Teamwork for Complex Projects with Digital Twins

Introduction to Project Design with GPD's TeamPort

GPD provides a capability – called *Project Design* -- to rapidly create and evaluate plans that are realistic and reliable. The plans are *designed by the teams* on the project -- including schedule, cost, use of constrained resources, and risk management. In a collaborative, visual modeling session the participants capture the full impact of changes, variation in assumptions, architecture, and other real-world execution parameters.

With *Project Design* teams develop a model of a project which integrates three fundamental systems: products, processes, and teams. A graphical depiction of the relationship amongst these three promotes a common view shared by management and program teams. A simulation engine, leveraging the model, generates forecasts with analysis across many scenarios. These forecasts provide root cause based detail of likely outcomes, including progress, risks, costs, quality, and schedule (e.g. Gantt charts are output, not input). GPD's approach provides a powerful **design space trade-off capability** that delivers rapid and rigorous analysis of options. The value is a high degree of certainty in meeting product functionality, schedule and cost objectives.

Design is an iterative and social process -- the evaluation of choices and outcomes early-on, before committing to a course of action. By rapidly exploring possibilities -- through dialogue, analysis, and prototyping -- awareness is built and better results are achieved. As things change (they always do, don't they?) a good design is easily adjusted. *Project Design* is this forward-looking capability applied to the complex portfolio and programs typical today. Much like design practices and tools revolutionized the product development of companies (e.g. 3D visualization, parametric modeling, QFD, CAD, CAE), Project Design is transforming awareness, speed, and performance of teams.

GPD's *TeamPort* is a method and platform to support Project Design. The platform enables collaborative visual capture of the product, process, and team architectures for a proposed project or program. These architectures emerge similarly to traditional work breakdown structures, integrated master plans, and workflow. They differentiate themselves by the high degree of consistency and completeness that can be achieved at an agreed to and meaningful level of granularity. The software platform further allows the user to subsequently track the evolution of projects and better understand the impact of any changes in key assumptions, requirements, scope, progress, uncertainty, skills, utilization, and processes.

In a workshop spanning several days working with a GPD team, the major stakeholders and team leaders bring their specific skills, experience, and knowledge of the proposed project to the table. Collaboratively the major elements of the three architectures are captured graphically. The GPD team facilitates relying on its experience and modeling skills, supporting the workshop participants to develop a realistic project model. The result is a project model representing the participants' best estimate of the overall scope including:

- The **product** structure breakdown down to a level of granularity considered appropriate (roughly equivalent to the notional functional breakdown structure plus other key elements deemed necessary by the participants because of criticality), and
- A **process** structure consisting of all required activities/actions by the team members to produce the required product (including dependencies amongst the activities and teams).
- The **organizational** structure (geographical location including time zones, team skill levels, roles and responsibilities, degree of availability, work schedules, etc.).

Specific features of global work are modeled including time zones, distributed decision-making, concurrent and mutual dependence, communication patterns, and travel. Depending on the complexity, size and, scope of the proposed project and number of participants in the initial modeling session, a converged model can be generated in one to several days. Very early in the workshop the participants understand how various areas of concern (team makeup, skills, availability, role of time zones, to name a few) affect the overall design of the project. GPD has shown that the overall sense of a complex, global project can be obtained without resorting to a very detailed level of the equivalent work breakdown structure. Relevant knowledge, available to teams early on, is captured while avoiding unavailable or unnecessary detail.

TeamPort Models

The project models can be generated early, while total architectural options are still under consideration. Where complexities and dependence fall within the activities of teams, further granularity in a project model has less value than modeling of the dependencies that fall across team architecture boundaries, and thus drive coordination across teams. It is these cross-team coordination activities that are least likely to be predicted based on previous judgment, whereas team and subsystem internal coordination is more likely consistent with previous experience.

A recent example for a global development program for industrial equipment is shown in **Figures 1- 4**. **Figure 1** shows a portion of the completed model for testing of three versions of a complex vehicle manufactured in and to be tested in several countries. **Figure 2** is the complete model. The complete model (including all dependencies between activities and connections between team, products and activities) can be explored. Various structured views and layers for connections can be turned on and off for clarity. As a collaborative modeling experience, teams explore parts of the project connected from separate workstations then together discuss a shared view at high resolution projected on a large wall. **Figure 3** shows a snapshot of such a projection and team discussion (in this case a printout of the model for the model shown in **Figure 1**). The organizational structure for the model is shown in **Figure 4**.

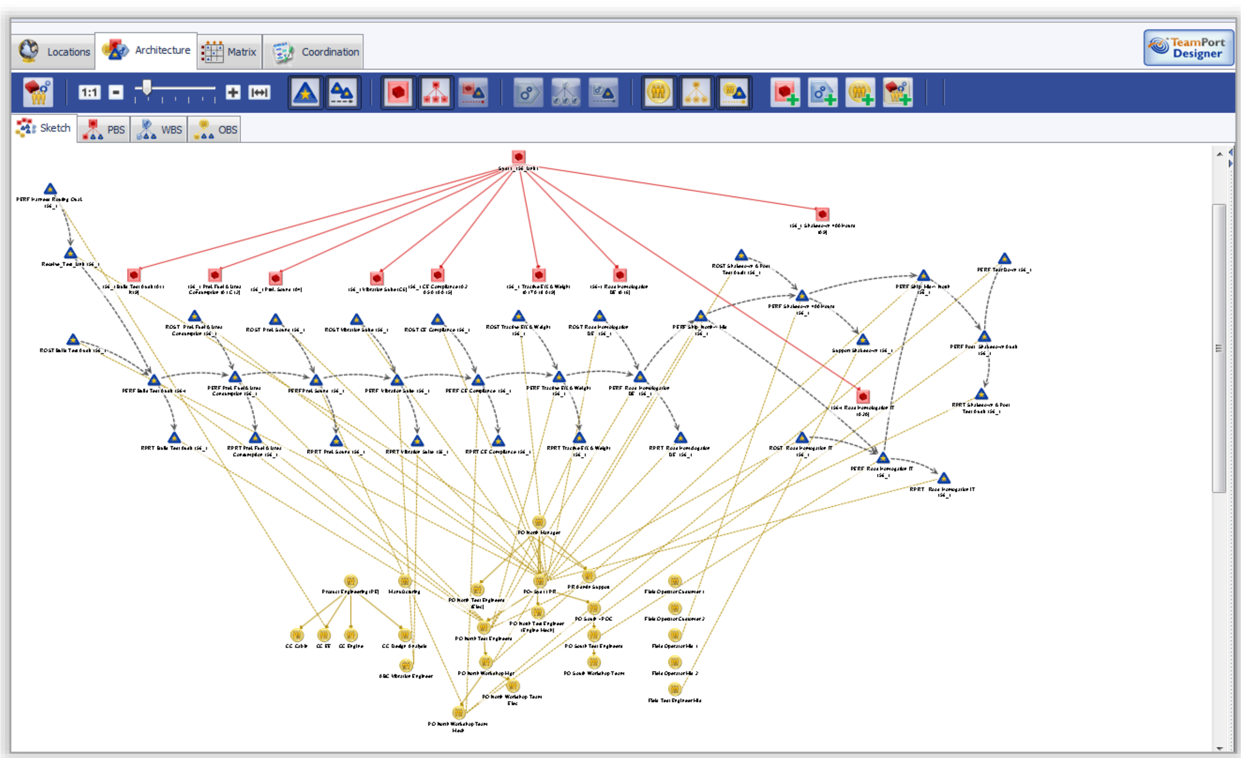
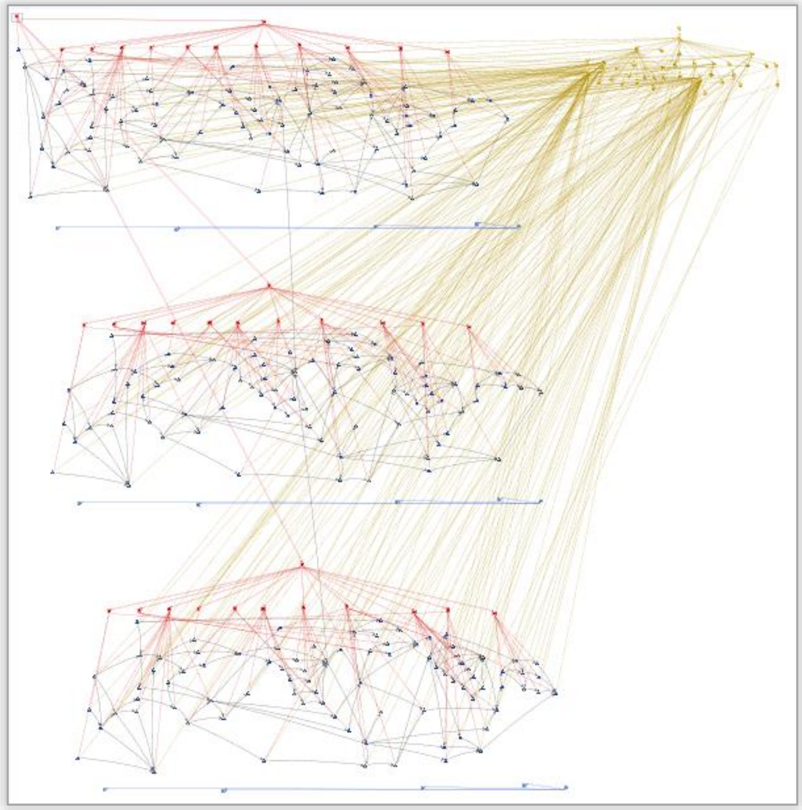


Figure 1*.The figure illustrates a team dialog based on graphical relationships at a high level between the product breakdown structure depicted by red squares, the work breakdown structure depicted by blue triangles and the organization breakdown structure depicted by yellow circles. Lines (yellow) of responsibility between and among teams, mutual and concurrent dependencies between work activities (black dashed curves) are shown; these can be hidden or highlighted in layers for clarity when working with the model.*

Figure 2. *The figure shows the entire project design model for the project described in Figure 1. Projection of such a complex model onto a wall or large screen aids in working with details of the model. Additional views, as matrices, structured layouts, and lists are also generated to promote exploration and a "forest for the trees" view of project architecture.*



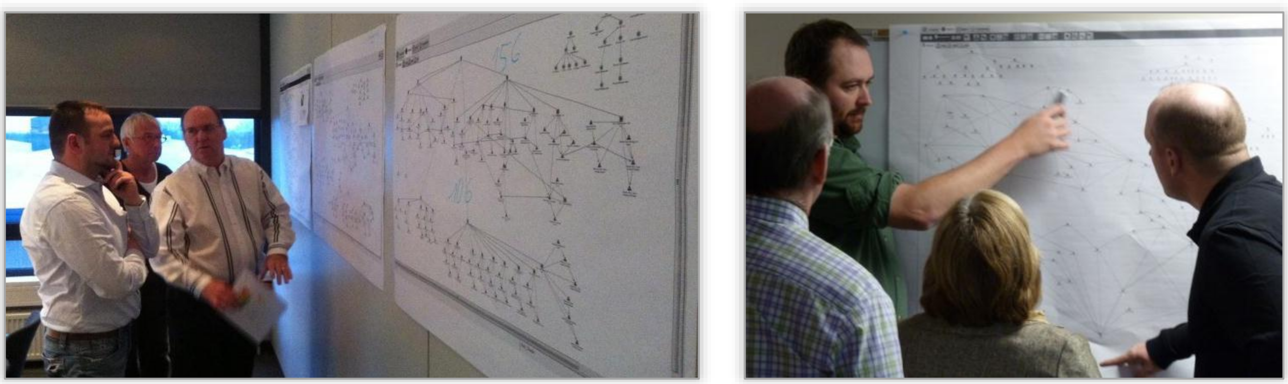


Figure 3. *The figure shows workshop design sessions where a printout of a project design model has been posted on the workshop wall. The model in the figure on the left is the one shown in Figures 1 and 2. GPD team members are receiving feedback from a member of the customer workshop team. Whether on paper or through real-time visual interaction, the teams quickly come to form a share mental model of their complex work and their own role in it.*

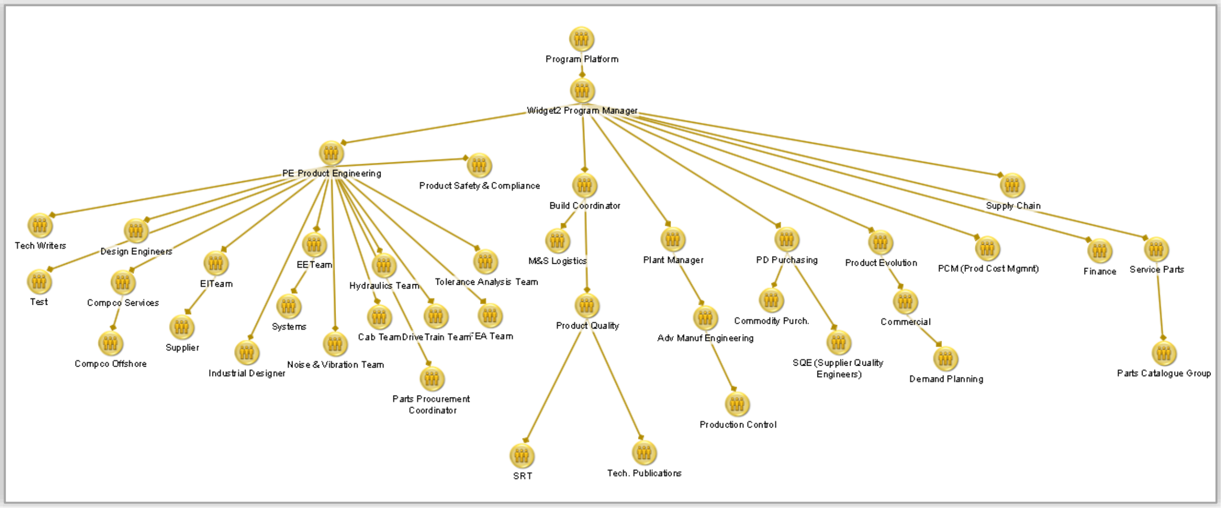
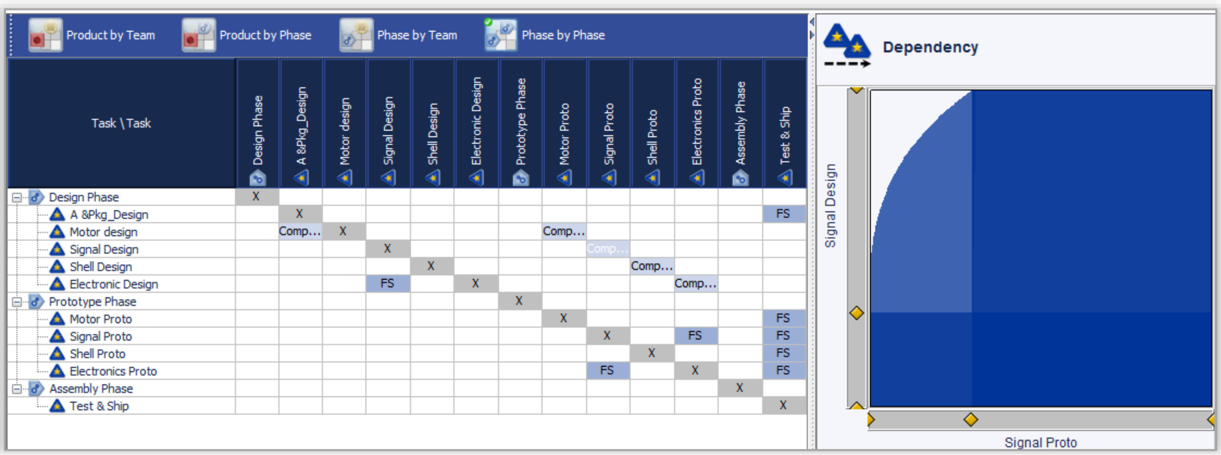


__Figure 4__. The figure shows a view of the organization breakdown structure depicted in Figures 1 – 3. For each of the various team's attributes such as skills, labor rate, location (time zones), availability, roles and responsibility among others are captured. These attributes impact the generated forecasts including schedule and cost.

TeamPort supports a rich set of alternate views of the same project. These views can be accessed and modified at conversation speed. Across a network or in a break-out session in the same facility, teams explore the project model collaboratively. In this way specific aspects of the project can be explored in parallel allowing rapid iteration and improvements by cross-functional teams. A meaningful level of detail is captured quickly, allowing project models that contain more knowledge with less detail. One example is the unique way that TeamPort captures dependencies.



Task \ Task	Design Phase	A &Pkg_Design	Motor design	Signal Design	Shell Design	Electronic Design	Prototype Phase	Motor Proto	Signal Proto	Shell Proto	Electronics Proto	Assembly Phase	Test & Ship
Design Phase	X												
A &Pkg_Design		X											FS
Motor design		Comp…	X					Comp…					
Signal Design				X					Comp…				
Shell Design					X					Comp…			
Electronic Design				FS		X					Comp…		
Prototype Phase							X						
Motor Proto								X					FS
Signal Proto									X		FS		FS
Shell Proto										X			FS
Electronics Proto									FS		X		FS
Assembly Phase												X	
Test & Ship													X

__Figure 5__ An architectural view of complex dependencies emerges as the total project architecture takes shape. Seen from an N^2 matrix (DSM) as shown on the left, or variously across the overlap of product, process, and organization, these aggregate views help teams to see patterns and form a shared mental model of the project at hand. By selecting a specific relationship, in this case the dependence of Signal Proto on Signal Design, one sees (on the right) a rich and realistic representation of the dependency – an ongoing need for progress and interaction.

Traditional techniques (such as CPM, PERT, and FS) show dependencies as precedence -- an expected schedule consequence rather than any coupled characteristics of the activities. The underlying drivers of dependence – the essential meaning – are not expressed. **Figure 5** shows our approach which models dependence as a continuous and mutual demand for coordination between teams. The satisfaction of dependencies is real and ongoing activity – coordination that matches the demand for information with the supply of coordination by teams. Poor coordination can trigger reduced quality, exception handling, wait, and rework.

TeamPort™ Forecasts via Simulation

As the participating teams in the design session converge on an agreed "baseline" model, agent based simulations are carried out to yield multiple plan forecasts. The plans include -- as output -- Gantt charts, progress trends of activity by product, process and organization, as well as cost breakdown across teams. Project progress, schedule, and costs are analyzed through an agent-based discrete event simulation (including a Monte Carlo algorithm delivering variances on key activity and team ability variables) in which team behaviors drive progress. Risk drivers are identified during the workshop as well as mitigation to be captured in the TeamPort model.

A unique feature of the simulation is that coordination amongst teams – activity to satisfy dependencies – is explicitly analyzed. *Coordination activity is real work and must be considered if realistic schedule and cost forecasts are to be generated. Recent studies have shown that most large complex global projects have 35-45% of real work associated with collaboration/communication*. Simulation generated forecasts include the demands, feasibility, and value of coordination to overall performance. Risk due to coordination misallocation is exposed.

Typical simulation results are shown in **Figure 6** including a "smart" Gantt chart (this Gantt chart can be queried to determine the amount over time of work, communication, wait, etc. that is associated with team, e.g. engineers, designers, etc.).

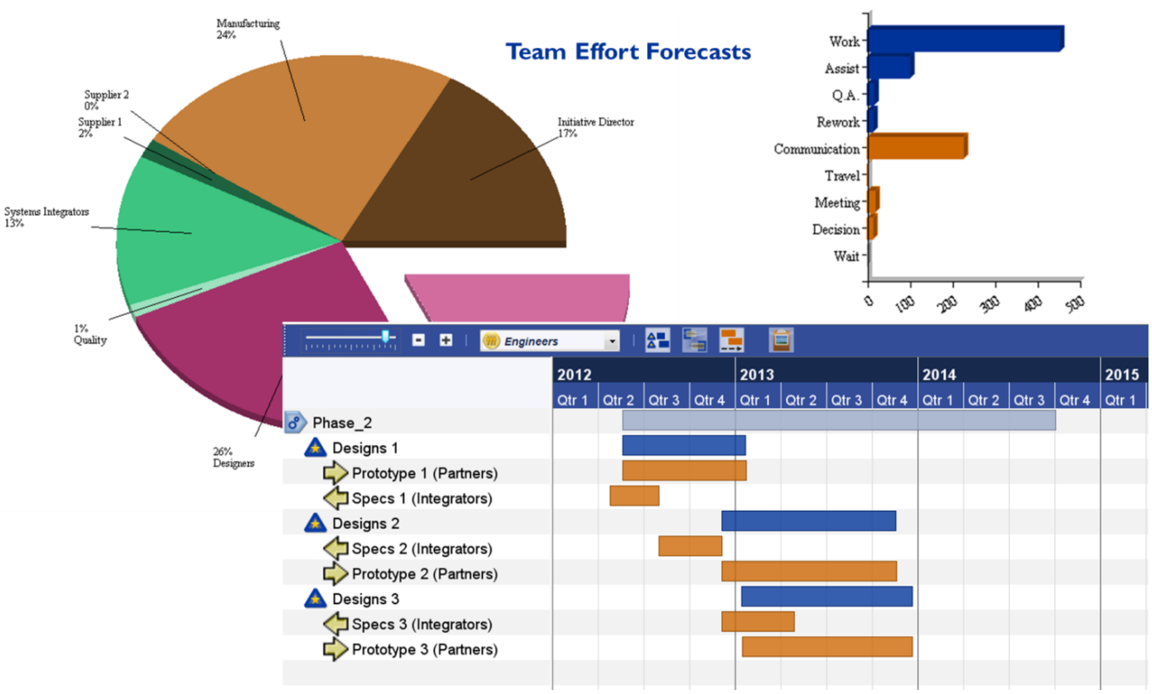


Figure 6. *The figure shows a typical result of a TeamPort forecast. The pie chart denotes the effort in man-hours of the various project teams and support organizations. The pie slice representing the engineers' effort is further queried (to the right of the pie chart) as to the distribution of activity across work, assistance, QA, rework, communications, etc. A snapshot of a piece of a Gantt chart generated by the TeamPort simulator shows one teams work and coordination on the schedule. The generated Gantt chart can also be queried according to teams and their corresponding schedule for work, coordination, wait, etc.*

Figure 7*. The figure shows a* ***Scope Progress*** *forecast of a metric across an entire phase – in this example the tests completion for a complete machine. Other sets of tests and their most likely completion can also be compared, providing foresight into the reduction of risk based on the most critical validation. These progress timeline forecasts can be seen at various product, phase, and activity layers in the project.*

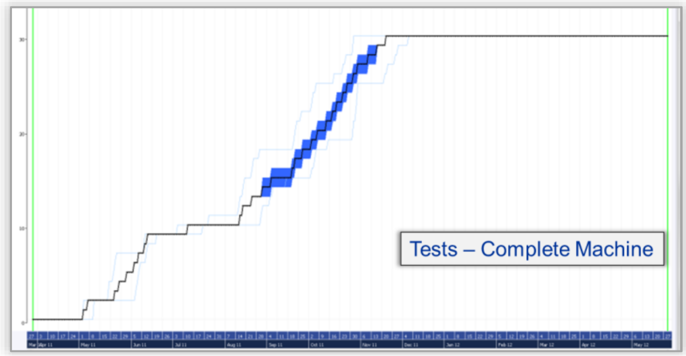


Figure 8*. The figure shows* ***Total Activity*** *for the Design team in this example project. Rather than simply an allocation assignment or capacity calendar, this forecast of expected utilization is analyzed with the interplay between various demands on this team and their skills, capacities, and priorities. Just because a team is available and assigned, does not mean it is well utilized.*

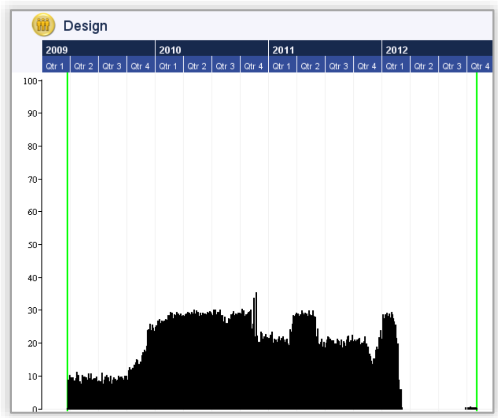


Figure 9. *The figure shows* ***Communication*** *as forecast for the Design team, a subset of the total activity shown in the figure above. The demand for communication is driven by dependencies, meetings, and other factors. Still, the Design team has limited capacity to respond, or perhaps other priorities. Very often, not all communication demand is satisfied, which can have delay and quality consequences.*

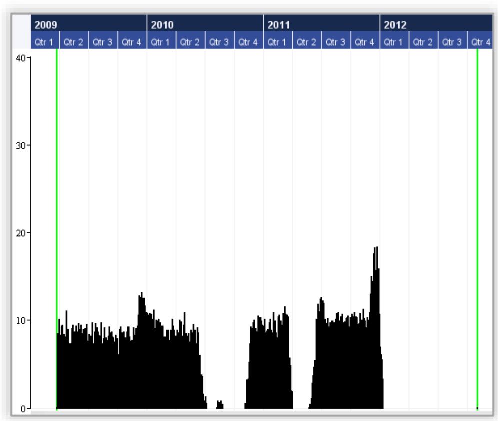
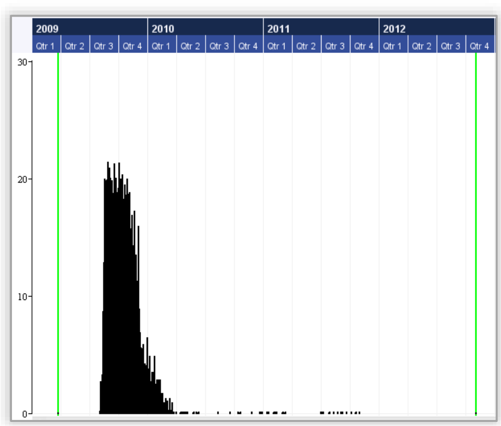


Figure 10. *The figure shows* ***Wait*** *as a predicted activity. In this example, the wait by the Design team is driven by too much concurrency early in the project, at a time when the Design team is active yet there are no other activities on which this team can work. By examining the component activity types of a predicted schedule, the teams can search for the root causes of unexpected outcomes, then propose changes within their control to improve the project's design.*



Trade-Off Studies during Project Design using TeamPort

The real payoff in using *TeamPort* in the project design workshop comes from the rapid assessment of trade-offs, what-ifs and contingencies that arise after the baseline model has been established. The baseline model can be adjusted (dependencies changed, activities added or removed, roles and responsibilities tuned, concurrency increased, worksites changed, etc.) according to suggestions of participants in the design session. Critically, these suggestions are changes in project behavior and architecture that are within the control of the teams in the workshop. Teams are uncovering how changes in their own roles, commitments, and priorities may have a systemic impact on results.

Subsequent simulations lead to a "design walk" which promotes alignment of team views of what affects schedule and cost outcomes and provides a vehicle for rapid trade studies. **Figure 11** shows the typical pattern of results of a one-day session to forecast changes in schedule and cost according to the project model changes at conversation speed.

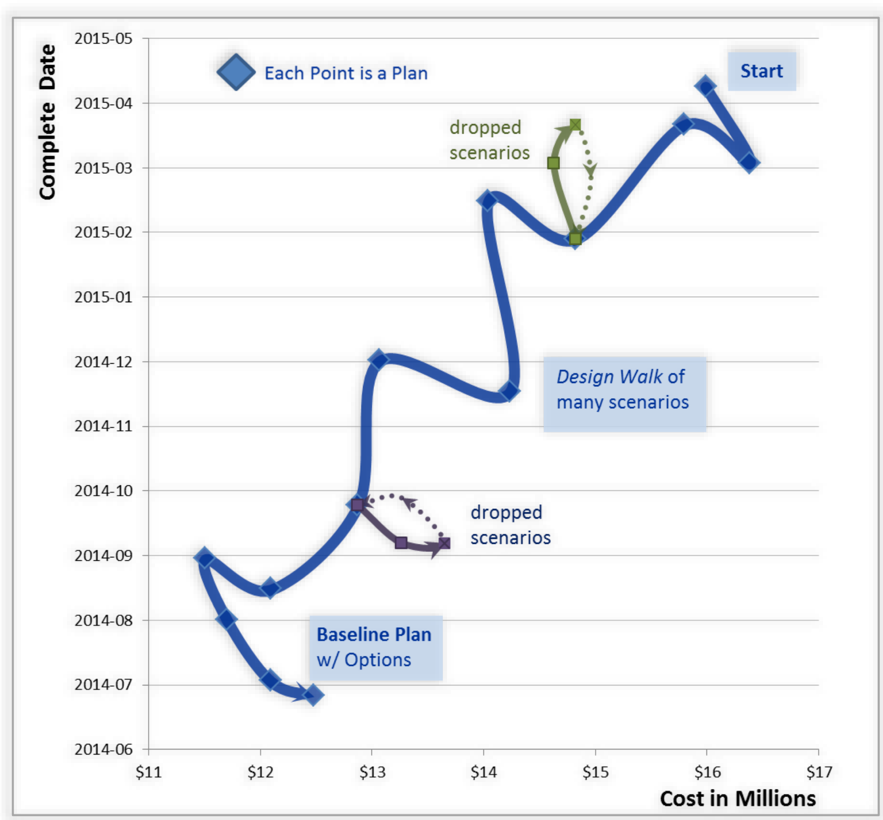


***Figure 11**.The figure shows the result of a typical design trade-off study where the project design trade-offs are given in the table. Starting from the top right the resulting TeamPort™ re-forecast results as they affect schedule and cost are shown for 17 different project trade-offs. Team rapidly test "what-if" scenarios, finding higher value improvements as the project becomes better designed – lean, focused, and tuned to the scope and teams at hand.*

The teams become engaged and aware through the planning process, with the method and platform allowing iteration around new scenarios in minutes. **Figure 12** shows the pace of proposal and analysis of new scenarios by a very large team on a recent project. **Figure 13** is the design walk from the project depicted in **Figure 1** to **Figure 4**. The design walk varies considerably due to changing priorities, re-assignment of teams and many other significant changes that occurred to the project design participants after generation of the baseline model. **Figure 14** is another view of the design walk shown in **Figure 13** where specific targeted milestones details of the changes are given.

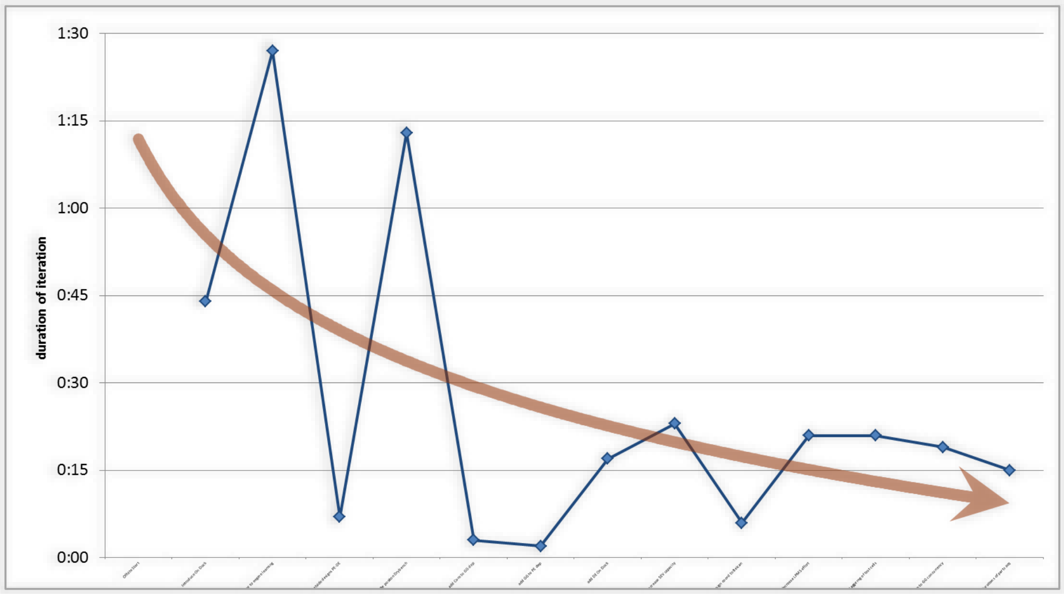


Figure 12. *The figure shows the same project trade study depicted in Figure 11 where the time required (in hours) to determine the model refinement, forecast and dialog is given on the ordinate and the refinements are described on the abscissa. As the team of teams iterates, discovers, and negotiates, their ability to more rapidly and smartly explore the tradespace improves.*

Project Plan Generation and Ongoing Relevance

With the rigor and collaboration of the project design process stimulating the teams to characterize scope and dependence, roles and responsibilities, uncovered assumptions, risks and their mitigation, and trade-off analyses they reach a consensus on a baseline model and options. A full and meaningful baseline project plan is now easily generated from the output of the TeamPort platform.

The project model can then be used over the lifetime of the project as a barometer of progress measured against the original plan.

As the project is executed, the project model can be updated as new refinements and contingencies arise, immediately yielding new forecasts of schedule and cost. Estimates to completion including adjusted paths forward can be rapidly and easily analyzed in minutes.

Various status reports are easily generated from the model, based on up-to-date estimates to completion of schedule, cost, and remaining scope. The project model easily evolves week by week -- as things change, progress is made, and new strategies are considered. In contrast to traditional methods which demand input of onerous detail and administration, the project model allows the teams themselves to remain aware and easily make adjustment to the plan. The data needed to maintain the model is relatively small yet remains relevant. TeamPort generates as output the details of expected progress, cost, schedule, quality, and utilization so that the team leaders can remain focused on the job at hand rather than detailed data management.

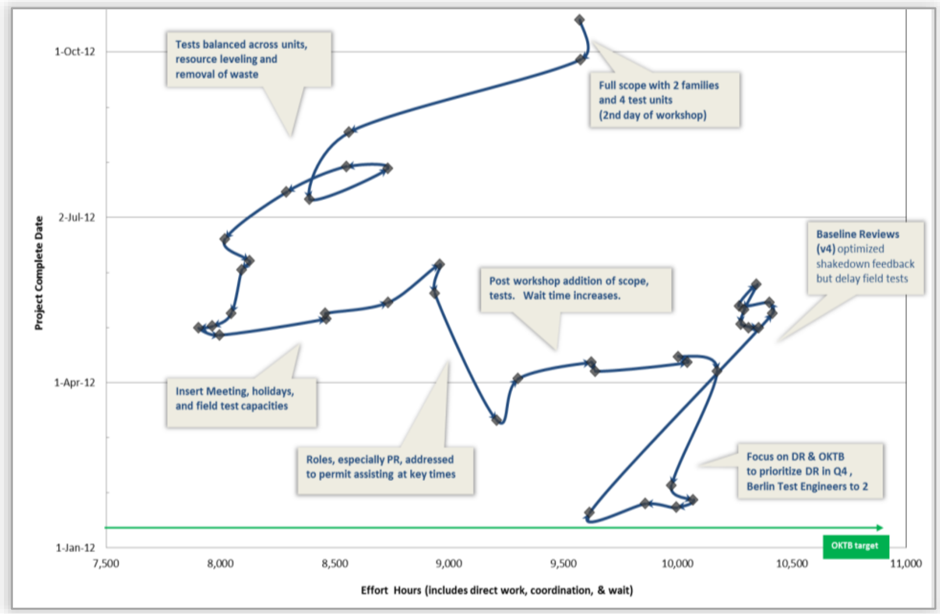


Figure 13. *The figure shows a project design trade-off study for the project represented by the model shown in Figures 1 – 3. The baseline model was completed in the 2nd day of the workshop and the trade-off analysis required 1 1/2 days. Many model refinements were required since certain details of the 3 breakdown structures were not known early on. The results show the completion date for the total project versus the total effort in man-hours required to complete the project.*

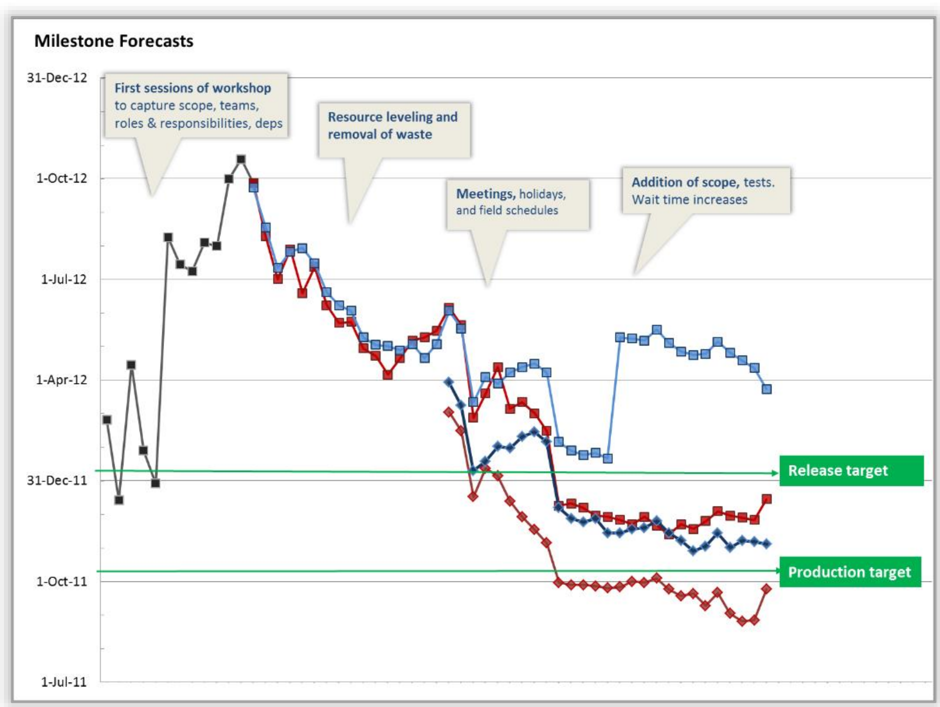


Figure 14. *The figure shows the results of the study depicted in Figure 8 where the model refinements are shown in detail on the abscissa with milestone completion dates given on the ordinate. The figure also shows the result of adding 2 other product lines at about the halfway point of the workshop exercises.*

Working with GPD

An on-site project design workshop includes customer participants with experience, skills and knowledge of the product to be developed. The primary sponsor an individual or office responsible for the development of a new product, service, or business line. The sponsor is expected to arrange for the identification of and securing the participation of the workshop participants, namely the commitment of the time and effort for the individual participants. These participants are typically at the level of program manager, project leader, engineering manager, manufacturing, supply chain and logistics manager, etc. GPD typically begins with a one day workshop to begin an initial model, outlines the information required to prepare for a full participant design workshop and a project model. Depending on availability of the key workshop participants, the workshop takes place over a 2 - 3 day period. GPD serves as a guide to the dialog, generates the *TeamPort*™ project model, facilitates discussion and becomes involved with developing trade-off scenarios. GPD remains involved throughout all subsequent interactions that may be needed to account for further model refinements – this is usually carried out via a remote connection.

GPD's *TeamPort*™ is used throughout the workshop and is managed by GPD staff on-site at the customer location or at GPD locations for subsequent model refinements. For longer customer engagements, access to *TeamPort*™ can be considered along with training of customer staff.

Comparisons with alternative approaches serve to show how TeamPort™ adds value over and above that of earlier enterprise architectures. TeamPort is part of a trend in digital twins and other model-based and collaborative tools which more holistically capture the integrated projects as a socio-technical system. While continuing basic research on these topics since 1999, GPD has been applying TeamPort on industrial programs for over a decade, and the results have shown practical and streamlined collaborative planning with rapid trade-off analyses. Model-based project management with TeamPort is taught at leading universities around the world.

GPD can provide case studies from successful customer engagements where large, global complex projects have been designed leading to successfully executed projects. GPD's case studies cover a wider range of industries including aircraft, energy, and vehicles, among others.

GPD's mission is to promote adoption of *project design* as a core capability. A typical GPD customer engagement involves three stages: show, teach, support. GPD shows during the customer workshop how TeamPort is used to develop a project model including capturing all team attributes, product attributes and dependencies among the many project activities. GPD over a period of time subsequent to initial workshops teaches the customer how to independently develop a project model and eventually will support the customer in ongoing and future initiatives.

Summary

The situation faced by advanced systems engineering and product development initiatives today includes changes in our product, our teams, and how we work together. Judgment and embedded practices – built on decades of traditional work processes and system architectures -- have lost relevance as these new, complex architectures emerge and overlap. Future engineering systems will continue to increase in complexity technically and organizationally. GPD's work is driven by root cause analysis of performance in these complex situations to significantly improve schedule, cost, and scope delivery.

GPD has shown that techniques which rest on traditional planning significantly misrepresent coordination. Coordination is real activity that requires effort, time, and cost, and for these projects can be one-third to half of the total attention by teams. Some falsely assume that coordination is qualitative rather than a real activity, and therefore do not recognize that teams have limited capacity to both do their own work and interact with others.

GPD's methods and tools for the design of project architectures include simulation of coordination activity and its impacts. Coordination activity should be managed -- designed, prioritized, allocated, measured, and adjusted. **Project design exercises rapidly expose old assumptions embedded deeply in our processes and professions, stimulating teams to build a new situational awareness as to when and where attention and coordination matter.**

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