Essential Elements of System Integration

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The inclusion of microprocessors and their concomitant software in railroad control systems such as the Advanced Train Control System (ATCS) marks a significant change from the previous integration practices of railroad equipment and also introduces issues and concerns that have not been encountered previously with the integration of analog systems. Systems integration is an engineering discipline that works to integrate many diverse parts, with independent operating characteristics, into an entity that functions as a system. The three basic elements of systems integration as they relate to the integration of ATCS by the railroads are goals, planning, and execution. The goals serve as a tangible framework for the many design decisions that must be made in integrating a complex system. Goals must identify the customer, provide a basis for an implementation strategy, and provide a manner for measuring success. Planning is needed to achieve these goals. Proactive project managers engage in thorough and extensive planning to ensure the success of the project. Experience has confirmed repeatedly that efforts spent in up-front planning have a 10-fold payback during the project execution phase. Execution is managing the project to the plan, modifying it when necessary to accommodate the changing environment. The systems integration process is dynamic and design decisions must be made constantly. Meticulous attention to these activities ensures success, reduces life-cycle cost, and reduces the project schedule. Failure to attend to these activities guarantees increased cost, extended schedule, and reduced technical performance.

Systems integration is more than just cabling black boxes together, turning them on as a unit, testing them, and then installing them in the field. Systems integration is a managed process that combines diverse elements into a single entity to fulfill a specific need. This engineering discipline was developed in the 1960s by the National Aeronautics and Space Administration (NASA) to manage mission-critical engineering efforts. It is a complex, nontrivial process.

Although systems integration is sometimes equated with software development, it is in fact broader in scope. For digitally based systems like the Advanced Train Control System (ATCS), systems integration includes the development of software as a subordinate task. Discipline is needed to successfully integrate many diverse parts, with independent operating characteristics, into an entity that functions as a system.

Systems integration is the resolution of design disconnects that occur when many diverse components are brought together, often for the first time, to solve a problem or achieve a goal. Each resolution requires engineering and management decisions, and each decision must consider the impact on the system as a whole. The impact of these design decisions on the components (downward) and on the system (upward) must be considered.

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Systems integration has been an evolving discipline over the past 30 years. It entails engineering and management aspects that have been developed as a body of knowledge for implementing complex systems. The weapons of Desert Storm are examples of successful integration projects. Although NASA invented systems integration, it has also provided examples of what happens when the planning and management guidelines are sidestepped or ignored: the Challenger in 1986 and the Hubble Space Telescope in 1990. In both cases, established procedures were sidestepped. Engineering findings that indicated seemingly trivial problems were ignored. But NASA has also provided examples of proper management of technical failures—for example, the safe return of the Apollo 13 astronauts after an explosion in the command module en route to the moon.

The inclusion of microprocessors and their concomitant software in railroad control systems marks a significant change from the previous integration practices of railroad equipment. Although the use of digital systems can provide better control and other advantages, it also introduces issues and concerns that have not been encountered previously with the integration of analog systems. In digital-based system, the software implements the required functionality and logic for train control and management information.

Changing requirements is a prevalent problem, especially in the design and implementation phases of software-based systems. Although software is flexible, it adversely affects the structure and coherence of the design when basic architectural structures are modified. Changes to the system required to accommodate these design decisions must be tracked, and their impacts on the system as well as on the schedule must be considered. This in turn affects design documentation and further implementation.

Systems integration is a cyclical process. Engineering and management must be involved in making design decisions to resolve ambiguities in the specification of the system and to overcome design problems. Projects rarely fail for technical reasons. Failures can generally be traced to the management of the project. The essential elements of systems integration can be distilled into three seemingly trivial and self-evident elements:

- Understand the goal.
- Plan the project.
- Execute the plan.

The commitment to these elements will define the degree of ATCS success.

Integration of a system such as the ATCS can be accomplished in many ways. A railroad may serve as its own systems integrator, contracting out the many parts of hardware and software needed for the entire system. This puts a significant engineering and management burden on the railroad. Mechanisms and procedures must be in place to resolve the inevitable design ambiguities and disconnects that will occur. These decisions must be tracked with regard to implementation and analyzed with regard to system impact.

At the other end of the spectrum, a railroad can hire a systems integrator to produce a turnkey system. Although greatly reducing the number of engineering and management design decisions to be made, this approach does not reduce their importance. In fact, with a systems integrator, design, engineering, and management decisions made by a railroad will be more important because they will be made at a higher level of system design and thus carry greater leverage.

A third approach is somewhere in between these two extremes, with a railroad using a carefully crafted strategy of implementation in conjunction with a systems integrator.

UNDERSTAND THE GOALS

Although it seems trivial and self-evident, the importance of understanding the goals of the project cannot be emphasized too much. "Understanding" means an intrinsic knowledge of what benefits are to be realized when the goals are achieved and how the goals interact among themselves. It is not sufficient to write a list of goals, then nod approvingly and relegate the list to the shelf. The stated goals must be articulated and made part of everyone's thinking.

The goals serve as a tangible framework for the many design decisions that must be made in integrating a complex system such as the ATCS. The basic goals of ATCS implementation are essentially the same for all the railroads: better operations, economy, safety, and customer service. However, in implementing the ATCS to support these broad, generally accepted goals, a diversity of opinion exists among the railroads.

What the ATCS is seen to provide for each railroad depends on that railroad's existing operations, market, economic viability, and labor relations. In the case of the ATCS, each railroad has stated different goals for its implementation. One sees the ATCS as an extension of the management information system (MIS) for dispatch orders. Another sees the ATCS as a communications system linking the operational elements of a railroad. A third sees the ATCS as a safety system. A fourth sees the ATCS as an active train control element, whereas a fifth views it as a system to help monitor locomotive health. In all cases, the ATCS is seen as a system to help the railroad as a body to become more efficient and competitive in a rapidly changing transportation marketplace.

These goals are manifested as the order in which the various ATCS functions and applications are executed and implemented by each of the railroads. But what of the process by which understandable goals are defined for a systems integration project? A starting point is to pose and answer a series of questions.

At the strategic level we must ask, What is the desired benefit for the business? Is it increased customer service, reduced operating expenses, more efficient operations, reducing accidents, or enhancing train control? The answers must include the specific problems to be solved and the operational concept envisioned to solve the problems. The goal must be stated specifically enough so that a strategy for implementation can be devised.

Second, we must identify who the customer is for the ATCS implementation. Is it the operating divisions, the information division, the maintenance division, or the R&D division? Some subsidiary questions include who must be satisfied—that is, Who is the system being built for?

Third, we must ask when the system needs to be operational. Now? next year? or 10 years from now? Some subsidiary questions cover identifying the schedule drivers, the timetable for realizing the benefits from the system, and any other schedule-related implementation requirements.

Fourth, we must define the commitment in terms of money and resources for the integration. How much is it going to cost? How will it be paid for? How will cash flow and operating costs be affected by the investment outlay for ATCS? What specialized external resources are required?

Fifth, we must specify what exactly we are going to build. Is it going to be ATCS specification components, an ATCS-compatible communications system, a train locator, or an enhanced MIS? We must ask what the operational elements of this system are and whether they satisfy the envisioned operational concept.

Finally, we must determine how we will measure success. Is it to be profitability, market share, customer response, or some other performance measures? In other words, how will we know when we have achieved our goals? The goals must be articulated clearly and explicitly linked to measurable performance parameters. If the goals cannot be explained and formulated so they are amenable to scheduling, staffing, and planning, they are too complex or too ambiguous or both.

Goals must be clear and well defined. Only then does everybody understand the same concept of what is to be implemented or realized. Only then can the team work in concert to achieve the goal. Systems integration of the ATCS is a complex undertaking, but the complexities can be reduced to manageable pieces in the context of clearly defined goals. With clear goals, we will know which path to take to reach our destination.

PLAN THE PROJECT

Once we thoroughly understand the goals, we must plan to achieve them. The second element in successful systems integration is to plan the project. Successful projects are managed by project managers who are proactive—or very lucky. Although luck is capricious, planning is not.

Proactive project managers engage in thorough and extensive planning to ensure the success of the project. The ATCS is a complex and sophisticated system. This makes planning all the more essential, because people will change and a realistic project plan will provide the only continuity. The importance of continuity is that it provides a baseline against which the steps toward achieving the goal can be measured.

Some believe that extensive planning is a waste of time. Managers who ascribe to that philosophy are demonstrating their own lack of proficiency. Experience has confirmed, repeatedly, that efforts spent up front planning have a 10-fold payback during the project execution phase. The dividends paid by proper planning always exceed their cost.

It is, for example, very inefficient to staff a software development team to complete a task in 6 months when the supporting hardware cannot be fully deployed for a year. The software development team could have done the same job, within the overall schedule, with fewer people and better coordination if it had been allowed the year. Overall, project planning allows the project manager to establish appropriate staffing levels to increase staff efficiency.

Proper planning also allows a manager to ensure that each required task is being addressed. How many times have we heard, "I thought Joe was doing it." Of course both Joe and the project manager thought Judy was responsible. When the oversight is discovered, Judy and her now understaffed and underfunded organization must do the work under extreme pressure. The project will probably be poorly executed and costs will spiral. Is it Judy's fault? Of course not. It is the manager's mistake for not properly planning and delegating the work.

The ATCS is a top-down design. This makes it very important that the integration be controlled by a series of plans so the resultant product does in fact meet the top-level goals. What we want to avoid is the electronics equivalent of the classic cartoon of two railroads meeting—but only one rail is connected. Carefully managed systems integration will avoid such a faux pas.

Based on the nature of a systems integration project and the supporting organizations, several management plans are required. One aspect of proper planning is to determine the plans required for a particular project. Some of the most critical and most often overlooked management plans should be developed very early in the project during the system requirements definition phase. Even the simplest turnkey projects require these planning steps. More complicated in-house integration efforts require more extensive planning.

Project Management Plan

The most important plan—and a key element in every successful project—is the project management plan. It is also the most often overlooked, and when not overlooked, the most often deemphasized. Every experienced systems integration project manager will agree that a thorough, well-thought-out project management plan will virtually guarantee success. The lack of one portends failure.

A comprehensive project management plan states, in a single place, the goals of the project, how those goals will be achieved, and how success will be measured. It identifies the customer for whom the system is being built. Even in-house development efforts have a customer, and it is critical to identify that customer and thoroughly understand the customer's expectations—that is, the project's goals.

The project management plan states the roles, responsibilities, and authorities of key members of the project team. It includes a project work breakdown structure and assigns a budget and responsibility for each element in the work breakdown structure. It identifies project and nonproject resource requirements. It specifies project constraints and establishes an overall project schedule. The plan clearly specifies the requirements for risk management, change management, product assurance, and vendor and contractor management. It establishes the mechanics of project performance monitoring and analysis. It specifies testing and acceptance criteria. It defines reporting requirements and establishes the administrative details for the project management office. It is impossible to manage successfully a complex systems integration project without having considered each of these subjects as they apply to the particular project.

Risk Management Plan

A second, often overlooked, project management plan is the risk management plan. This plan describes the process for evaluating implementation risks and mitigating their impact. Risk management includes both risk assessment and risk control. Risk assessment is identifying, ranking, and analyzing the probability of occurrence and the impact of risks. Risk control is mitigation planning, resolution, and monitoring.

The risk management plan specifies the procedures used to implement the risk management requirements from the project management plan. Some risks can be identified at the beginning of the project, others are more subtle and invisible until the project is under way. The risk management plan identifies each anticipated risk and is continually updated to keep it current. For each risk, the plan specifies a course of action to be taken when a risk tolerance threshold is exceeded. Some predictable risks should always be addressed:

- Productivity and sizing estimates,
- Contractor and vendor performance,
- Vendor decision to abandon the business area,
- Requirements and specification interpretation,
- Availability and attrition of key personnel,
- Assumptions for planning decisions and technical specifications,
- Changing requirements and technical specifications,
- Changing priorities,
- Unnecessary functions, and
- Disruptions to operations.

In addition, each project has a set of unique risks. Overall project cost, schedule, and uncertainty are reduced when each of these risks is identified and monitored from the beginning of the project.

Change Management Plan

The third plan that must be addressed from the beginning is the change management plan. Requirements will change, and it is only prudent to recognize this in the beginning. The change management plan specifies the procedures for managing the change. It must cover, at a minimum, (a) technical, cost, and schedule impact analysis of proposed changes; (b) review procedure for proposed chances; (c) classification and prioritization of proposed changes; (d) approval authority delegation for proposed changes; (e) notification to affected organizations of the approval of changes; and (f) performance monitoring of changes.

The importance of understanding the impact of changes on the total project is critical. A seemingly trivial software change may affect the system, hardware, and installation engineering, as well as training and product assurance. "Inconsequential" efforts may end up costing the project tens or even hundreds of thousands of dollars.

Once the true impact is known, who has the authority to approve such changes? Does the customer really want the change? How much is the customer willing to pay for it? Does the development staff understand the proposed change's broader implications—to operations, for example? What is the impact of delaying the change to a later build? The change management plan must include procedures for answering each of these questions. An effective change management plan has the added benefit of obtaining customer buy-in for each change and for the overall project effort.

Product Assurance Plan

The product assurance plan should address the need for and the methodology of implementing independent verification and validation, quality assurance, configuration management, data management, and independent testing. It should specify the methodology for certifying individual configuration items, subsystems, builds, and the completed system. It must address the need for project standards, organizations responsible for developing project standards, and the review and approval cycle for project standards. It should define (generically) configuration items and establish certification and audit requirements.

A key part of product assurance for software-based systems is the verification and validation plan. This should describe an overall design verification program, covering development of the functional requirements, criteria, specifications, test, and qualification methods and procedures; this should include a plan for software design verification and validation. Specific methods of conformance to approved specifications and accepted guidelines must be demonstrated in detail as well as how the independence of the verification team is achieved.

Effective verification and validation is more than just checking off blocks on a test sheet and generating reports and other documentation. The test sheets and reports are evidence that the software product was examined and reviewed in detail and that it was found to be correct with regard to the requirements. The emphasis of the verification and validation plan should be on tools and techniques for finding problems and the process for resolving the problems identified.

Deployment Plan

Although often delayed until later in the project development cycle, a deployment plan should be considered early in the development cycle. Often deployment considerations affect development sequencing. Long lead-time procurement items or extensive installation efforts may require that system architectural decisions be made early in development. The deployment plan can uncover new risks that need to be addressed. Very frequently, deployment considerations will drive the design. It is always less expensive to do it right the first time than to do it over.

Operation and Maintenance Plans

Like deployment plans, operation and maintenance plans are often delayed until late in the development effort. As with deployment planning, operation and maintenance planning often uncovers design, scheduling, and risk considerations that should be addressed early in the project. The operation and maintenance planning also provides a vehicle for input from those people who must work daily with the system being developed, in this case, the ATCS.

Other Elements

These six plans, once developed, are not unchangeable. They are living documents that are modified to reflect changing conditions with respect to the project. They do, however, contribute to a life-cycle cost baseline against which proposed changes may be evaluated.

To complete the list of essential planning elements for systems integration, the system engineering plan and the system development plan require mention. The necessity for additional implementation-type plans will grow out of the requirements established in these high-level plans. Training plans, staffing plans, configuration management plans, and other detailed planning documents will evolve from the requirements established in the top-level plans.

In addition to these plans, each project should have a project bill of materials, a configuration item list, and a project critical path network. The bill of materials, of course, is necessary to track the materials required, ordered, and received. It is often expanded to include storage and need locations. The quantity portions of the bill of materials are usually configuration-managed.

The configuration item list consists of all deliverable software, procedures, plans, and documentation. It is sometimes expanded to include services such as training.

A critical path network is necessary to understand project dependencies, resource utilization, and cash flow. It is essential to understand project performance and the impact of changes. To be effective, a critical path network must show all internal and external project dependencies. A good rule of thumb is that the critical path network should contain one task for each man-week of labor. For example, the critical path network for a 20 man-year effort should contain about a thousand tasks.

The experienced project manager will involve key members of the project team, his superior, support organizations, and the customer's organization in developing these plans. Once developed, the project manager will secure acceptance and approval from these same people. Before finalizing these plans, the project manager will likely have the drafts audited by an independent third party—a coworker or a peer—to make sure that everything has been considered and a solution set has been established for managing a complex systems integration project.

EXECUTE THE PLAN

Proper planning is reduced to an academic exercise if the plan is not maintained and followed. For the plans to be responsive to the needs of the project they must be maintained, reviewed, and updated to reflect the changing project priorities and requirements. The plans must be thoroughly understood and followed by everyone on the project team, and customer, and support organizations.

The management of a complex systems integration effort, such as the ATCS, is beyond the capabilities of any one individual. Such an effort is generally managed by an organization established for that purpose. The project manager heads the organization, generally called the program management office (PMO). The PMO is chartered to be responsible for the following:

- Ensure that project goals are met;
- Develop, implement, and refine the plans;
- Define the framework for project design decisions; and
- Document, coordinate, and communicate the decisions.

In practice, the PMO performs the following functions, as a minimum (additional responsibilities may be included to satisfy the organizational needs of a particular project):

- Manage the project operations;
- Track, analyze, and audit technical performance;
- Track, analyze, audit, and improve cost and schedule performance;
- Manage vendors and subcontractors;
- Manage risk;
- Manage changes;
- Coordinate with users, customers, and executives;
- Coordinate designs and activities within the project organization;
- Plan project activities;
- Administer the project; and
- Report on project progress and issues.

Historically, projects of the complexity of ATCS invest 8 to 10 percent of the total project budget in the operation of the PMO. The PMO will save many times that amount in project cost and schedule.

CONCLUSION

Planning is essential for success. Each system integration of the ATCS must focus on success. This means that the goal is clearly in mind when each of the intermediate steps is taken and design decisions are made. There is no magic "cookbook" approach to systems integration. Prepackaged solutions are applicable only to prepackaged problems.

The systems integration process is dynamic; design decisions must be made constantly, whether by the railroad or the turnkey systems integrator. Keeping the goals in sight and the plans updated, the systems integrator must always consider ways to reduce risks of implementation and to enhance the safety of the overall system, all the while working within the cost and schedule constraints imposed by top management.

Each railroad must make an assessment within the context of its own business operations and ATCS goals how these essential elements of system integration are to be satisfied. Although having each of these elements in place does not guarantee success in integration, the potential for failure is increased when these elements are overlooked.