Catering To End -To – End Requirement Traceability Needs in Rail Signalling Systems

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Abstract*— Requirements remain at the heart of all software development process models and not only do they help outline the system capabilities, but also provide the foresight for how the project would shape and how the outcome products may look like. The embodiment of requirements at various stages of system and software development help engineers understand the system to be developed, and also enables them to be more disciplined towards each and every phase of development and test cycles. This paper talks about how requirements can be traced from the inception of system definition down to the last stage of product development and delivery cycles. Requirement traceability has been a concern and a major dimensional hole in current technological practices. The need therefore is to understand the growing complexity and magna-city of development projects wherein rail vertical is also a significant player and impart standard process conformance through requirement traceability and compliance. The paper discusses how better traceability techniques can be applied to Rail Signaling Systems for effective impact analysis, requirement control and change management.

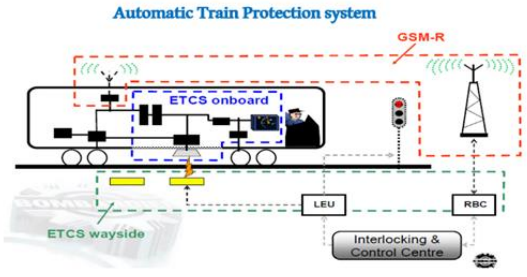
Index Terms- End-To-End-Traceability, Signaling Systems, Rail Control, Automatic Train Protection, Traceability Management, Requirement Traceability, Systems Engineering

I. TRACEABILITY MANAGEMET – AN INSIGHT

The organizations try hard to knit every component of the system together and show case, the traceability or the tracking of their value chain which comprise of each stage of software development cycle primarily comprising of design, architecture, detailed design, implementation, test and delivery. Traceability management is one such information tracking mechanism by virtue of which we can track each component's creation, design, development and delivery phases. It applies fundamentally not only to the software product families, but potentially to all manufacturing processes where information flow control and governance is important and integral part of solution. Mostly though, in the software industry, the traceability analysis and management is referenced more in the terms of requirement traceability as this is considered as the starting point of the production cycle.

- An Overview of Rail Control and Protection Systems

Rail signaling systems aim to provide capabilities to enable safe and reliable automatic train control and protection operations keeping in consideration all relevant standards for inter-operability, safety, availability and reliability for safe train control and traffic management. Automatic Train Control & Protection Systems integrate various trackside equipments like balises , loops for the transmission of information which can be used for speed and distance monitoring within the control procedures. Also, radio communication systems connected to the Automatic Train Control Unit provide necessary information for train movement protection and control across various geographically separated railway lines. The following figure summarizes some of the features of Automatic Train Control Systems:



The figure above demonstrates An Automatic Train Protection (ATP) system connected with the wayside equipments (balises, radar, Line Side Equipment (LEU)), and also with Radio Block Centre (RBC) for receiving as well as transmitting train position

parameters, trackside protection details, speed limit restrictions, mode of operation of train and many other information of use in controlling the train movement and the speed with which the trains are allowed to move.

The above example demonstrates the European Train Control System (ETCS) onboard and wayside architecture which is based on common set of rail standards used for safe, inter-operable and maintainable system operations.

- Adopting Modernization & Promoting Inter-Operability

The dawn to dusk of starting from requirements elicitation, design, deployment, maintenance & up keep of complex real time systems like rail signaling & infrastructure management require diligence and consistent strategical planning & execution enabling safety for the track being operated and ensuring comfort for the passengers desiring a pleasant on-route experience. As human wants are end-less, so are the requirements for advancements, invention and every day discoveries which empower safe, reliable and intuitive rail operations.

Most of the rail control systems are legacy systems where in either the fitment of equipment's are quite outdated or the software control system deployed is conventional. Transforming such systems is not only cost-centric but also requires huge investment in deciding the most viable standard specification which is at par with the national policies, provide safe alternative to current infrastructure and also aid in future maintenance & repair cost. To decide such transformations, require adequate investment in time to compare on market solutions available and the amount of inter-operability promised.

With the geo-political dynamics changing rapidly, the world is seeing fast paced developments in northern, eastern and southern corridors and all countries participating in the rail route would have benefits in diversifying trade and transportation routes and restructuring logistics flows. There is therefore a need for harmonizing the IT platform and developing rail protection systems which have conformance towards universal safety standards as well as traffic control system requirements. The bigger challenge here as well remains to adapt the existing systems towards new technological advancements which cannot come without considerable evaluation of cost involved and the benefits of gradually enabling the legacy hardware /software fitments with iterative stratification and mitigation policies.

The engineering solutions adopted therefore would not only pave a way for partnering in the current rail deals across nations but, would also be a game-changer for comprehensive rail and shipping connectivity between different countries, increase flow of energy, trade and digital communications.

- Drawing the line between SYSTEM and SYSTEM OF SYSTEMS

When software components are connected with each other through various hardware and network interconnected channels, nodes and devices, it sometimes becomes hard to understand where the system boundary started and where it is directed to end. A system generally defines a set of collected elements aiming for a common purpose. The purpose meant to fulfill the demands of a certain set of stakeholders, might indirectly also be a beneficial viewpoint to extended set of stakeholders. It is indeed vital therefore to set the boundaries of what is considered as a system so that the reach and visibility of the environment is controlled, configured and traceable. As far as possible, the end-to-end traceability should be maintained within a system boundary only, as it helps in defining and controlling the scope of change management, alignment of any deviations from defined interface specifications and provides an easy to use and manageable system having viewpoints of use for all connected stakeholders.

Rail signaling solutions generally are inter-connected systems where railway infrastructure authorities, track side fitment units, and onboard rail operation control centers work hand-in-hand to provide safe passenger transit. With such diverse set of engineering units working closely, clear delineation of software system (i.e Automatic Train Control & Protection Unit), its role, and its boundaries towards overall rail network operations need to be defined and the project management should only start once it is defined what all standard specifications categorize as part of system scope.

- Work Flow Management for Rail Signaling Operations

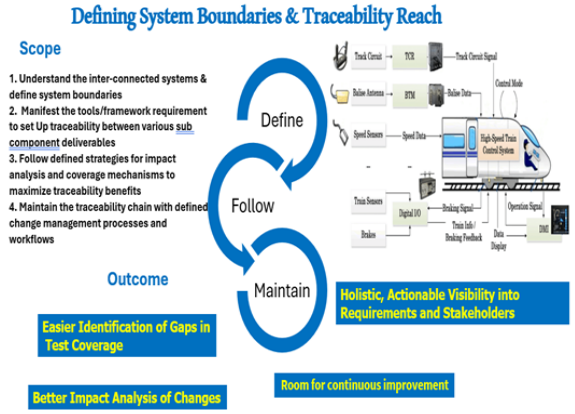
Coverage and traceability when applied to signaling systems has a whole together different meaning because of many many reasons, some of them are:

- Signaling systems rely lot on how legacy systems where developed, and since legacy systems cannot be upgraded very easily, because of infrastructure, technology, political as well as environmental conditions, therefore, bringing any type of changes in the ways of working incurs huge cost, which organizations are reluctant at the first submission.
- The inter-operability concept and standards used with railway signaling is relatively new, and with the known challenges, adopting to new process frameworks, changes in documentation formats and upgradation of current system towards a new "framework" is not only time consuming, but has its own risk.
- For a seamless use of traceability and coverage schemes and techniques, it is needed to bring an approach, where in a parallel process upgrade can be planned and executed in a separate stream of operation, which finally can be integrated in the mainstream production environment.

- Understanding Heterogeneous System Architectures

Current day software systems follow vivid development & test cycles where every product may or may not have the same set of deliverables and would also not have the same expectations from different stakeholders. Not all projects require the use of traceability frameworks in order to achieve end to end coverage cycle. Depending upon the budget, constraints & the magnitude of the project, it therefore becomes important to strategize the need for investment in a requirement traceable solution & then make a conscious decision for the tool/framework which best fit the project needs.

As rail signaling systems cross national boundaries, the number of incidents reported per day is also huge. The number of track incidences is also dependent on the rail infrastructure, track layout and the safety parameters used & any software-based solution would require a careful investigation of the impact any change in the product would have on the overall performance of the trains on track. Requirement linking & coverage enhances the functional index of the deployed system & increases the confidence that the delivered solution is much closer to the initial requirement & is also deemed safe for operation.



The above figure talks about a lot of things that should be manifested in the project life cycle principles aiding in the traceability plan. At the outset, it is vital to identify the system boundaries, and to know, which all phases of product development & which document deliveries would be entitled to be part of the traceability chain. Once these deliverables are streamlined, further investment can be made in selecting the tools/frameworks to be used. This is the most difficult phase in terms of decision making as not all organizations can pay heavy cost associated with project management software's, and neither do the complexity of projects allow to put so much investment in purchasing high end traceability solutions. Some projects are smaller, with strict timelines and require more emphasis on product development, than following strict processes. For such projects, the project & technical managers may want to give little importance to maintaining good process paradigms, presuming, that low-cost projects have limited bandwidth in terms of time & cost to bring new scope for document linking, coverage & completeness checks. These justifications may sound reasonable looking at the constraints, but such perception only would lead to ignorance to the fact, that small scale projects are also opportunities towards laying templates which can be compact open-source solutions. Experimentation on small scale projects open doors to create process blueprints which would

offer long term advantages for time critical low budget projects. The experience evolved can be shared with other upcoming endeavors.

After the decisions are in place, with the framework with which traceability would be maintained, the emphasis must shift towards maintaining a stringent change management process where impact analysis and coverage gaps identification becomes simpler, efficient and fruitful.

- Benefits of End-To-End Traceability

Out of the many benefits of having a well-defined traceability cycle, some are listed below:

- Easier Identification of Test Coverage Gaps

With any system design that manifest a traceability framework that links almost all development phases, it becomes quite easy to find out requirements which have a missing/incomplete test coverage. Considerable effort should be made to link all testing types to the system/software requirements in order to achieve 'near complete test coverage'.

- In-depth Analysis Support

Traceability frameworks provide holistic view of the system where stakeholders can analyze from any corner, the component requirements fully covered and the ones which are yet to be implemented or tested. Such transparent layout aids in better investigation and impact analysis.

- Predictive Planning & decision making

Railway undertakings test software solutions first in field environment and then the proven software are deployed for commercial operations. There are various findings /defects / change request which are reported to the software service organizations for resolution or mitigation analysis. Such findings sometimes take time & effort in first understanding the root cause, and then realizing the impact which can be trivial or it may even have safety considerations. Having visible coverage for affected requirements bring the power to make wise decisions for non-compliance reports which might be critical for system operation.

- Improved software life cycle management

Bringing 100% compliance to requirements and delivering a fail safe system is easier said than achieved. Organizations remain under constant pressure to deliver within time limits, not increase the project cost and provide deliveries worth a praise. Achieving all this, and still maintaining process compliance requires discipline in the way quality considerations are followed and coverage gaps are filled. End-to-end traceability management is a positive step towards better control of software life cycle phases and helps in providing relevant information in real time.

With all the benefits that exist in following traceable solutions, there are also some considerations which should be kept in mind before starting to bring such frameworks. Below are some points to ponder.

- Answering the right questions through Right Process Measures

Before selecting any framework for coverage and traceability management, the below questions should be asked & brainstormed, before deriving the process changes

- Is my chosen strategy to maintain information traceability going to be a scalable solution keeping the futuristic needs, growing complexities in due consideration?
- Is my traceability work flow helpful to understand the root cause or coverage gaps easily?
- Are the software component(s) tracked providing sufficient information /value-add to the engineers who become the actual users of this data to carry out day to day development and test operations?
- Does a requirement traceability matrix provide enough symbolic guidance to "each" stakeholder who officially belongs to the System Under Development?
- Will the current traceability help me to take prudent decisions to carve a better plan for the upcoming/future activities?
- Does my current traceability model contain the capabilities to isolate risk, mitigate change management needs and re-orient the system through regular updates and maintenance?

- Develop “System Thinking” With an Umbrella View of System

Not only it is important to have traceability in the system to be able to track changes or comply standard specification, but , it is equally paramount to look at traceability study as an aid to grow “System Thinking” which not only helps system engineers in looking at the system from every pole , but equally enables creating viewpoints which can manifest wisdom for system and software architects leading towards better decision making , qualitative system evolution providing also scope for improvisation & betterment suggestions for lifecycle management.

- Reaping the fruits through evidential Impact Analysis

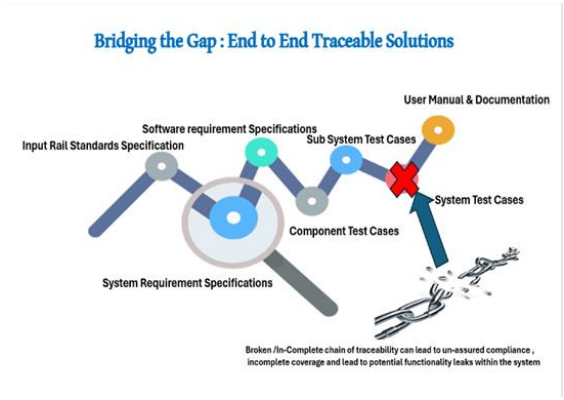
With the growing need to control & manage data which is pumped into the system every second instance, it is important to draw useful information from this giant set of data source. Statistical data analysis at every stage of software development can aid in better understanding the problem statement, visualize the system through modelled architectures and promote better decision making for safe operations.

- Traceability Management for Signaling Systems

With the growing Rail signaling system complexity and the maintenance releases that are currently managed, it is even more necessary to consolidate system behavior that can be well interpreted by all stake holders of the system.

With signaling systems, major emphasis is given to maintain the safety of the system, and in order to ensure standards are followed, all products are rated as per Safety Integrity Levels (SIL). In situations where new defects or non-conformity reports are obtained from field trials which indicate safety leaks, it becomes vital to analyze the underlying root cause behind scenarios which can lead to hazardous situations to occur. While implementing solutions towards safety designated reports, the interpretation of data becomes essential and also the study of adjacent scenarios /environment /platforms /sub systems is required to detect faults that may occur in the system if left un-identified causing severe safety crisis.

II. CHALLENGES AND RISKS



Rail Signaling systems hold several challenges in implementation of an end-to-end traceable solution as the product development as well as management is spanned across various geographical locations, with various teams/vendors/partners contributing towards product fulfillment and project lifecycles ranging from few to several years of production and maintenance work. With such a magnanimous scope of operations for rail control and protection, it becomes difficult as well as taxing to keep control of all phases, have a central view which reflects on the actual state of signaling requirements and their coverage.

- Migration From Current Solution Types

With almost all rail signaling systems deployed since decades, the transformation of software processes towards better traceability is very challenging but equally promising. To combat the underlying risk of additional cost & time, seamless automated transition into a end-to-end network could be the best approach to reach a well-structured requirement traceability matrix. For already developed software systems, which are under sustenance, need based plug-in automation can be added only for software life cycle phases where there is no direct linkage to the traceability chain. For systems getting developed from scratch, as part of project planning phase itself, there need be a traceability plan added which can later be undertaken as a phased activity.

Better Practices

- COMMON FRAMEWORK/ INFORMATION BACKBONE For All Traceability Needs

With diverse software development culture and vivid ways of execution , it becomes important to have a system where the system level requirements , software architecture specification , software requirements, system and software level test cases , test plans and validation process results are all maintained on one single platform preferably onto a single framework or tool which can manifest all the software details and also provide system interface details explicitly to all stakeholders looking for information views belonging to individual project phases.

- Linking the block/component deliverables together in diverse development environments

For legacy systems or deployed architectures, where flexibility is limited and the software development environment provide limited opportunities to add additional work flows, small gateway or bridge plugins can still be scripted to understand the underlying deviations and where all compliance is partial or limited.

In circumstances where achieving full end traceability is difficult, such projects still can ensure corrective quality maintenance by regular audits, periodic failure count analysis, static coverage analyses on various testing types and adaptation of robust regression mechanisms.

- Capturing All Documents in the Traceability LINK chain

The software/hardware development lifecycle might have various documentations being maintained as part of each phase deliverable which convey deliverable details for each milestone completed. As per the defined lifecycle model, any document deliverable which had been created /maintained for the accomplishment of a defined set of requirements must belong to the traceability LINK chain.

Requirements remain the core of any software system under production and the better the requirements are managed, there are better prospects of having a robust system. The “link chain” ensures that all artifacts/deliverables are taking requirements as there foundation and the link is maintained just like a tree is nurtured from the roots, where fruits and flowers grow as profits from the investment on the root level. Controlling & governing the entire system thus would be more fluid, and maintainable.

Bringing End-To-End Traceability

Not many organizations in this fraternity of software manufacturing and development have declared to have achieved end-to-end traceability, probably because, it is easier said than done!. There are inherent challenges in doing that, as it would mean that, all our documents, at-least all system & software level specifications are linked with a chain and with that it is also possible to pick any one object (eg. Stakeholder /system level requirement) and see its entire path of induction in the system, its allocation to various software segments and then finally, its linkage to design, development and test. End to end traceability is ONLY said to be achieved if ALL stages of software development and test can be linked to the parent requirements in a way that looking from the top-most object, it is POSSIBLE to trace down to the last/bottom object in the system, NOT leaving any phase being skipped/missed in this traceability link chain.

CONCLUSION

Complex command & control systems like rail signaling remain vulnerable to safety & hazard situations where emphasis need to be given on which component fixes would not lead to further system damage. Understanding rail standard specifications and then diffusing them in component deliveries requires complete understanding, analysis & interpretation at various phases of software development. It does not happen always, that all parts of the system requirements are implemented, and the lack of proper coverage statistics then hides incomplete realization leading to non-compliance.

End-to-end traceability not only promises closer compliance to standard requirement specifications, but also affirm software product deliveries as reliable and safe for on track operations.

As new generation systems grow towards inter-operable, “self-learning” predictive maintenance environment, it is the need of the hour , that the rail signaling operations and the software product development cycle ensure seamless requirement traceability providing multi fold benefits in better

impact analysis, easy isolatio, efficient change management and measurable planned scope.

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