The Virtual Design Team and Quantum ™: Comparison of Project Organization Models

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Abstract

Large scale multidisciplinary projects involve many activities and require intensive coordination to deal with the task interdependencies. To make such projects more efficient, it has to be established how coordination requirements are generated, and what are the coordination mechanisms. The paper compares two models that attempt, in vastly different ways, to address the problem of project improvement.

One model is the Virtual Design Team (VDT), a computational model analyzing how interdependencies between sequential, and especially parallel, activities raise coordination needs and how organization design and introduction of communication tools may change the coordination capacity of project teams (Jin, 1996). Based on an information-processing view of organizations, VDT explicitly models tasks, resources and communication tools, and simulates interaction between resources as processes of attention allocation, capacity allocation, communication, etc. VDT was commercialized as SimVision™ in 1997.

Another model based on entirely different assumptions is the model implemented in Matlab 7.x. This is a standalone application software package called Quantum™ (Fishman, Hoglund, Volchegursky, 2005), where the same problem is addressed by calculating probabilities of project milestones using rules of quantum mechanics. Project tasks are described by wavefunctions interfering coherently at the project milestones. Task delays result in wavefunction phase shifts and reduction of milestone probability (Fishman, 2005).

In this paper, we will briefly describe both models and compare them from the point of view of information processing.

I. Project as a MAS

Many types of Multi-Agent Systems that are used to model social and economic events have been applied to Projects. Each project implies interaction of at least three types of agents:

a) task implementers (workers doing project tasks),

b) managers (responsible for work coordination and actual worker activity),

c) external stakeholders (executives, marketeers, customers, consultants, policy makers etc).

Tools for project formalization decompose projects into tasks, summary tasks (aggregating several tasks belonging to the same professional activity), and milestones (intermediate and final results of the project execution in time). These tools are well-developed and currently implemented in software packages such as Microsoft Project and Primavera.

Though project management is a well-defined profession, the ability to predict outcomes for non-routine projects using modeling is not well developed. A common approach is to use PERT/Monte Carlo simulation; however, to provide useful results, this approach needs reliable duration distributions for each project task. In this way, the probability of achieving a given milestone is "broken-down" to the level of individual tasks. No actual modeling is involved, and in many cases, additional relevant information about task duration tolerances may not be available to the user.

Another problem with this approach is that only the "direct" work project component is accounted for; interaction with other agents (managers, executives, customers) is ignored. Specifically, the inter-task coordination and communication efforts between task implementers, or "hidden" work is not taken into account.

Two models discussed in this paper offer alternatives to Monte Carlo simulations; both models describe "direct" and "hidden" work components. The strategy of the VDT model is to carefully simulate important micro-processes affecting project outcomes. The predictions become more and more precise when the majority of substantial processes is captured, but it is the program designer's responsibility to determine which processes are "substantial". To provide relevant outcomes for a complex project extensive information gathering may be required.

The Quantum approach replaces specific agent-to-agent interaction with a physical model that considers task implementers to be similar to particle waves that propagate to milestone dates, where they combine coherently to form the planned milestone. When tasks are delayed, the milestone probability is affected. The approach is focused on project and milestone structure – information that has previously been neglected — rather than on the specifics of tasks — and can therefore be modeled without the need for detailed information about individual tasks. Managers and external stakeholders might affect the milestone probability, and this is modeled by scaling of two internal parameters, each having a specific numerical value for each milestone.

II. Virtual Design Team Model

The VDT model is based on the view of organizations, including project organizations, as information-processing entities. An organization processes information to coordinate and control its activities. Information is processed through a communication system, structured to achieve a specific set of goals, and comprised of limited capacity ("boundedly rational") information processors ("agents" in MAS or "actors" in the VDT model). These information processors send and receive messages along specific communication lines with different transmission lags and persistence (e.g., memos, voice mail, meetings). Both primary production work (for example, design) and coordination work (i.e., communication and decision-making facilitating design) can be viewed as information processing, so that the total amount of information being processed models the total work volume. This method of incorporating organizational tasks presents a level of abstraction provided by VDT model.

To model "hidden" communication and coordination work VDT utilizes a Monte Carlo simulation approach, with an input of direct work taken from a precedence diagram. In addition to sequential dependencies derived from precedence relationships between tasks, two other kinds of dependencies among groups of tasks (reciprocal dependencies and rework dependencies) and task uncertainty contribute to "hidden" work. Hidden work consists of supervision - i.e.

"exception handling" in the spirit of (Galbraith, 1977) - and various forms of coordination. Supervision (exception handling) work is implicit and is generated stochastically by VDT based on activity complexity, uncertainty, and task-resource skill match. Coordination work is generated by reciprocal and rework dependencies between tasks and by formal meetings.

To simulate a real engineering project in VDT and relate the simulation results to the project performance, a link between these task properties and real project data is developed that maps project information into a VDT model. This can be done using judgment, or more formally through structured Quality Function Deployment (Hauser and Klausing, HBR, 1988) and Design Structure Matrix (Smith & Eppinger, 1977) techniques.

VDT models a project team as a set of actors, actors being entities that perform work and process information. During simulation, actors perform *production, supervision* and *coordination* actions as composites of two fundamental behaviors, *attention allocation* and *information processing*. Attention allocation in VDT is related to how an actor chooses which task to work on when he has alternatives. Information processing models both production (i.e., design) and coordination processes. Any actor has a specific information-processing capacity for different kinds of tasks determined by its skill type (e.g., civil, mechanical), skill level (e.g., high, medium or low), and allocable percentage of full time equivalent (FTE), for example, 0.5FTE.

In the VDT model, communication messages have the attributes of sender and receiver, priority and time of arrival, and also attributes of synchronicity (synchronous, partial, asynchronous); cost (low, medium, or high); recordability (whether or not a permanent record of the communication is available routinely); proximity to user (close or distant); capacity (number of messages that can be transmitted concurrently); and bandwidth (low, medium or high) representing the capability of the tool for communicating information represented in each of the natural idioms supported (i.e., text, numbers, schematics, geometry, etc.). For example, voice mail is partially synchronous, low cost, medium persistence, and high bandwidth for spoken voice, but low bandwidth for text, schematics or geometry. Telephone is similar except that it is synchronous, not recordable, and has low persistence.

VDT modeling also addresses how changes in organization structure affect an organization performance, through influence on actor micro level actions for a given task. A control structure is defined by Supervise/Report-To relationships among actors. It is often represented as an organization chart. VDT represents control structures as either flat hierarchies or multiple level hierarchical structures. Supervise/Report-To links determine with whom actors should communicate exceptions up the chain of supervisors when a work item encounters an exception, i.e., it requires additional information; and the level of centralization determines at what level of the hierarchy a decision about the exception should be made. For example, in a highly centralized project organization structure, most decisions are made by the project manager, through the chain of sub-team member - sub-team leader - project manager. In a more decentralized organization, decisions are made by the sub-team leaders or even by the engineers themselves. Therefore, in a decentralized organization fewer communications are sent to and processed by high-level managers, generally saving time and cost but maybe decreasing process quality. VDT replicates this common organizational phenomenon through attention allocation and information processing in actor micro-behavior models. In particular, it can predict when centralized decision-making may lead to lower quality because of delays in handling exceptions caused by an overloaded project manager.

Besides the control structure, VDT represents communication structure by coordinated relationships among actors. The communication structure of an organization defines who can talk to whom. It is assumed that communication needed for information exchange between designers is purely task dependent (vs. decision-requests following work-item failures, which depend on organization structure and centralization policy). Coordinated relationships among actors are derived directly from the reciprocal relationships among their responsible activities. For example, if activity A is reciprocal with activity B, then their responsible actors, Actor A and Actor B, are linked to each other by a coordinated relation.

While a communication structure defines who can talk to whom, the level of formalization of the organization defines how frequently they will send informal communications to each other, instead of communicating through formally scheduled meetings. A more formalized organization relies on scheduled formal meetings for coordination, and reduces the frequency of informal inter-actor communications, and conversely.

II. Quantum^{TM} model

Quantum^{TM} software analyzes the project structural integrity at the most general level. The key idea of the Quantum model is that human task duration tolerances cannot be defined accurately, and some kind of uncertainty principle manages uncertainties of task duration and human productivity. Hence, the project tasks and milestones are modeled by appropriate wavefunctions (probability amplitudes). Each task is described by its own wavefunction ψ_i. The milestone probability amplitude is presented as a superposition of probability amplitudes of individual tasks interfering at the milestone in the same phase: $\Psi = \psi_1 + \psi_2 + \psi_3 + ...$, each task wavefunction is calculated in a quasi-classical limit and has a universal form (Feynman, 1965)

$\psi \approx (\sqrt{k})^{-1} \exp(\int k dx)$, and the milestone probability is calculated as $P=/\Psi/^2$. It is postulated that if the milestone is not perturbed (tasks are finished without delay), the probability amplitudes of individual tasks interfere at the milestone in the same phase creating a maximum in the interference pattern.[1]

In the vicinity of a milestone, superposition of diffraction fields from individual tasks composes a milestone diffraction pattern (temporal structure of the milestone) defined between closest minimums. To interprete this diffraction pattern as probability density, it has to be normalized to unity (milestone probability as planned = 1).

If a task slips by ΔD days, its phase ϕ slips by $\Delta\phi=\kappa_0\Delta D$ changing the task contribution to the milestone probability. Coherent interference is partially destroyed, and the milestone probability drops. The model accounts for bigger probability drops (larger phase shifts) associated with tasks

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[1] The fundamental task wave vector κ is defined as $\kappa_0 = 2\pi/D$ where D is task duration, meaning accumulation of 2π phase shift during the task performance. Between the task and the milestone, the wave vector is $\kappa_1 = \varepsilon\, \kappa_0$ where $\varepsilon = L/nD$, L is distance between the milestone and task end. If $L < D$, $n = 1$, else n is selected from a set $n = 1, 2, 3, ...$ closest to provide $\varepsilon \sim 1$. With these rules in mind, all task wave functions have maximum contributions at the milestone point. Amplitude $(\sqrt{k})^{-1}$ emphasizes contribution of long tasks to the milestone.

that have dependencies to other tasks. Tasks scheduled to be completed just before milestones have higher impact on milestone probability than similar tasks performed long before milestones. In chains of mutually dependent tasks, perturbation of the first task causes perturbation of the whole chain increasing the delay risk for the milestone. For large and remote milestones, the probability drop is smaller than for immediate ones, etc.

Analyzing the project plan, Quantum model calculates two parameters, Milestone Date Uncertainty (MDU) and Recovery Period (RP). MDU depends on distribution of task durations and slack times (times between task ends and the milestone), and decreases for short tasks close to milestone. Recovery Period (RP) is time needed to correct for possible tasks delays that might occur before the milestone. Both parameters depend only on the task structure (no external information is required), and even if no additional information about the project is available, these two parameters provide time units of task duration tolerances as well as project recovery capability. If additional information characterizing project "climate" is available, MDU and RP are scaled to larger or smaller values describing less or more risk in different aspects of the project execution.

Unlike the idea of critical path, where milestone probability changes from 100% to 0% when a task delay pushes the milestone to a later date, the Quantum™ model shows that delay of *any* contributing task will always result in *some* impact to the milestone. Mathematically, this is due to the resulting task phase shift at the milestone, but in practice it is a reflection of the fact that any task delay affects the milestone probability by reducing schedule flexibility. Quantum modeling analyzes all possible paths simultaneously, resulting in understanding not only which tasks might become critical, but which parts of the program can cause any risk. The quantum approach demonstrates smooth, not abrupt change of probability because milestones are presented as events having a certain probability density that extends over time rather than occurs at a discrete point in time.

IV. Model Comparison

VDT was probably the first model seriously assessing hidden work in projects. It was commercialized starting in 1997 as SimVision, and is currently used primarily in the petroleum and petrochemical industry. Although its use is growing over time, it is still far from being a standard tool for project management. Quantum™ has not yet been exposed to the industry. In this paper, we will concentrate on a theoretical (internal) comparison of two models related to their self-consistency, degree of abstraction, area of applicability etc.

1. Model Philosophy

Both models are self-consistent (were tested for small and specifically designed projects) but have different philosophies. The VDT philosophy is to improve plan quality by analyzing ADDITIONAL information describing the project environment (company structure, staffing details, communication tools, etc.). Based on this information, VDT creates a virtual working project where information exchange between the key actors is included. Therefore, two projects might have similar plans or schedules, but because of the specific nature of the work process or organization, VDT might predict very different schedule, cost and process quality outcomes.

VDT was specifically developed to diagnose organizational risks for fast-track, highly concurrent projects. VDT diagnoses organizational risks (including delays in task completion and milestone achievement, cost overruns and process quality risks) resulting from information overload for particular actors in the structure at particular times during the project, given a specific configuration of tasks, actors and organization structure. Based on this diagnosis, the manager can intervene pro-actively to change the product (by reducing its scope), the process (by reducing the degree of task overlap and extending the schedule), or the organization (by adding staff, increasing the skill levels in particular positions, etc.) to mitigate the risks. Like the way in which analysis tools support engineers doing structural or mechanical design, the process of diagnosis, synthesis and reevaluation, using VDT for the analysis step, can be iterated multiple times in the computer to reach an acceptable solution.

The Quantum™ philosophy is that though the Gantt chart presentation is not adequate, quantum mechanical modeling of plans reveals substantial untapped information, and makes it available for plan improvement. In other words, Quantum™ attempts to deal with plans that have inadequate or incomplete information, and still offer some path to improve project structure. Without further communication with the project owners, Quantum calculates two INTERNAL parameters characterizing the milestone (MDU and RP) providing an order of magnitude of task delay and milestone recovery time affecting the milestone probability. Thus, expected probabilities of any milestones may be compared on the same basis.

Another general aspect is a different choice of the central object of the model, which is an *actor* in VDT and a *milestone* in Quantum™**.** This aspect is closely related to the previous one, because Quantum would analyze the project plan with or without resources assigned to the tasks, and the structural difference is expected to be relatively minor (resource assignment changes the structure of parallel and sequential tasks dependencies). VDT would not affect the project structure unless additional resources are assigned and further characterized, but after this additional information becomes available, the VDT network would be applied to further improve the plan.

2. Degree of Abstraction and Scalability

VDT models communication between actors. The formalized items for simulation are specific communication tools (e.g., voice mail), the degree of reciprocal information interdependency between certain activities, the skill level of an actor, etc. Thus, VDT is flexible – changing and/or increasing respective informational items is a natural procedure with a relatively straightforward common sense validity check. Inherently, VDT is scalable meaning it could deal with as much information as could be provided by the external sources. However, receiving this information from the project owner may be increasingly difficult with the growth of the project size: if the number of actors grows as N, the informational flow grows as N^2.

For Quantum™, the project structure itself is abstracted, so that projects are considered physical structures, not unlike a system of particles. The model manipulates such parameters as wave-function frequency, amplitude and phase, task delay, task mutual coherence, etc. Adding or changing Quantum features to incorporate budget, resources, organizational structure etc. means "projection" of these variables onto numerical values of the model parameters (MDU and RP). The model is naturally and readily scalable to many thousand tasks or actors N, with complexity growing linearly with N.

3. Information Flow and Utilization

Both models present a project as a communication network where information is propagated and processed. However, in VDT a network node is an actor, having in- and out- trays and processing information ranked by its importance, urgency, timing etc. VDT builds network in the "empty" project structure. Unlike this, Quantum^{TM} is a communication network itself, with a milestone being a network node. A Quantum network can be visualized as a system of waveguides (fibers), each fiber carrying one-task related information, and all fibers focused in the milestone plane.

4. Task Interference vs. Hidden Work

Both models start with the notion that a Gantt chart or precedence diagram does not fully characterize the project. In VDT, it is the concept of hidden work that exists-to be "exposed" by careful analysis of task interdependencies and task assignments to agents. In Quantum^{TM}, wavefunction interference and loss of mutual coherence can be considered to describe the same phenomenon in a more abstract and general way– indicating a possible need for project clarification and re-planning. Thus, both models target and address quantitative means for planning improvement.

5. Future Model Coexistence/Convergence

Currently, the two models co-exist in two separate project domains having almost no intersection. VDT proves to be efficient for small project models (less than 100 tasks) with well-characterized resources and company information. Although the number of tasks is small, appropriate use of abstraction in tasks and actors can allow modeling of large, multi-year efforts involving hundreds or even thousands of workers, e.g., the Lockheed-Martin Launch Vehicle, or the Procter & Gamble Thermacare™ product development program. If the information necessary for the model can be obtained, VDT provides unique capabilities for designing the project organization to mitigate schedule, cost and quality risks. Quantum^{TM} works well for large (over several hundred tasks) and incomplete external information (no resources, etc.). Schedule analysis is based on very general assumptions, and hence provides only a structural view of the project, without specific granularity or accuracy.

Looking forward, it seems possible to converge these two models to improve their performance. The following is an example illustrating improvement of an industrial project consisting of about 300 tasks (Fig. 1) using both Quantum and VDT models.

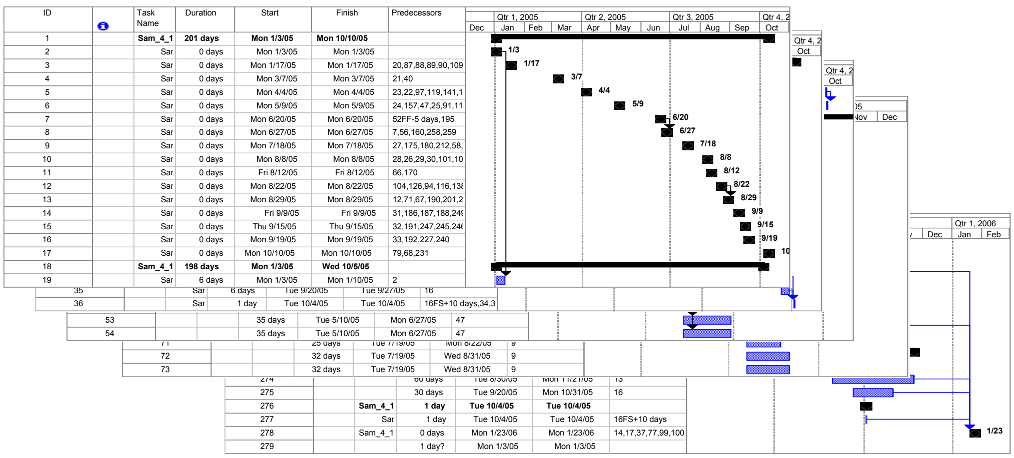

Figure 1. Microsoft Project file of 279-task project

For each milestone, Quantum would calculate a non-perturbed temporal profile (Fig. 2, black curve), and, based on milestone MDU and RP parameters, perturbed temporal profile (Fig. 2, red curve). The integral over time of the red curve within the limits of the black curve (shaded area) is the milestone probability.

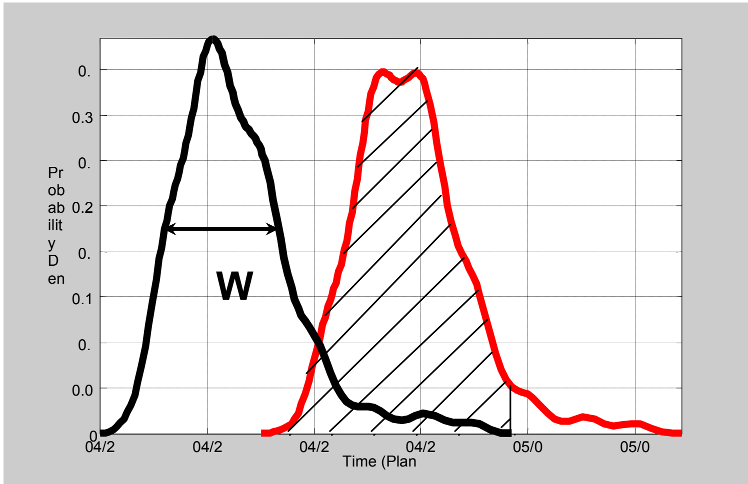

Figure 2. Temporal diagram of non-perturbed (black) and perturbed (red) project milestone. W is "Milestone Date Uncertainty", see Section II "Quantum™ Model".

With all milestones' probabilities defined as in Fig. 2, the expected structural probability of the project can be presented (Fig. 3).

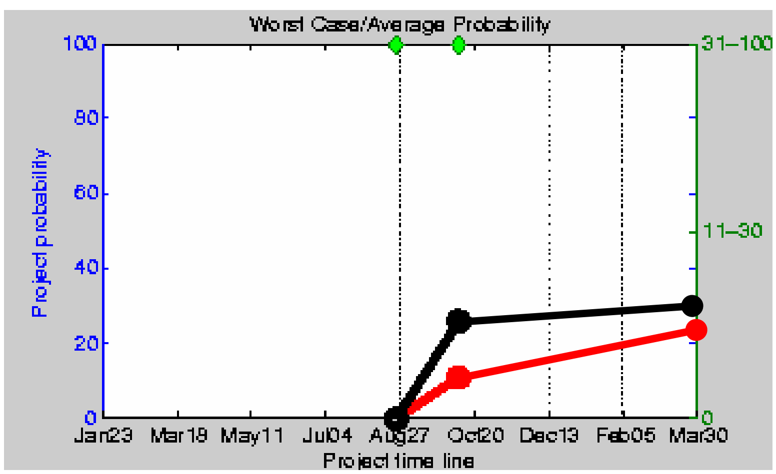

Figure 3. Expected probability of success for the project of Fig. 1.

In Fig. 3, red line shows worst case probability of the first half of the project, ¾ and full project to succeed. For the design of Fig. 1, first half of the project totally fails (probability = 0), and through the rest of the project, its probability does not exceed 20%. Black curve shows project probability averaged over each milestone, and the data of Fig. 3 suggest that the project design problems are not local (worst case) but global (average probability does not exceed 30%).

The first page of the file (Fig. 1) represents major project milestones. Each milestone aggregates many tasks, suggesting durations of direct work shown in Fig. 4 of VDT analysis. Using VDT formalism, re-work, coordination and decision times are added to each direct work item, and Quantum analysis is repeated for the corrected plan (Fig. 5).

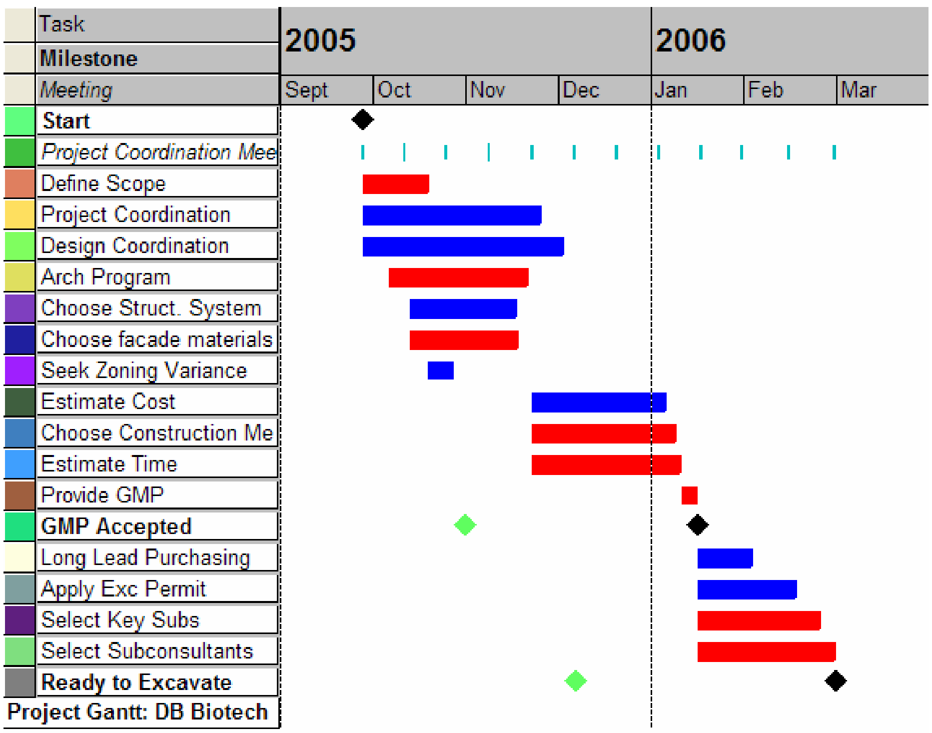

Figure 4. VDT analysis of major milestones (Green diamonds show desired milestone completion dates; black diamonds show expected milestone dates predicted by VDT simulation).

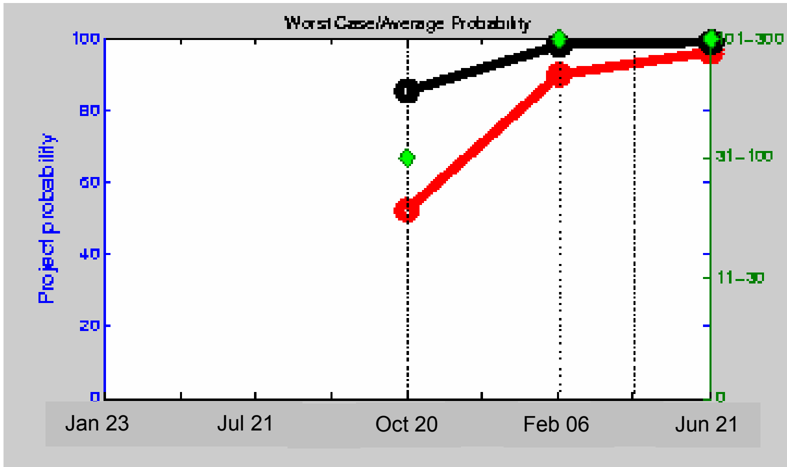

Figure 5. Expected probability of success for the re-worked project of Fig. 1.

Fig. 5 shows that the expected project duration increased, and the expected probabilities have also increased. This combined approach is productive if all the information required for VDT analysis is available. Today, the major problem with commercial projects is a lack of planning data. Conventional projects are poorly created and poorly maintained; even for a large scale construction projects where the project plan is vital, it is almost impossible to have subcontractors assign resources to the tasks, not to mention task budget and/or task duration tolerances. Very often, the plan structure is extremely poorly defined: tasks do not report to milestones, milestone hierarchy is not established. Given this, the Quantum™ approach may be applied first to correct errors, define first-order milestone probability and rank all project tasks in terms of their risk to the milestone no matter what is the project size and industry vertical.

For more mature projects (in fact, for more mature organizations with PMOs and established planning culture), tasks described by Quantum may acquire features of better defined tolerances, specific metrics for milestone probability, ranking enterprise corporate structure etc. This first step, though not accurately presenting the project details, identifies risky milestones and establishes suspicious tasks responsible for high risk. At this point, a VDT model can be applied to high risk segments of the project rather than to the project as a whole.

V. References

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