Reliability Challenges in Rail Transport Industry

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1. Introduction and Context

The purpose of this paper is to survey various reliability challenges which in our opinion are currently posed to the Rail Transport industry and to evoke the requirements which they arouse in terms of mathematical approaches. Reliability is considered in a wide sense which also includes availability and maintainability (RAM).
ALSTOM's activities as equipment designer and manufacturer, turn-key system designer, and maintainer, and its interaction with numerous operators, make it both a stakeholder and a good observer of the situation.
Several challenges are examined in turn and a concluding statement is made. First, the context must be briefly described.
The evolution of the railway industry over the last 20 years could be characterised by the following trends: globalisation, appearance of new stakeholders ; and, at least on the supply side, increasing integration. Yesterday, Clients tended to be only government agencies, which specified technical choices in detail . Today, in addition to this traditional client base, they are also increasingly private operators or even banks, which impose performance targets – among which reliability and availability are prominent- but leave entire freedom as to the technical solutions selected to achieve those targets. They also tend to subcontract activities such as maintenance . Suppliers therefore evolve from being just manufacturers to becoming system designers and integrators, as well as maintainers. At the same time technical solutions rely increasingly on advanced technology.
The key objective then becomes to make the appropriate design choices, but also maintenance and operational choices, in order to reach reliability and availability targets, and to do so at lowest cost—the latter being understood most often as life-cycle cost.
Suppliers increasingly have to manage performance-related risks throughout the life cycle.

2. First Challenge : functional modelling

Given that, ultimately, it is functions which are provided (such as "transporting passengers or goods" or " braking" or "controlling speed"), it is fundamental to be able to reason from the start in terms of value analysis and functional analysis. Languages such as UML or SYS-ML are increasingly in use at specification stage and a challenge is to relate them to reliability and availability analyses, which means to model malfunctions in addition to normal operation. Functions have to be related unambiguously to the items of equipment which perform them.

3. Second Challenge : model true reliability behaviour of basic equipment

In order to reduce the risk arising from poor reliability prediction, it is increasingly important to acquire an improved understanding of failure and degradation mechanisms. This in our opinion requires a two-pronged approach: on the one hand, going back to physics to model failures and degradation mechanisms; on the other hand, to rely on advanced mathematical statistics in order to extract real information from field data. The two—physics and statistics—converge for instance in designing accelerated life tests. In particular, the standard assumption of constant failure rate is often not substantiated by either physics or statistics and in many cases leads to inappropriate conclusions and policies (for instance in maintenance)

4. Third Challenge : Model interactions between components

Once a suitable and realistic reliability model has been put in place for individual items of equipment- the building blocks of systems-, there remains to model the interactions between these individual building blocks. This implies in particular modelling redundancies and modelling the impact of maintenance on reliability, as, in rail transport, we are always dealing with repairable systems. Modelling redundancies implies an understanding of the way redundancies are managed and requires addressing the issue of testability: how a failure can be detected and with which degree of accuracy its cause can be isolated.
Maintenance efficiency and its impact on the reliability of equipment after maintenance can and should be modelled too.
A sound representation of those parameters is a necessary condition if some optimisation of design and maintenance policies is aimed at, with a view to achieving availability constraints at lowest life-cycle cost as mentioned in introduction.
Modelling techniques include Markov models and Petri nets with Monte-Carlo simulations.
While simulations do not entail restrictions on life time distributions, on the other hand Markov models allow more in-depth understanding and sensitivity analyses.
Other techniques such as neural networks or max plus algebra are gaining ground.

5. Fourth Challenge : factoring in operational conditions and human errors

Because contractual targets are often defined in terms of operational objectives—such as : “not too many delays greater than a given threshold”, or “achieving a minimum percentage of planned missions” , it is necessary to translate equipment failures into operational consequences.
Therefore ,models such as FMECAs must allow for inclusion of nominal and degraded modes of operation and the transitions between modes. This implies the ability to simulate operations, often by Monte-Carlo simulations
But, in view of the fact that the human factor is key in those operations, it is increasingly necessary to model probabilities of human errors as well: those of drivers or supervision personnel, for instance.
The nuclear industry has been a pioneer in that area (with NUREG) ; human failure databases rely on cognitive psychology experts as well as on some statistics. In our opinion however, a rigorous actuarial approach to that question remains to be put in place.
Another area of increasing importance is “software reliability” , as several key subsystems of a rail transport system now have a strong IT content (in particular, signalling and train control).

6. Fifth Challenge : risk management

In the end, reliability management is about risk management. Risks have to be managed already at the tender stage, which is when commitments are made. Some risks have to be exported to suppliers. Finally, operational reliability or availability demonstration entails the definition of a maximum acceptable client risk and supplier risk—a special case of the risks of first and second kind in statistical hypothesis testing.
Thus, with increasingly complex systems and increasingly demanding contracts, the reliability engineer is faced with the same issues as the actuary, and should probably benefit from borrowing some of the latter’s methodologies which combine sophisticated statistics with financial insights.

7. Concluding Statement

Rail Transport, although stretching back to the early 19^{th} century, is an area of great vitality worldwide, spurred by urban growth, focus on environmental protection and, recently, governmental infrastructure investments in response to the economic crisis.

Whether the end customer is the general public or private entities (in the case of goods), performance requirements are increasingly demanding in terms of service quality, availability, reliability. With the growth in technological complexity of rail transport systems, this situation creates challenges for the reliability engineer, who has to use the whole arsenal of mathematical techniques creatively while always verifying the realism of his models.