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Contribution of chronobiology vigilance in public transport safety

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Abstract
Chronobiologia studies human biological rates including alertness and performance. The analysis of human alertness rates shows that hypoalertness episodes occur at foreseeable periods in the daytime. The alertness drop of the human operator is one the main causes of road accidents. It also often leads to rail transport incidents and accidents. The peak of accidents risk through hypoalertness has been detected in the middle of the afternoon, late at night and early in the morning, which complies with the circadian patterns of drowsiness. As far as we know, in the field of rail transport safety, the chronobiological aspect of alertness has not yet been addressed. However, the rotation rate of the human operators work schedules sets the same problem as shift work. To take into account the chronobiological data can improve safety, proposing solutions to adapt work schedules to the circadian changes of the human operator functional capacities. To determine the times of best performance by the human operator and to make them match his work schedules improves the reliability of the man-machine system and reduces the risk of accident. This study gives an overview of alertness and performance chronobiologia, an analysis of the contribution of these notions in road transport safety, and presents a methodological approach to be applied to the concepts linked with alertness chronobiologia for a better guided rail and transport systems safety.

Keywords: Chronobiologia, Alertness, Sleepiness, Performance, Human factors, Transport safety, Risk of accidents

1. Introduction
One of the research activities which is currently in progress at the French institute lFSTTAR relates to the certification of automated public transport systems and the safety of digital control systems. As part of its missions of expertise and technical assistance, IFSTTAR evaluates the files of safety of guided transportation systems. These files include several hierarchical analysis of safety such as the preliminary analysis of risks (PAR), the functional safety analysis (FSA), the analysis of failure modes, their effects and of their criticality (AFMEC) or analysis of the impact of the software errors [1] (figure 1).

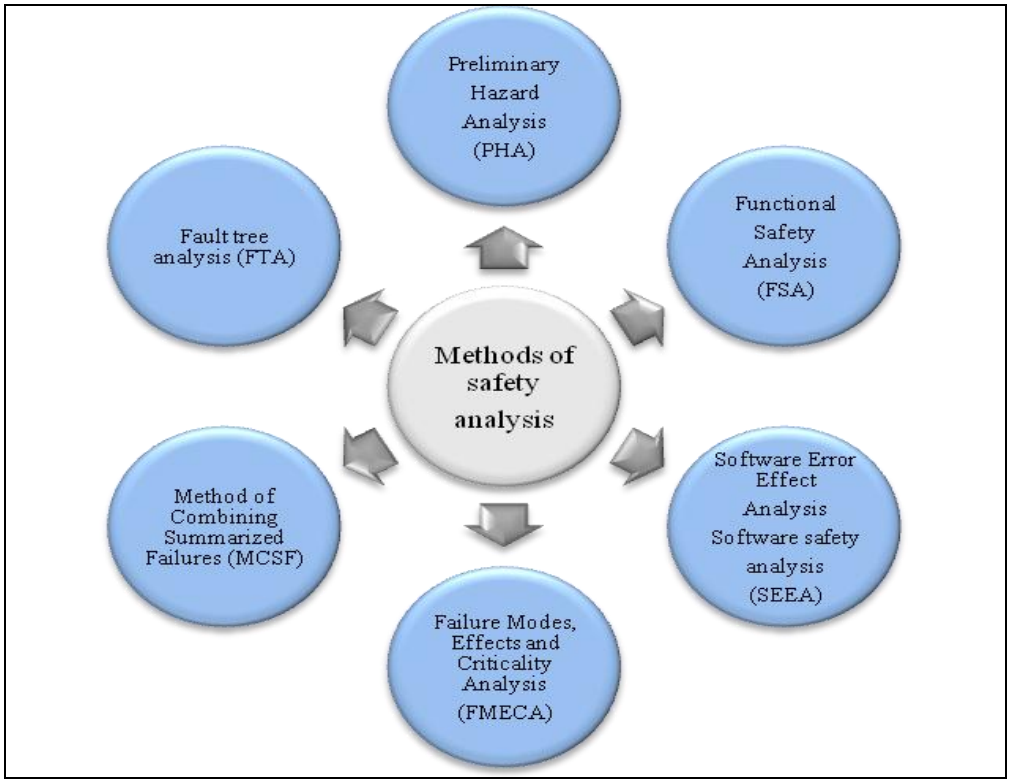

Fig 1: Main methods of analysis of the safety of railway transport systems [1]

These analyses are carried out by the manufacturers. It is advisable to examine these analyses with the greatest care, so much the quality of those conditions, in fine, the safety of the users of the transport systems. Independently of the manufacturer, the experts of IFSTTAR carry out complementary analyses of safety. They are brought to imagine new scenarios of potential accidents to perfect the exhaustiveness of the safety studies. In this process, one of the difficulties then consists in finding the abnormal scenarios being able to lead to a particular potential accident. Our study took place within this context and aimed to design a new methodology to improve Analysis of transport safety.

This article presented a bibliographical study on the concepts of chronobiology alertness and performance by highlighting the contributions and limitations of the recommended measures to detect and prevent the drowsiness of the human operator. He then proposes a methodological approach of application of chronobiology vigilance in the field of the safety of transport.

2. Human error

The human error [2-4] is the sign of an inadequacy, a lack of compatibility between the features, organizational functional of the situation of work, and the physical, mental, psychosocial characteristics of the human operator. The human error as a dysfunction of the system man-task, is an event not desired, whose recovery is possible on condition that to be detected, or whose fatal consequences must be minimized. The occurrence of the human error is thus defined by the total behavior of the system man-task. In the field of work, Rasmussen defines the human error as being the negative counterpart of the human activity, likely to lead to a failure of the operator. The error thus constitutes a revealing, an indicator or a symptom of the activity. It results in an action unsuited on the system which will not succeed in making the results in conformity with the goal. A human error is not reducible with the incapacity or the incompetence to carry out a task, but can come from the impossibility in which is an operator to carry out a task correctly. This impossibility comes from an incorrect definition of work.

Finally, the various definitions of the human error adopted are generally divided into three categories [5]: that which focuses on the manifestations of the errors (industrial approach), that which is based on their modes of production at the same time (approach psycho-dynamics of work). The human error is thus analyzed according to its negative aspect in terms of consequences on the man and/or the system, or according to its positive aspect by examining the mechanisms which explain the production of it. Whatever the definition chosen, the human error term (or erroneous action expresses), means dysfunction of the human operator (on the level of the mental activities, psychomotor, sensory, or physical) who results in a variation or a deviation compared to an action or with a strategy supposed optimal and being used of reference or standard. The common point to the majority of the definitions of this concept contains the idea of variation compared to a standard.

The various models of human error worked out according to the field or the discipline, are generally divided into two main categories [6]. The first category is of a conceptual theoretical which analyzes the cognitive operating process of the man. The objective of this category is to explain the various mechanisms of production of the error (Rasmussen [7], Reason [8], Norman [9], Rouse [10] and Nicolet [11]). The second category is of a descriptive nature because it classifies the errors independently of the subject. It is based on the analysis of the task like on the consequences and the traces of the error in terms of behavior or erroneous action. Specific of work, it aims to predict and reduce the error in order to improve the reliability of the sociotecnical systems (Cellier [12], Leplat [13], Laprie [14] and Villemeur [15]).

Finally, it seems essential to us to make the distinction between failures, lapse and fault like between type and from of error. The types of errors are conceptually related at the stages or the subjacent cognitive mechanisms. They are in close relationship with the supposed origin of the error located at the cognitive stage of planning (faults), storage (lapses) or execution (failures). In addition to the types of error, which are specific to the level of the control adopted for the activity, Reason [16] and Hoc [17] distinguish the forms from errors which are common to a great part of the errors. They are recurring forms of failures which appear whatever the type of activity cognitive or of error. They indeed meet in the faults, the lapses or the failure. Their omnipresence lets think that take their roots in universal cognitive processes, in particular in the mechanisms of recovery in memory. While referring to the three hierarchical levels of the cognitive operation of the man one distinguishes three types of error (figure 2):

1. Failures: they errors of know-how very related to the automatisms, which result from a defect in the execution of the actions, they are explained by the presence of a sensor motor automatism unsuited to the context of the activity.
2. Lapses: they are errors bases on the rules which result from a defect in the information storage. They represent activation or a choice of a diagram of action (mental procedure) inadequate, taking into account the situation and of the constraints of the tasks.
3. Faults: they are errors based on knowledge which results from a deficiency of the judgment and planning. They reflect an action plan or an inappropriate intention with the characteristics of the task and situation

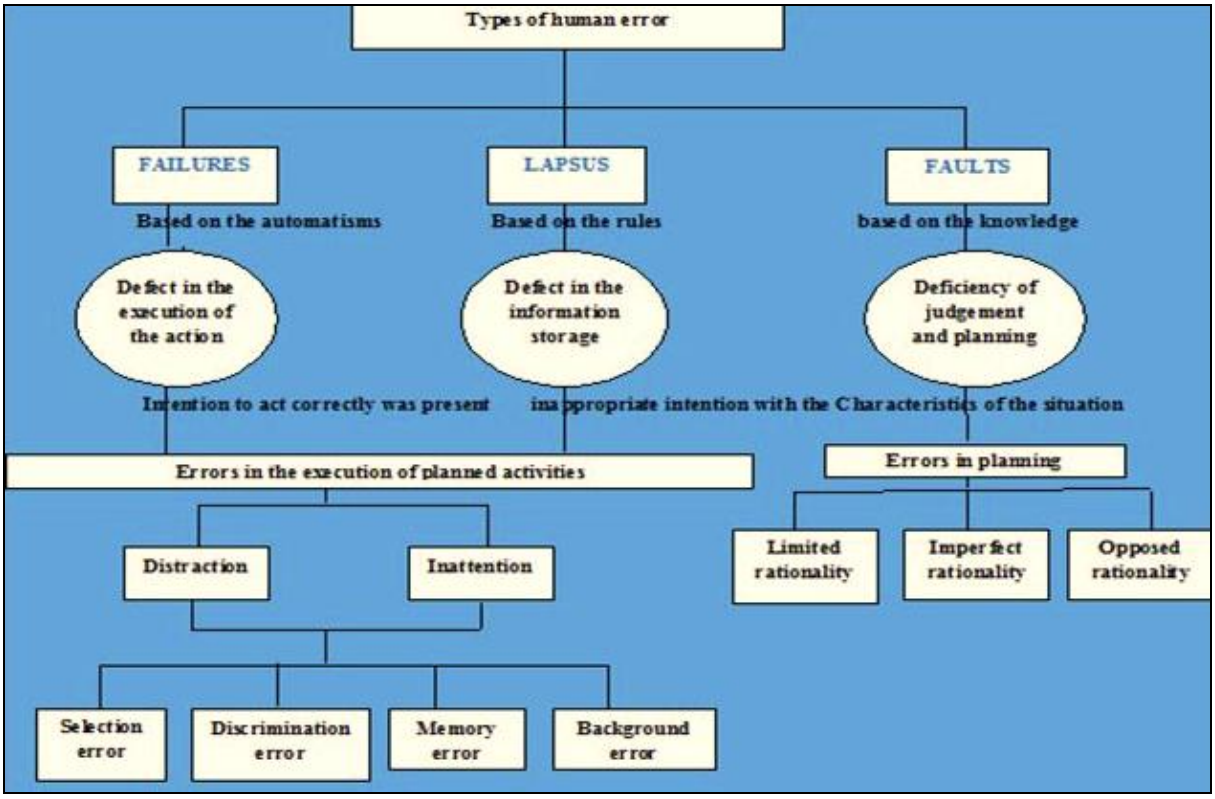

Fig 2: Distinction between Failures, Lapse and Faults [6]

Thus, the complexity and the originality of the new transportation systems confer a decisive role for human operator in the safety of circulations of the trains. Its success in the achievement of a task of control depends on several factors. It depends on its perceptive and cognitive capacities, of the validity of the various mental models which it forged of the system, its psychological state, his state of vigilance, its workload of the complexity of the situations of control or of its state of stress, for example in emergencies where the safety is threatened. Determining the best performance schedules of the human operator and consistency with his working hours increase the reliability of the man-machine system and thus reduce the risk of accidents [18] and [19].

3. Hypovigilance is a major contributor of accidents in public transport

Subheadings Chronobiology is the study of biological rhythms of man. These different rates fall harmoniously in time making a genuine additional time structure of anatomical spatial structure of the organization. Maintaining the temporal coherence of the human body is a prerequisite to maintaining its biological balance, psychological and social. A biological rhythm can be likened to a sinusoid characterized by its period, amplitude and phase. Several families of rhythms can be identified by the length of the period: circadian rhythms (period of about 24 hours) infradian (period greater than 24 hours) and ultradian (less than 24 hours). The most studied are the circadian rhythms [20-24].

The contribution of chronobiology lies not only in the identification of the temporal structure of man, but also in the study of its different rhythms of alertness and performance.

This is what we have documented [18, 19]:

- The concept of mindfulness has two sides, corresponding to a physiological arousal of the central nervous system and psychological defined by the attention. Attention is a concept associated with alertness reflecting a major psychological aptitude requiring alertness levels determined to contribute to the reliability of the human operator in the land vehicle driving tasks.
- There is a relationship between alertness and performance represented by a curve inverted U model. The performance level increases with the alertness until an optimum beyond which performance declines with increasing level of vigilance. The optimal level of vigilance for the best performance varies across subjects, as nycthémère and the type of task.
- The level of vigilance of an individual varies during the day making a rhythm with a maximum and a minimum lying at specified times. Schedules reduced alertness (13h to 16h and 1 to 6 hours) coincide with those of impaired performance.
- To circadian periodicity of about 24 hours, superimposed fluctuations in period of about 90 minutes vigilance and a strong propensity to sleep every 12 hours (at 15 am and 3 pm).
- Drowsiness, as measured by sleep latency, shows a marked circadian periodicity with maximum need for sleep in the middle of the night associated with a significant decrease in performance, which explains sleepiness among night workers and increased frequency of errors and industrial accidents in this period nycthémère.
- The sleep - wake rhythm is characterized by two essential parameters, sleep duration and spontaneous normal hours (sleep and waking) without any external constraint. Individuals are distributed differently in these two parameters that are causing a real typology of sleep. Be distinguished as the usual duration of sleep, long sleepers,

small sleepers and sleeper's means. In practice, it also defines as spontaneous sleep schedules, subjects in the morning, evening and intermediate subjects of subjects. The Morningness or vespéralité is an individual characteristic that, time better shape different chronotypes are significantly shifted in the day. Subjects in the morning had an earlier peak; people in the evening feel they are in better shape afternoon. The morning is more attentive in the morning and the evening Vesper. The mornings are more efficient in terms of accuracy in performing the task and Vesper in terms of speed.

The study of different features consecutive road accidents decreased alertness at the wheel [25-30] has revealed the following findings [19]:

- Laboratory studies and vehicle have shown that drowsiness impairs driving performance. Indeed, it is accompanied by a slower reaction time, a slowdown in the information integration process and a decrease in short-term memory with reduced mental performance. The maximum psycho physiological deterioration is between 3am and 5am, the minimum period of vigilance.
- Drowsiness is the leading cause of fatal accidents, 34% in France, 19% in Australia and 13% in Canada. In the US, it represents 1-3% of all vehicle accidents and is the cause of 56,000 annual accidents whose 1550 death. During the period from 1988 to 1992, 29% of fatal accidents in France and 13% of cases in the US are attributed to drivers nodding off.
- The assessment conducted over 15 years (1979-1994) by ASSECAR (Security Association on Highways) and ASFA (Association of French Motorway Companies) revealed that fatigue, inattention, the asleep at the wheel, and reduced vigilance that results is the leading cause of fatalities on connecting highways (28%). Despite the improvement of infrastructure, this percentage remains constant for 10 years.
- Trucking is involved in 5% of all road accidents and 20% of fatal accidents. The lack of attention would cause 20% of accidents involving heavy goods vehicles and in 50% of cases, the driver is at fault. Fatigue is the underlying cause of 41% of truck accidents in the USA. The rate of accidents attributed to truck driver's inattention is estimated according to studies 31%; 41%; 54%.
- The occurrence of accidents schedules vary according to the authors, but are on average in the intervals of 1h-6h morning and 13h-16h in the afternoon. These peaks can be explained by fluctuations and impaired driving performance during these specific times of the day. These schedules compatible with the circadian pattern of sleepiness, emphasize the close correlation between the pace of vigilance while accidents by drowsy driving, apart from other factors.
- The consecutive accidents to sleepiness at the wheel have characteristics varying with age. Young drivers aged under 45 have more accidents at night on isolated following a corner car. Older drivers are involved in accidents especially in the afternoon on the same direction and as a result not commensurate stop or movement.
- Young male drivers, shift workers and patients with untreated sleep disorders are a high-risk population. Young drivers aged 16 to 29 years are 4 times more likely than those aged over 30 years. They are responsible for 2/3 of accidents as drowsy driving. They are responsible for 35% of road accidents between 1989-1992. Shift work, night or extra is the source of almost half of the accidents attributed to drowsy driving. 95% of night nurses (12 hours of work) and 25% of internal (24 hours or more of work) are victims of accidents or near - accidents during their return home.
- The main causes of road accidents by drowsy driving are: sleep disorders, alcohol intake and taking psychotropic drugs. Sleep disorders affect its duration, its quality and its position in the nycthémère (synchronization); they include sleep debt, sleep fragmentation, spooling and sleep disorders.
- Sleep disorders such as sleep apnea syndrome and narcolepsy are associated with a risk of falling asleep at the wheel and accidents 5 times higher than in the general population. They are involved in 28% of accidents on public roads and affects 20% of the general population in France.
- Alcohol is involved in 30% of fatal accidents in France involving the responsibility of the driver, and 45% with a single vehicle. It interacts with the circadian rhythm and sleep restriction or to aggravate sleepiness at night and in the afternoon, increasing deterioration in driving performance and increase the risk of accidents.
- Taking psychiatric drugs is the cause of 10% of victims of road accidents in Europe: 5,000 deaths and 150,000 injuries each year.

These findings have led many authors to develop detection methods hypovigilances driver to prevent, to ensure optimal vigilance at the wheel and thus improve road safety. To do so, various studies have been directed towards improving the state of the driver and to the equipment of the vehicle by aid in maintaining vigilance systems. The principle of these methods is to establish a correlation between physiological signals indicating a drowsiness (electroencephalogram, electro-oculogram), behavioral data driver (eye closing time, tilt the head back, posture, etc.) and kinematic indicators (speed and trajectory of the vehicle, the steering wheel angles...).

Embedded systems in the vehicle are devices that detect continuously and noninvasively loss of driver attention and trigger a visual or audible alarm that can maintain or even increase the level of alertness of the driver. Other device classes are intended not only to detect drowsiness and automatically warn the driver when driving "abnormal" but to cause, if any, the automatic stop of the vehicle. Besides the instrumental means of detection and prevention hypovigilances the drivers, there are behavioral interventions to the ouster of sleepiness risk factors. They include minimizing the effects of sleep debt by short naps of 20 to 40 minutes, to develop and adapt the schedules of work to change the circadian rhythm, improve lifestyle (especially avoid alcohol and driving after midnight) and to use, if necessary, stimulating substances like coffee or drugs. But prevention of drowsy driving by adequate sleep before driving or during pauses remains the easiest and most effective way. All of this work says the scale of the road safety related to the decline of the human vigilance (driver).

What - he of rail transport that involves several operators responsible for the security systems?

Incidents and accidents involving traffic safety in this area are frequently due to human error. Indeed, a bibliographic study by IFSTTAR [6] revealed that human error was considered one

cause of 270 accidents in 1283 with 113 collisions and 67 derailments. It is the same 103 derailments per year on average from 1971 to 1975, 72 in 1987, 64 in 1988, 28 in 1989 and 43 in 1990. It is still the case for the number of signal crossings with engagement of the protected point (25 in 1992 and 36 in 1993). SNCF said that human error is the cause of 64% of rail accidents. Between 1985 and 1988, these accidents have been the basis of 144 dead and 239 wounded.

Human error due to a decrease in alertness has become a critical element in the reliability of man-machine system [31], [32-36].

Human operators in the field of railway transport (CPC controllers, train drivers and maintenance workers) are subject to several constraints that have become more nervous (psychological and behavioral) and physical.

The mismatch of work schedules with schedules better shape and alertness peaks, imposes an extra effort to adapt to these times, increasing the workload and could affect the reliability of these operators. Thus, the problem of reliability in human-machine systems is that of the compatibility between changes in the functional state of the operator and those of the job requirements.

We have shown that [6, 18, 19]:

- The driver fatigue may have originated in staggered hours services and the monotony due to prolonged inactivity or a lack of informative system. The hypovigilance monotonous period remains the key factor in loss of control and efficiency during driving test.
- The impact of circadian variability of functional status of the human operator on the reliability cannot be precisely evaluated without taking the exact measurement of the characteristics of the task (monotony, lack of interest), the level of its requirements and its variations, the place of the operator's activity in the system and the conditions in which this activity is taking place (noise, heat, etc.).
- Human error is often the inability of an operator is found to cope with an abnormal situation, whether the failure of a device or a set of unexpected circumstances: organizational change, process, environmental, or even impaired interpersonal and interdepartmental relationships. Human error is a symptom of a poor work organization, poor or inadequate training. By understanding and managing it can paradoxically become a safety element.
- Rather, poor equipment design, inadequate integration man-machine and inappropriate design of the Human-Machine Interfaces which are the main causes of railway accidents. The difficulty experienced by OH, during the performance of a task is all the more important that the system and the human-machine interface are not suited to the tasks which it is responsible.
- Automation can prevent operating errors, but it can in no way eliminate design errors or unexpected errors. In some critical situations of insecurity, OH can be a reliability factor, restoring the proper functioning of the system, sometimes by actions not covered by the operating safety regulation but related to his knowledge, his experience and know-how, then catching errors committed by the operator designer.
- Even if the presence of the OH is sometimes a cause of error, it remains indispensable. It remains the key element of the system, the most reliable agent and plays a key role in degraded situations. It will be even better than its role will be expected from the specification of requirements and that automation will focus on him.
- Need to integrate human factors from the requirements specification and from the design of the system to design systems that fit oh and not the opposite.

All these observations raise the magnitude of the problem of human error in the field of rail transport safety. Our contribution focuses mainly on the proposal of a conceptual model centered on the rights and security of rail transport.

4. Conceptual model of integration of chronobiology vigilance in the rail transport safety

The improvement of human reliability in this area requires consideration of factors that may affect performance in nominal or degraded. The level of vigilance determines the performance and its alteration is a major source of accidents and incidents. The chronobiological approach is interesting to consider in the critical area of rail transport safety. We propose a novel methodological approach of application of chronobiology alertness to the field of railway safety. This approach, which is inspired including data and results from the analysis of accidents in the transport road, involves twelve steps (Figure 4) [19]:

1. The collection of accident data from a database (feedback) and / or a prospective study using the knowledge collection techniques (questionnaire, interview, protocol analysis,...);
2. The establishment of the list of accidents due to human error;
3. The determination of the temporal distribution of these accidents (accidents pace) from their occurrence schedules;
4. The search for a correlation between the foreseeable schedule of drowsiness (rhythms of wakefulness) and accidents occurrence of peaks due to human error (rate of accidents);
5. The establishment of the list of causes of accidents related to human error;
6. The identification of different causes of drowsiness causing accidents;
7. The development of behavioral and instrumental means of detection and prevention of the human operator hypovigilances (OH);
8. The identification and selection of OH (maintenance staff or operating) to which the system is intended;
9. Determination of the OH circadian typology of sleep to determine their chronotype "morning" or "evening";
10. The search for their better performance schedules based on the criterion of "Morningness / vespéralité";
11. Analysis of the task entrusted to these OH;
12. The establishment of job profiles of different types of OH stressing the need for consistency between their work schedules with those of better performance.

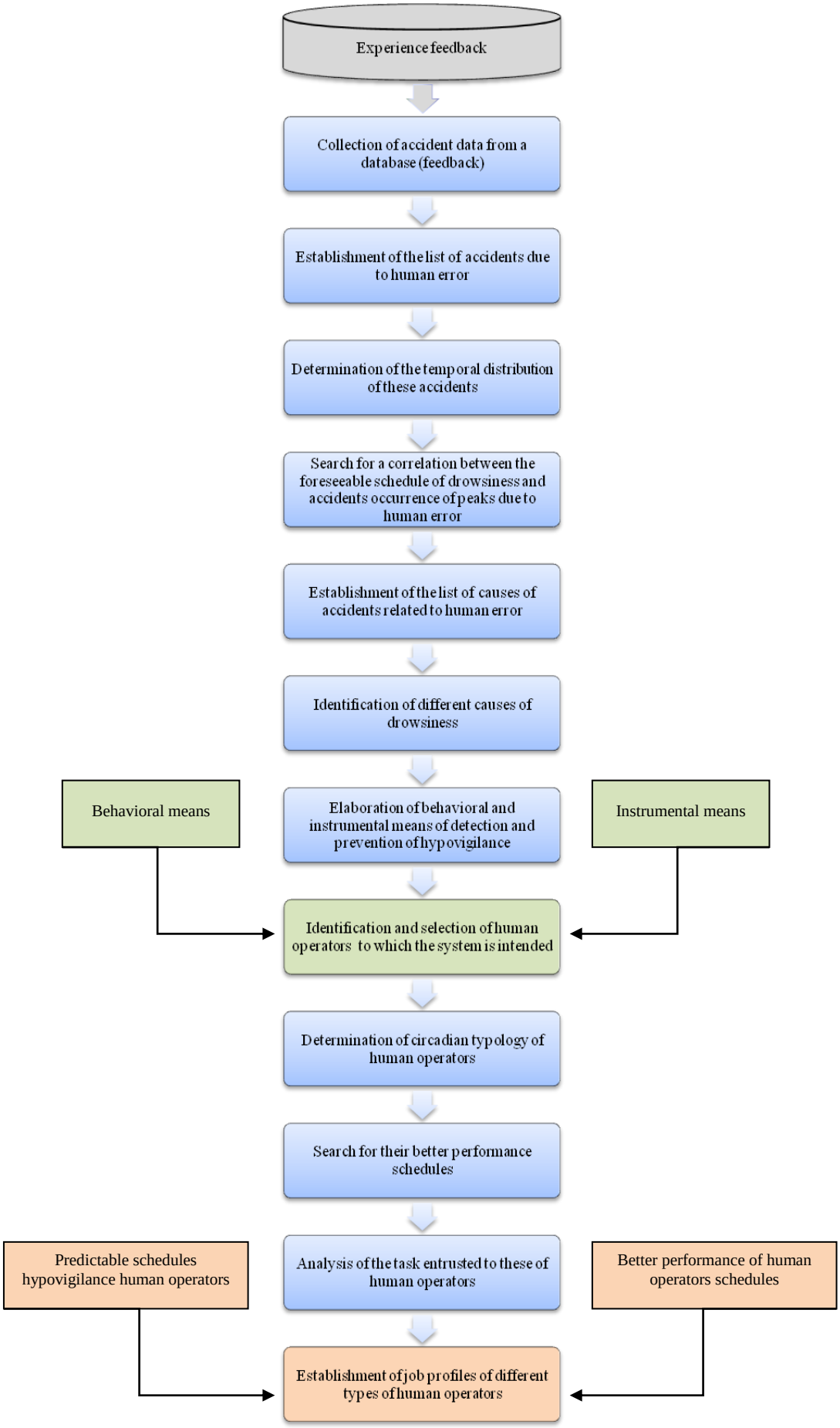

Fig 4: Methodological approach of integration of chronobiology vigilance in railway safety

5. Conclusions

Despite some limitations including the collection phase and analysis of accident data from the feedback that deserves further reflection, this approach allows to structure the knowledge of chronobiology alertness. It provides a methodological framework for the analysis and assessment of drowsiness related rail safety. This new approach can be extended beyond the framework of rail transport, and could well be adapted to other areas where it requires absolute security and high levels of vigilance.

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