perform a specific work (Sperandio, 1988). In other words, the concept of mental workload is defined fundamentally in terms of the relationship between the supply (resources) and demand (requirements) (Wickens, 1984).

To improve the performance of the team to design the electrification projects, the homogenization of documents and deliverables seems to be an effective solution. Indeed, through the standardization, it is possible to improve performance and quality by defining rules in order to make the reading of a project easier for everyone (Fig. 10).

Generation of deliverables from the unique description made by the systems engineer requires a second reading. This cognitive task asks for more concentration of the systems engineer because it is about the documents validation which he/she would have to write previously (but not anymore). This phase of proofreading also allows the systems engineer to have a critical look on the generated elements. This feedback allows improving the generation. He/she must be concentrated to analyze the lacks and complete the generated elements. This task requires, also, a significant concentration of the systems engineer. He/she has to complete at the same time the deliverables but also the programs.

The robust filter can inhibit command errors of an operator, the sending of an erroneous command will be filtered by the safety constraints implemented in the robust filter. This kind of error can occur when the operator is mentally overloaded, in case of simultaneous incidents. This additional safety helps to decrease the stress suffered by the operator due to the decision-making in a limited time. The inhibition of a command sent by the operator will have the effect of awakening the human supervisor vigilance (Hancock and Verwey, on 1997). This effect can be beneficial when the human supervisor undergoes an overload peak after mental underload phase due to the waiting for an event.

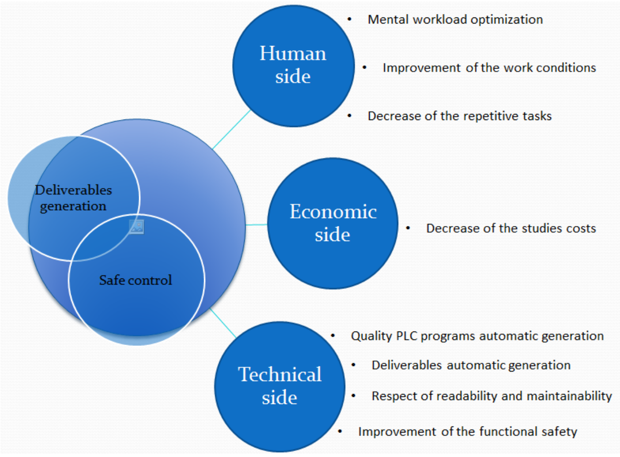

Fig. 10. Improvement of the methodology.

This new workflow eliminates the mental underload phases (Fig. 11), replacing them by cognitive phases which the sequence avoids the mental overload. The unique data entering in a software environment allows the systems engineer to stay focused and not to lose in performance. Indeed, the information contained in the deliverables may be duplicates, systems engineer must then write the duplicated information several times. This monotonous repetitive work makes the systems engineer work unattractive. That is a source of error and is also a source of mental underload.

The concentration of the systems engineer is then focused on a new task, in which he/she has to describe only once all the parameters of the design project of the PSEEL to generate the standardized deliverables. When the standardized deliverables are generated, the systems engineer must implement all his/her know-how to design and compute the elements that are not standard. Indeed, the variety of elements makes impossible to have a complete standardization. Each installation has particularities of which the systems engineer must take care.

The generation avoids repetitive tasks due to the data entering of redundant information. The solution of generation allows to refocus the concentration of the systems engineers on the cognitive tasks and so to avoid mental underload. The standardization approach prevents mental overload, due to the proliferation of computing supports, by integrating a software environment based on a unique data entering.

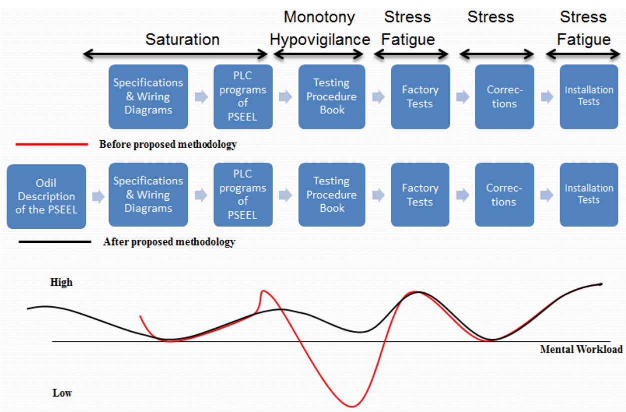

Fig. 11. Mental Workload evolution.

A new workflow is defined to integrate Odil GREMLINS. The writing tasks are replaced by the graphic description in Odil GREMLINS and verification of generated deliverables. The systems engineers can spend more time on complex tasks such as schema validation. Repetitive tasks such as writing the recipe book are replaced by proofreading tasks if necessary, eliminating steps under mental load and reduce the time required to study an electrification project.

The workload can be diminished by the implementation of this new workflow. Given that there are about 8 projects per year, approximately 920 hours per year can be saved. Besides this approach has also been applied to power positions, including regenerations are shorter but more numerous projects over the year, about 20 projects per year. The detail of time saved per project is given in the table 1.

Table 1. Workflow Comparison for a PSEEL Project.

Workflow Without Odil GREMLINS	Workflow actuel	Odil GREMLINS	Workflow With Odil GREMLINS
		5h	Description Odil GREMLINS
		3h	Description Plant
		2h	Description Controller
Pre-study	50h	25h	Pre-study
Specifications and equipment	30h	5h	Generation of Specifications and equipment
General Diagrams	20h	20h	General Diagrams
Study	50h	25h	Study
Diagrams Validation	20h	20h	Diagrams Validation
Programs and parametrics files	30h	5h	Relecture of the generated code
Verifications	50h	35h	Verifications
Receipts	20h	5h	Relecture of the generated receipts
Factory tests	30h	30h	Factory Tests
Corrections	10h	5h	Corrections
Corrections	10h	5h	Corrections
Validations	30h	30h	Validations
Site Testing	30h	30h	Site Testing
Total hours	190	125	Total hours

Concerning the safety, we have proved by Model-checking that 3 safety properties expressed by SNCF were not respected by the original controller (without the robust filter). Thanks to the filter, these properties are now formally cheked. This verification is a heavy computing which imply combinatory explosion. To solve this problem, the ROMEO HPC Center of the University of Reims ChampagneArdenne have been used (https://romeo.univ-reims.fr/pages/aboutUs). This center delivers high performance computing resources for both industrial and academic researchers, along with an entire ecosystem of services like secured storage space, specific software and support in its usage, as well as an in-depth expertise in 3 main application domains (mathematics and computer science ; physics and engineering sciences ; multiscale molecular modeling).

Project homogeneity, productivity increase, programs reliability and errors diminution, fewer tools, and solution usability are the defined expectations about Odil GREMLINS. This tool has permitted to meet these expectations by generating a standardized and readable code approved by systems engineers. Odil GREMLINS is an interface of unique data entering which allows to reduce tools number. The deliverables can be generated once that the installation architecture and control-command part are defined. The use of this tool by systems engineers should not present any particular difficulties. It integrates the job language and draws on existing documents (single-line diagram) for graphic description. Some project phases can be fully reduced through the use of Odil GREMLINS in the entire project. For the moment systems engineers have not estimated the percentage of workload reduction, but there is no doubt that Odil GREMLINS optimize their working time.

4. CONCLUSIONS

This article shows the interest of the SNCF to standardize and generate all the deliverables to improve the level of performance. It presents the results of 2 years of exploitation by the electric traction engineering department. Human is takes into account at the input of the tool and its workload is considerate in each step of an electrical project.

The proposed methodology and tool developed Odil GREMLINS are now operational and allow improvement of engineers in charge of projects without changing their profession because of PLC programs development principles are preserved. It is a significant economic gain because the time spent in study is reduced. The reliability of the controller is done due to the proposal of an algorithm (or design pattern) easy to implement and based on a basic logical constraints filter (formally verified).

Each installation has particularities of which the systems engineer must take care. Consequently, extensions for all types of electrification projects (1,5kV ; 25kV ; 2x25kV) must be considerate.

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REFERENCES

Askenazy, P., and Caroli, E. (2003). *Pratiques innovantes, accidents du travail et charge mentale*: résultats de l'enquête française sur les Conditions de travail. Pistes, 1 (5), 1-30.

Behrmann G., Bengtsson J., David A., Larsen K.G., Pettersson P., Yi W., 2002. Uppaal implementation secrets. *7th International Symposium on Formal Techniques in Real-Time and Fault Tolerant Systems.*

Coupat, R. (2014). Méthodologie pour les études d'automatisation et la génération automatique de programmes Automates Programmables Industriels sûrs de fonctionnement. Application aux Equipements d'Alimentation des Lignes Electrifiées. PhD Thesis, University of Reims Champagne-Ardenne, France.

Coupat, R. Meslay M., Burette M.A., Philippot A. Annebicque D and Riera B. (2013). The standardized generation and the robust filtering of the command as tools of optimization of the mental workload of the systems engineer. IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems (HMS 2013), Las Vegas, USA.

EN 50126. *Applications ferroviaires* - Spécification et démonstration de la fiabilité, de la disponibilité, de la maintenabilité et de la sécurité (FDMS) (2000).

Gilmore, W.E., Gertman, D.I., Blackman, H.S. (1989). “User-computer interface in process control”, a Human Factors Engineering Handbook, Academic Press.

Hancock, P.A., and Verwey, W. (1997). Fatigue, workload and adaptive driver systems. *Accident Analysis and Prevention*, 29(4), 495-506.

IEC 61131-3. *Programmable controllers* - Part 3: Programming languages Ed. 2 (2003).

ISO 10075. *Principes ergonomiques concernant la charge de travail mental* -- Termes généraux et leurs définitions (1991).

Marangé P., Benlorhfar R., Gellot F., Riera B., 2010. Prevention of human control errors by robust filter for manufacturing system, *11th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems*, France.

Riera, B., Philippot, A., Annebicque, D., Gellot, F. (2012). *8th Symposium on Fault Detection*, Supervision and Safety of Technical Processes (SAFEPROCESS 2012), Mexico.

Sperandio, J.C. (1988). *Ergonomie du travail mental*. Paris.

UTE C 18510. Operations on electrical work and installations and in an electrical environment - *Electrical hazard prevention.*

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman and R. Davies (Eds.), *Varieties of attention* (pp. 63-101). New York: Academic Press.

Young, M. S. and Stanton, N. A. (2008). Attention and automation: New perspectives on mental underload and performance.