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**RELATIONAL PROJECT
MODELING AND RISK
PROJECTION FRAMEWORK**

Brian D. Gould

Thesis submitted to the College of
Engineering and Mineral Resources at
West Virginia University in partial
fulfillment of the requirements for the
degree of

Master of Science
in
Computer Science

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Morgantown, West Virginia

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Abstract

RELATIONAL PROJECT MODELING AND RISK PROJECTION FRAMEWORK

Brian D. Gould

The relational project modeling and risk projection framework enables a projection of the consequences of initial project schedules and schedule changes with respect to risk realization in resource constrained project environments, and the identification of unrecognized schedule risks implied by those schedules.

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1 Introduction

The current state of software project management

The High Rate of Project Failure

Citing a 1995 survey, Addison and Vallabh [1] state that only one sixth of all software projects are completed on time and within budget, one third of all projects were cancelled and over half were considered “challenged.” Citing another 1998 study, they also suggest that this high failure rate is due to managers not taking cautious measures to assess and manage risks involved in software projects. As a response to these discouraging statistics, the discipline of risk management, as applied to software projects, has gained great acceptance among project managers in an attempt to come to terms with and manage the wide variety of risks pertinent to the development of software systems.

Chapman and Ward [4] define project risk as “the implications of the existence of significant uncertainty about the level of project performance achievable.” Risks as such are any factors that can affect project performance when this effect is uncertain and significant in its impact, and range from general external factors such as the level of managerial and user commitment to the uncertainty surrounding project scheduling and estimation. If project performance is to be repeatable and predictable, the identification and management of risks must consist of methodical and disciplined processes. A variety of frameworks and methodologies for risk analysis and management have been proposed, qualitative and quantitative, formal and informal.

At best, unchecked project risk relegates forecasts of project cost and duration to the status of guesswork. At worst, unmanaged project risk can lead to a cascade of unforeseen consequences that ultimately dooms the effort altogether. In the absence of an effective risk management process, project managers and their teams continually find themselves engaged in a reactive struggle to fend off the consequences of unmitigated risks, or in the case of sufficiently proactive groups engaged in a haphazard effort to address issues as they are raised by conscientious and forward thinking team members. In either case, it is not possible to achieve the predictable level of project performance required to realize the intended benefits of advanced planning. [1]

However, the benefits of risk management do not come without a cost. Successful risk management requires time, commitment, and effort on the part of project teams, as well as the support of management. Where an organization's culture tends toward a reactive stance, the associated costs of enacting such a process are formidable, and even a mature organization with proactive management and project teams must exhibit much discipline in order to reap the large-scale benefits of systematic risk management across multiple projects in the long term. [4]

Shortcomings of contemporary solutions

Qualitative vs. Quantitative methods

In the words of the British physicist William Kelvin

“I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot measure it, when you cannot express it in numbers, your knowledge is of meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be.”

This quote captures the essence of the central debate in risk management in relation to projects. The widely varying nature of the risks associated with project performance makes it extremely difficult to create a practical and comprehensive theoretical framework for the analysis of risks in a purely quantitative sense [4].

Since the 19th century, there has been significant debate concerning quantitative and qualitative paradigms. Within the physical sciences, methods evolved from the assumptions of logical positivism, which soon became the essence of science, emphasizing the collection and objective verification of “hard” data. Mathematical and statistical methods of analysis, working from probabilistic and inferential assumptions, were utilized to explain, predict, and control phenomena. [11].

Given the history of these successful and respected techniques, quantitative risk analysis has enjoyed significant cachet among risk analysis practitioners, in lieu of methods of qualitative risk analysis. The quantitative methods are commonly thought to be more objective, being based on models and metrics, where qualitative methods are clearly more subjective [4].

Despite this, quantitative models with their specifically quantifiable results can result in risk analysts underestimating the interdependency of project risks. Risk exposure metrics, quantitatively or qualitatively arrived at, are undermined by some uncertainties. The perception of risk impact and risk probability is plagued by subjective evaluations and then utilized in formal mathematical operations. This manipulation of such values of indeterminate validity can render such seemingly positivistic results practically unworkable. The quantitative methods of risk analysis are also undermined by an additional factor. Commonly used quantitative techniques marginalize the intuitive considerations creating an “illusion of accuracy”, when true accuracy in a positivistic sense is in reality a practical impossibility. In the case of less formal and more subjective qualitative analyses, the quality of decisions is enhanced despite this, since intuitive estimates are certainly a more worthy basis for informed decisions than no estimates of risk exposure at all. [13]

To detail the specifics of the shortcomings of purely quantitative methods further, according to Padayachee [13]:

1. Some types of risks have a general effect on the entire project and cannot be modeled in terms of cause and effect relationships or dependencies.
2. Some risks are not well suited to quantitative representation
3. Even when risks can be quantified, it may be difficult to trace and quantify the effects of their realization with regard to the project as a whole.
4. It is difficult to model the complexities of the actuality of a given risk, leading to oversimplified abstractions.
5. Even though it is possible to consider risks using well-known statistical methods, the lack of historical data regarding most types of risk leads to a lack of credibility when such methods are used, and may lead in some cases to a dangerous illusion of control.

6. The benefits of utilizing a quantitative method in risk analysis may be outweighed by the costs of utilizing the methodology, in terms of the time and effort required to adequately capture the details required for its valid application.

In light of these issues, many organizations choose a qualitative approach to risk management. Although qualitative analyses may be perceived to lack the legitimacy imparted by purely quantitative methods, which are generally highly esteemed in business and engineering environments, a number of researchers have made a case for its usefulness [4].

Qualitative Methods

Qualitative methods are generally more intuitive and easily integrated into existing software development processes, and are able to accommodate the complexities of the reality of a project by leveraging the unquantifiable experience of the project team. Advocates of qualitative risk management methods have also pointed out that although a numerical analysis may enjoy a privileged status, all too often the misapplication of quantitative methods, or the overestimation of their accuracy (due in part to the status that such methods enjoy) may result in the mismanagement of risks [4].

Most qualitative risk processes involve roughly the following steps:

1. The organization keeps a checklist of potential project risks that project team members will use as a reference point during their risk management activities. This list is updated and refined over the course of many projects and reflects the accumulated knowledge of the organization regarding project risk.
2. Project team members participate in several sessions of risk identification, where risks pertinent to the project are identified, documented, and assigned a scalar value for the following attributes: probability, priority, and impact on the project.
3. In subsequent sessions, a risk response plan and responsible party are assigned to each risk. The parties so assigned are given the responsibility for addressing the risk in a manner appropriate to the nature of the risk.
4. Throughout the project the identified risks are tracked by project management with the risk owners reporting on the status of their assigned risks. Further sessions of

risk identification, evaluation, and assignment may take place at various stages of the project in order to manage emerging risks and reevaluate identified risks that have changed or require new management strategies.

According to Chapman and Ward [4], approaches such as this are often taken on the grounds that a ‘quick-and-dirty’ approach can yield substantial benefits despite its conceptual shortcomings. However they caution that the following are potentially serious shortcomings of this approach:

1. Important interdependencies between risk drivers are not readily highlighted.
2. A list, particularly a long one, provides limited guidance on the relative importance of individual risk drivers.
3. Individual entries may encompass a number of important, separate risk drivers implicitly.
4. Risk drivers not on the list are likely to be ignored.
5. The list of risk drivers may be more appropriate for some projects than others.
6. Individual risk drivers may be described in insufficient detail to avoid ambiguity and varying interpretations.

Despite these shortcomings, this approach remains a viable and attractive option for many organizations for a number of reasons. It is readily acknowledged by most project management practitioners that where more quantitatively rigorous means are not available or practical, it is better to utilize a limited methodology than to have none at all [13]. Most quantitative methods of risk analysis also require a significant level of expertise that may not be available to the organization. The successful utilization of a complicated risk management methodology is also dependent to a great extent upon its viability in the context of a particular organizational culture. With resource and time constraints, project teams are often unwilling or unable to adopt complicated risk processes due to the high overhead in terms of effort or the cultural resistance in reactive project environments.

Quantitative Methods

A number of project planning methodologies exist that explicitly utilize primarily quantitative risk analysis methods, most of which are extensions of the PERT methodology, which was developed for use in the US Navy's Polaris Missile projects. The complexity of the Polaris projects was such that the analysis of project dependencies and projection of completion dates required a much more abstract and conceptually sophisticated tool than the simplistic graphical timelines of the Gantt chart. Additionally, the Polaris project was to be completed in the shortest amount of time possible, and due to the nature of research and development (a large component of the Polaris project), it was necessary to utilize a tool that could accommodate activities of indeterminate duration. PERT allows for multiple estimates of completion time, and provides a range of possible completion dates based on a statistical analysis of the most likely completion time ranges for each individual task. This planning technique utilizes an explicitly quantitative model of schedule risks, and is not generally applicable to the majority of risk types identified above, although to a certain extent other risks may be implicit in the selection of probability distributions on a task basis [14].

The statistical distribution upon which PERT is based is known as the Beta distribution. The Beta distribution looks and behaves much like the normal distribution when the realistic time estimate is exactly centered between the optimistic and pessimistic estimates. When the realistic estimate is closer to the optimistic than to the pessimistic, the Beta distribution becomes positively skewed, and when the realistic estimate is closer to the pessimistic than to the optimistic, the Beta distribution becomes negatively skewed. This difference allows a better fit of real-world data to activities than would the normal distribution. When activities that are Beta distributed are summed, the result approaches the normal distribution that can then be used to estimate completion times [14].

According to Chapman and Ward [4], there are several key shortcomings of the basic PERT models. The assumption that the probability distributions of tasks are causally and statistically independent is problematic, and leads to oversimplification of the impact of realized schedule risks. This flaw has been recognized and addressed in the Generalized PERT, which uses embedded decision trees in the PERT network to accommodate causal activity dependencies. Other shortcomings of the model have been addressed through GERT

(Graphical Evaluation and Review Technique) by employing a Markov process model, to track the ‘state’ of the project and rates of progress for specific tasks, to provide more direct estimates of task duration. Another key shortcoming is addressed by the SCERT (Synergistic Contingency Evaluation and Review Technique) approach. This approach takes into account the nature of the risk realized as a prelude to considering effective responses, which involves the embedding of a fault tree or event tree model in a GERT model [14].

Another issue that has been raised regarding these probabilistic planning methods is the fact that the utilization of probability distributions assumes the existence of a sufficiently large sample size for legitimacy. In the absence of historical data related to specific activities such estimations are somewhat suspect in a theoretical sense. This significant concern has been addressed fairly successfully through the use of Monte Carlo simulation techniques also known as “simulation by random sampling”. In Monte Carlo simulation, random values are repeatedly generated for each variable in the model, and the outcomes collected, yielding an overall distribution for the simulation, which is then used as a decision tool in evaluating the general viability of the project model.

Difficulties with Historical data

There are a number of obstacles to the collection of accurate historical data related to projects. The collection, scrubbing, storage, analysis, and reporting of useful historical software project data, is non-trivial and requires among other things, organizational commitment at all levels, full time staffing to support the effort, significant cost increases, and perhaps most unfortunately the collected data will always be suspect for a number of reasons. These factors can be daunting to almost any software development organization, and with the increasing market pressures of the software industry to cut costs and decrease the length of development cycles, such collection and analysis efforts all too frequently must take a back-seat to more immediate and pragmatic considerations. [3]

In a report detailing the lessons learned from 25 years of collecting and analyzing software project data at the NASA Software Engineering Laboratory (SEL) (one of the landmark efforts in the development of useful software project and process metrics), Basili, et al, [3] indicate that their data collection and processing efforts incurred a 10% overhead cost to

projects. Collection costs were initially around 5% and gradually dropped to 1% to 2% of development costs, but taking into account the analysis function of the SEL, costs overall remained at approximately 10%, including analysis, measurement, and report generation.

To summarize the pertinent lessons learned in the SEL study [3]:

1. Data collection requires a rigorous process and professional staff.
2. You must compromise in asking for only as much information as is feasible to obtain.
3. Establishing a baseline of an organization's products, processes, and goals is critical to any improvement program.
4. The accuracy of the measurement data will always be suspect, but you have to learn to live with it and understand its limitations.
5. Having a shared commitment over research and development is vital for success.
6. Having upper management support is important for continued success.
7. Staff training in data collection is a never-ending vigil. As important as data collection is, it still takes second place to deadlines.

With regard to the utilization of existing quantitative positivistic methods, the complications arising from this are clear. Organizations intending to utilize a purely quantitative approach to risk management based on historical data must be willing to incur greater project overhead costs, foster broad organizational support for the collection and utilization of data, dedicate resources to the ongoing task of collection, analysis, reporting and staff training, and possess foresight in the proper measurements to be made. Even organizations willing and able to make the necessary commitments and expenditures must still contend with the likelihood that the data so collected is not entirely accurate.

Addressing the shortcomings

Importance of human judgment

Mizuno, et al [9] attempted to characterize risky projects using the data sets from previous projects, but were not successful. Initially trying to correlate between software metrics and risky projects and faced with discouraging results, they then changed their approach and attempted a qualitative characterization by acquiring information regarding perceived project

risk factors from project managers and senior managers. Their questionnaire was designed to capture intuitive knowledge regarding risky projects, and was then distributed to project managers. The responses were collected, subjected to a statistical analysis. Using a logistic regression analysis, the risk assessment data set was used as a basis for a logistic model that was shown to be statistically significant. An analysis of the constructed model showed that it was able to consistently predict risky projects in a new data set.

According to Chelst, in his “Critique of Decision Analysis in Survey Texts” [5], the purpose of a normative model should be to “update the intuition of a decision maker.” In applications of models such as linear programming and decision analysis, enhanced insight is the purpose of the study. The structured approach of decision analysis tends to enhance communication and group learning in a group decision-making context. Similarly, Arnott has this to say on the subject of Quantitative Management [2]:

“Quantitative techniques are not magic, they are merely tools. What they can do, whether good, indifferent or downright bad, is introduce much-needed discipline to traditional methods. They are not inherently better than traditional subjective methods. After all, the human brain is a remarkable instrument. It is an analytic tool, capable of assessing the myriad influences on and implications of a thousand variables and factors. Quantitative tools tend to break down when weighing more than a handful of variables.”

Another relevant perspective, this time regarding the nature of intelligence in heuristic search, was set forth in the 1975 Turing Award Lecture presented by Allen Newell and Herbert A. Simon [10]. In searching a space of possibilities in a game like chess, programs typically grow enormous search trees. However, the strongest human players rarely examine trees of more than one hundred branches. This economy of effort is achieved by branching sparsely and selectively. From the perspective of heuristic search, this is only possible by exhibiting greater selectivity in generating search possibilities, examining only the branches that are likely to reveal important information about the board position. The nature of intelligent search, they conclude, is not the capability of completely evaluating the space of possibilities,

but the application of appropriate heuristics in choosing the appropriate possibilities to evaluate.

“The task of intelligence, then, is to avert the ever present threat of the exponential explosion of search. An intelligent system generally needs to supplement the selectivity of its solution generator with other information using techniques to guide search. The quality of performance depends on the characteristics both of the problem domains and of the symbol systems used to tackle them. Even in highly structured areas like linear programming, theory has been much more useful in strengthening the heuristics that underlie the most powerful solutions algorithms than in providing a deep analysis of complexity.” [10]

Managing schedule risks with decision support

The economic pressures of today’s software industry, not to mention the increasingly sophisticated nature of software development, mean increased complexity in decision-making processes. Additionally, instantaneous communications make organizational environments less predictable, reducing available time for the examination of data and relationships. Subsequently the data required for an in-depth quantitative analysis is difficult to obtain and quite often the analysis itself is impossible in the time available. Correspondingly, managers find themselves with a greater need for new decision support tools. It has therefore been suggested that decision support tools should allow a symbiosis of quantitative analytical tools with intuitive heuristics to allow insights about complex factors, and such tools can be used to test and verify intuition before decisions are made.

2 Methodology

Problem Definition

Despite the sometimes discouraging conclusions of this introduction, one should not conclude that rigorous methods of project analysis and optimization should be discarded wholesale. Significant opportunities exist for the use of quantitative analysis in combination with quantitative and qualitative data, to augment and inform the judgments of project leadership. This paper proposes a framework for the analysis of project schedules and their relationship to project risk, and a description of a practical implementation of that framework. The purpose of this framework is to support structured reasoning and informed decision-making with regard to a project model that encompasses both quantitative and qualitative aspects. The implementation of this framework is intended to act as a decision support tool that is capable of providing timely results, cost efficiency, and sufficiently accurate estimates of cost and project time in a variety of projected risk scenarios.

The polarization of existing risk analysis and management techniques into relatively informal qualitative techniques and rigorous probabilistic decision analysis methodologies, is largely focused around two issues – the trade-offs between the two types of approaches in terms of practicality in the context of a variety of organizations and the debate between the relative merits and hazards of the fuzziness of qualitative methods as opposed to the sometimes misleading, although numerically precise, purely quantitative methods. Where quantitative/probabilistic approaches yield significant results at the high level of abstraction required for strategic decision analysis, and qualitative approaches yield significant results by virtue of their ease of use and generic applicability, there yet remains a middle ground where project management might benefit from a more rigorous project risk model than the purely qualitative, that is also more appropriate for support of tactical decisions regarding a project in progress.

The relational project modeling and risk projection framework enables a projection of the consequences of initial project schedules and schedule changes with respect to risk realization in resource-constrained project environments, and the identification of unrecognized schedule risks implied by those schedules.

The framework proposed in this paper directly addresses the following functional goals:

1. Definition of a robust and flexible model of project-related data
2. Evaluation of project plans in terms of cost and estimated completion time.
3. Integration of relevant qualitative factors that may influence a project schedule.
4. Projection of the effects of realized risks in the context of project schedules, with consideration for contingency plans, and available resources and their skill levels.
5. Determination of a project's expected value with respect to cost and completion time.

The implementation of this framework attempts to present a practical, easy-to-use method to realize these goals. The method will:

1. Utilize straightforward and easily modified data relations as inputs to facilitate the use of existing project data.
2. Automate the construction of project networks from simple task precedence relations.
3. Provide rapid automated evaluation of the project-wide consequences of scheduling decisions.
4. Provide rapid projection of the effects of realized risks.
5. Present the analysis results in visual, numerical, and textual forms to support a variety of cognitive styles.
6. Provide a flexible platform that may be customized to use different heuristics, algorithms, scaling functions, etc.

This method is realized by the PM Eye decision support application, developed to illustrate the framework described in the following sections, and to exhibit the potential applications of the framework as a decision support tool for project managers. Utilizing the framework, PM Eye performs an automated analysis of project schedule data stored in a relational database and provides several analysis views.

Overview of the Relational Project Modeling and Risk Projection Framework

Intended usage

The relational project modeling and risk projection framework is a means of evaluating the impact of risks on project schedules. Project data is considered in a relational form, which

facilitates the evaluation of the complex attributes, relationships and dependencies of a project environment, acting as a bridge between project complexities and an analysis of the implications of those complexities. The integration of qualitative information about the skill sets of human resources is an important aspect of the framework, and is utilized to more effectively determine the impact of resource assignments in the context of a project schedule.

The framework, in its current form, is not intended as an estimation tool, but rather an augmentation of the reasoning and judgment of project leadership, allowing project managers to rapidly project the consequences of scheduling and staffing decisions in relation to hazards posed by project risk. The more rapidly and readily that decision makers can explore the space of possibilities and probabilities in a dynamic high-pressure environment, the more quickly and efficiently they can seek out improved configurations and deployments of their resources and communicate them to team members and stakeholders.

Much effort has been spent to identify optimal methods of producing optimal schedules and resource allocations, but the existence of an optimal project configuration that can be determined in advance rests upon the assumption that the environment in which that configuration will be communicated and enacted is to a great extent static and uniform. In the contemporary world of software development, such a static and uniform environment is a tenuous assumption.

One might posit that, rather than further developing methods of optimization with respect to a highly abstracted search space, greater gains may be had in some contexts by seeking innovative and structured ways to plumb the possibilities of the project environment by seeking to more closely model the realities of that environment. Because useful and accurate historical data is difficult to obtain, this requires, for the time being at least, the utilization of qualitative data, but it could be argued that the integration of qualitative and quantitative approaches is certainly no worse than the rigorous application of purely quantitative abstractions that fail to adequately capture the reality they seek to describe.

Scope of Analysis

The projection of the interactions of project risks with scheduling and assignment decisions, effectively limits the risks that may be evaluated to those whose consequences directly impact the project schedule. For the purpose of illustrating the framework the following types of risks have been evaluated, although, as currently defined, any risk could be accommodated whose contingency plans involve the introduction of new tasks, dummy tasks (to represent delays or new dependencies), reassignment of tasks, or the precedence relationships between tasks.

1. Resource Availability – A critical resource becomes unavailable during the course of the project, in which case the contingency plan consists of reassignment of that resource's tasks to another.
2. External Delay - Introduction of schedule delays by a party external to the project, in which case the contingency plan is simply accommodating the delay in the project schedule.

Analysis steps

An analysis utilizing the project modeling and risk projection framework consists of the following stages:

1. Prepare project relations
2. Generate project risk scenarios
3. Scale task durations
4. Generate the project network
5. Perform CPM Calculations
6. Schedule to resolve resource conflicts
7. Analyze scenario outcomes

Set up the project relations

As stated previously, the flexibility of a relational representation of a project is well suited to capturing the complex relationships of a project environment. A general overview of the project entities that are to be described and their role in the framework follows, with a more detailed description of the project relations in later sections. The reader will note that there is some divergence in the representation of the relations described in these sections from

the actual database utilized in the sample implementation of the framework, detailed in Appendix B – Example Database. The discussion of the project relations includes only the essential abstractions, while the actual implementation includes some data necessary for a practical application and makes some allowances for efficiency in the practically applied data model.

Projects

Projects are the entities that represent the totality of associated tasks, resources, skills, risks, and the relationships between them, and as such, are the subjects of the analysis - and subject to comparison via the analysis with other projects designed to achieve the same goals with the same risks. The projects to be compared may differ in terms of contingency plans, assignments, and tasks, but must be constructed to accomplish the same goals for such comparisons to be meaningful.

Tasks

Tasks are the basic elements of the project plan, and consist of the work packages that are to be completed during the course of the project. Each task is assigned a resource that possesses the skills required to successfully complete that particular task. Each required skill is assigned a weight, indicating its relative level of importance in successfully completing the task, and an ideal skill level. An idealized duration is also assigned to the task which represents the time taken to complete the task by a resource with a level of expertise in all required skills equal to the respective ideal skill levels mentioned above. Tasks are associated with a particular project, or in the case of the contingency plans corresponding to the project risks, are associated with a particular project and a particular risk. Tasks are also related to each other in addition to their association with a particular project or risk, in the sense that tasks must be given a temporal order, the constraints of which are given by successor relationships, such that a task must be scheduled and completed before all of its successors. It is from this last type of relationship that we are able to create the project network utilized in CPM calculations discussed in later sections.

Resources and skills

Resources are participants in the project, possessing skills that are brought to bear in the completion of tasks to which they are assigned. Their level of expertise in each skill is

relevant in our analysis, and determine, to some extent, the actual duration of the tasks to which they are assigned. The assigned resource may affect the actual duration of their assigned tasks in the sense that being deficient or expert in the required skills will correspondingly influence positively or negatively the actual time taken to effectively complete the task - as opposed to the ideal duration of the task as described above.

Risks

In terms of our relational model, risks are entities which represent the potential for disruptions in the original conception of the project. Each risk is assigned a probability of occurrence and is associated with a particular project. The consequences of a realized risk are characterized as a contingency plan, which is in turn defined in terms of additional tasks to be completed, delays to be accommodated, assignments of resources to tasks, and changing precedence relationships between the tasks. The contingency plans are essentially a modification of the original project plan in order to accommodate or mitigate the disruption introduced by the realization of the associated risk.

Generate project risk scenarios

Project risks may be realized in various combinations, assuming that they are not mutually exclusive, and so we may define a set of risk scenarios that represent the various combinations of risk that could be realized during the course of a project. Each of these scenarios is assigned a probability, defined as the probability that the risks included in the scenario are realized and *only* those risks. Each scenario is also associated with a transformation of the original conception of the project to accommodate the contingency plans associated with the risks included in the scenario.

Scale task durations

At this stage of the analysis, the tasks and task assignments included in the risk scenarios for the project being analyzed have been determined, and it becomes possible to project the actual completion time of the included tasks. As described above, a resource assigned to a task possesses a set of skills with corresponding levels of personal expertise that affect the actual completion time of a task, diverging from the idealized duration of the task. By considering the skill's 'weight', or relative level of importance, and the difference between the ideal skill-level for that task, it is possible to project a reasonable estimate of the actual task

duration. This divergence from the idealized durations of the tasks, as a consequence of the actual assignments corresponding to a particular risk scenario, allows us to project the effect of a set of realized risks with a greater sense of realism.

Generate the project network and perform CPM calculations

The task precedence relations defined for each risk scenario enables the generation of a project network that captures these relationships and is to be utilized in the CPM calculations necessary for creation of a project schedule that accommodates the contingency plans for each risk in the scenarios. The project networks is an acyclical directed graph, wherein each task is represented as an edge between nodes of the graph, and assigned attributes designating the duration, and start time and finish time for that task. For a detailed discussion of project networks, which is beyond the scope of this paper, the reader may consult the work of Weist and Levy [14]. Several effective project network creation algorithms exist and the reader is referred to the work of Fisher, et al [7] for a more detailed treatment of the problem. The selection of an appropriate algorithm to accomplish this stage of the analysis is largely a matter of implementation, and is thus not included in the discussion. The PM Eye implementation of the analysis framework described here utilizes the algorithm described by Fisher [7].

Schedule to resolve resource conflicts

It is in this stage that the consequences of the realized risks in each scenario are played out in terms of an actual schedule for the included tasks. Assuming that multitasking decreases the efficiency of a resource, tasks that are concurrently assigned to the same resource must be rescheduled to preserve that resources productivity rate and the consequences of that rescheduling throughout the project must be resolved. Although some adjustments to the productivity rate of a resource over the time span where they are required to multitask might be utilized to model this effect, doing so would incur greater computational costs, and with little advantage, since it is generally accepted that multitasking will involve a greater time penalty than temporally contiguous assignments.

The generation of a reasonably time-efficient schedule has received significant attention in the disciplines of management science and operations research, and the reader is referred to Elsayed and Nasr [6] for further information on this topic. Again the selection of an appropriate scheduling algorithm is primarily a matter of implementation, and beyond the

scope of this paper. The PM Eye implementation, utilizes the relatively simplistic MINSLK scheduling heuristic which gives scheduling preference to tasks with less schedule slack, although more evolved implementations could provide heuristics of greater sophistication. The MINSLK heuristic was deemed adequate for illustrative purposes and ease of implementation at this early stage of development of the decision support tool.

Analyze scenario outcomes

The final stage of the analysis is the determination the project costs and completion times for each risk scenario, which are then used to create cost and time distributions for the project as whole. Since each project cost and project completion time are possible outcomes of the project and have an associated probability, which are the probabilities of the associated scenarios, the definitions of the cost and time distributions follow naturally. Given these distributions, expected values for cost and time can be determined readily.

Project comparisons

As stated previously, projects with identical goals and identical risks may be compared readily. There are comparable risk scenarios for each project and the efficiency of each scenario in terms of time and cost may be evaluated by comparing the time and cost outcomes associated with those scenarios. In addition, the relative merit of each project across all scenarios may be evaluated via a comparison of the expected time and cost values, which are determined by the distributions of the scenario outcomes. In all cases it may be assumed that lower completion times and costs are preferable, and an ordering of the projects or scenarios by those criteria can be considered an acceptable determination of a particular project's relative utility.

3 Results

The PM Eye Framework Implementation

The PM Eye application was developed for Microsoft Win32 platforms with the ActiveState ActivePerl 5.8 Implementation of the Perl programming language and a Microsoft Access 2000 ODBC database. The graphical user interface was implemented using the Perl/Tk GUI toolkit. Project network visualization was made possible with the GraphViz 1.10 binary distribution for Win32 platforms.

Other publicly available Perl Modules utilized in the PM Eye Application include:

1. DBI
2. Data::Dumper
3. Graph::Directed
4. Tk::Graph
5. Tk::NoteBook
6. Tk::ProgressBar
7. Tk::Pane

PM Eye consists of the following software components:

1. Project Database – Stores multiple projects and their related tasks, resources, task relationships, project risks, and contingency plans, etc.
2. Event Driven GUI – Interface to database, analysis, and display functionality. Built using the Perl/Tk GUI toolkit.
3. Analysis Functions – Interacts with a relational database of project data. Automatically prepares projections of project risk scenarios from project data relations, and calculates the scenarios' probabilities, minimum times and costs, as well as the expected value of the project across all projected scenarios.
4. Graphing Module - Creates a graph representation of project schedules utilizing an algorithm developed by A.C.Fisher et al [7].
5. Scheduling Module – Assigns start times and calculates the critical path of schedules using standard CPM (Critical Path Method) calculations [14].

6. Set Manipulation Module – Provides set relationship and manipulation functions, utilized throughout the other modules and main program.

For simplicity of implementation and demonstration, the version of PM Eye developed to illustrate the Schedule Analysis Framework uses several computational simplifications of a project environment. A practical implementation of the framework would require a more detailed treatment of the environment; however, they are inessential to illustration of the central concepts of the framework.

1. Eight hour work day - A work day is assumed to consist of eight man-hours per resource, and the idealized durations of tasks are measured in units of one work day.
2. Contiguous work days – Project time is assumed to be uninterrupted, with resources working on tasks through a single eight hour shift over contiguous working days.
3. Uniform resource calendar – All resources are assumed to be available on all working days throughout the duration of the project.
4. One-to-one resource-task assignments – Tasks are assumed to have one and only one assigned resource throughout their duration.
5. Utilization of MINSLK scheduling heuristic - There are a number of scheduling heuristics that might be utilized for the purposes of a decision support application. The MINSLK heuristic, which prioritizes tasks to be scheduled by increasing total slack as determined by standard CPM network calculations, was chosen for its simplicity and speed.

Essential Concepts

Project Plan

A project plan is defined as:

1. A set of tasks and corresponding task durations.
2. The precedence relationships of the tasks
3. The resources assigned to complete the tasks, their compensation rates, and their levels of skill in their areas of expertise.
4. The risks associated with the project and their probabilities
5. The contingency plans associated with the project risks

Project

A project is a tuple of the relation schema Project (P#, PNAME) with primary key P#.

1. P# - unique project identifier
2. PNAME – Project Name

P#	PNAME
1	p1
2	p2

Figure 3-1 Example of the Project relation

Risks

A risk is a tuple of the relation schema Risk (RK#, P#, RKNAME, PROB) with primary key RK#.

1. RK# - unique risk identifier
2. P# – project associated with the risk
3. RKNAME – risk name
4. PROB – probability of the risk's occurrence

RK#	P#	RKNAME	PROB
1	1	rk1	0.2
2	1	rk2	0.5

Figure 3-2 Example of the Risk Relation

Resources

A resource is a tuple of the relation schema Resource (R#, RNAME, RATE) with primary key R#

1. R# - unique resource identifier
2. RNAME – Resource Name
3. RATE – Billable rate of the resource in dollars per hour

R#	RNAME	RATE
1	r1	\$35
2	r2	\$40

Figure 3-3 Example of the Resource Relation

Skills

A skill is a tuple of the relation schema Skill(*S#*, SNAME) with primary key *S#*

1. *S#* - unique resource identifier
2. SNAME – skill name

S#	SNAME
1	s1
2	s2

Figure 3-4 Example of the Skill Relation

Tasks

A task is a tuple of the relation schema Task (*T#*, P#, PTID, TNAME, TDUR, RK#) with primary key *T#*

1. *T#* - unique task identifier
2. P# - project associated with the task
3. PTID – task identifier relative to the associated project
4. TNAME – task name
5. TDUR – task duration in idealized work units
6. RK# - risk associated with the task if it is designated as part of a contingency plan.

T#	P#	PTID	TNAME	TDUR	RK#
1	1	1	a	1	
2	1	2	b	1	
3	1	3	c	1	
4	1	4	d	1	
5	1	5	e	1	1
6	2	1	f	1	
7	2	2	g	1	
8	3	1	h	1	
9	3	2	i	1	

Figure 3-5 Example of the Task Relation

Precedence Relationships

A task is a tuple of the relation schema TRel (TR#, P#, PTID, TSUCC, RK#) with primary key TR#

1. TR# - unique task relationship identifier
2. P# - project associated with the task relationship
3. PTID – task identifier relative to the associated project
4. TSUCC – task identifier of a successor task in the associated project
5. RK# - risk identifier indicating that the relationship belongs to a contingency plan associated with the project.

TR#	P#	PTID	TSUCC	RK#
1	1	1	2	
2	1	2	4	
3	1	3		
4	1	4		
5	1	4	5	1
6	1	5		1
7	2	1	2	
8	2	2		
9	3	1	2	
10	3	2		

Figure 3-6 Example of the TRel Relation

Assignments

An assignment is a tuple of the relation schema Assign (P#, PTID, R#, RK#) with primary key {P#, PTID, R#}

1. P# - project associated with the assignment
2. PTID – task identifier of the task to be assigned relative to the associated project
3. R# - resource identifier of the resource assigned to the task
4. RK# - risk identifier indicating that this assignment belongs to a contingency plan associated with the project

P#	PTID	R#	RK#
1	1	1	
1	2	2	
1	3	1	
1	4	2	
1	2	1	2
1	5	2	1
2	1	1	
2	2	2	
3	1	1	
3	2	2	

Figure 3-7 Example of the Assign Relation

Resource Skills

A resource skill is a tuple of the relation schema RSkill(R#, S#, SKLVL) with primary key {R#, S#}

1. R# - identifier of the resource possessing the skill
2. S# - identifier of the skill possessed by the resource
3. SKLVL – the level of the resource’s expertise in the skill

R#	S#	SKLVL
1	1	4
1	2	3
2	1	2
2	2	5

Figure 3-8 Example of the RSkill Relation

Required Skills

A required skill for a task is a tuple of the relation schema

TSkill (P#, PTID, S#, TSLVL, WEIGHT) with primary key {P#, PTID, S#}

1. P# - project associated with the skill requirement
2. PTID – identifier of the task for which the skill is required.
3. S# - identifier of the required skill
4. TSLVL – the ideal skill level for a resource assigned to this task
5. WEIGHT – the relative importance of this skill for the successful completion of the task.

P#	PTID	S#	TSLVL	WEIGHT
2	1	1	3	1
2	2	1	4	1

Figure 3-9 Example of the TSkill Relation

Risk Scenarios

Given a set of risks associated with a project, the project's risk scenarios represent the potential combination of realized risks during the course of the project. The risk scenarios are then members of risk set's power set, and represent situations where a subset of the risks are realized. For example:

Recalling the relation schema Risk (RK#, P#, RKNAME, PROB), consider the project p_1 with identifier '1' and set of risk identifiers

$$RK_1 = \{ 1, 2 \} = \{ a \mid (\exists b)(\exists c)(\exists d)Risk(abcd) \wedge b = 1 \}$$

The set of risk scenarios RS_1 is then the power set of RK_1

$$RS_1 = *RK_1 = \{ \emptyset, \{1\}, \{2\}, \{1, 2\} \}$$

The element $\emptyset$ of the power set corresponds to the situation where no project risks are realized. Element $\{1\}$ corresponds the situation where only risk '1' is realized, $\{1,2\}$ to the situation where '1' and '2' are realized, etc. We define a mapping function $\text{prob}(x) = y$, with $x \in RK_1$ indicating the probability of risk x occurring during the course of the project given by:

$$\{ xy \mid (\exists w)(\exists z)\text{Risks}(xwzy) \}$$

A risk scenario is a set $S_i \in *RK_1$. Let $S_1 = \emptyset$, corresponding to the base scenario with no realized risks. Let $S_i' = \{ r \mid r \in RK_1 - S_i \}$. We then define the function $\text{sprob}(S_i)$, $S_i \in *RK_1$, the probability of a scenario's occurrence, given by:

$$\text{sprob}(S_i) = \prod_{r \in S_i} \text{prob}(r) * \prod_{t \in S_i'} 1 - \text{prob}(t)$$

The probability of the base scenario is a special case notated as

$$\text{sprob}(S_1) = 1 - \sum_{i>1} \text{sprob}(S_i)$$

Contingency Plans

For each risk associated with a project, contingency plans may be defined in order to reassign resources to different tasks, redefine existing tasks, alter the task precedence relationships, and/or add additional tasks to the project. The tasks, assignments, and task relationships of the contingency plans coexist with those of the base scenario in the relations and are distinguished by an association with a particular risk.

Consequently, we may define a transformation of the original project plan associated with each risk scenario, which includes additional tasks, task relationships, task-skill relationships, and reassignments, and may or may not involve the modification of existing tasks. Potentially distinct precedence, task, and assignment relations exist for each risk scenario defined for a project.

Let p be a project identifier. Let T_i , A_i , TR_i , and TS_i be the task, assignment, task precedence relations, and task skill relations defined for S_i , with schemas:

1. $T_i(PTID, TNAME, TDUR)$
2. $A_i(PTID, R\#)$
3. $TR_i(PTID, TSUCC)$
4. $TS_i(PTID, S\#, TSLVL, WEIGHT)$

Recalling the relation schema Task ($I\#, P\#, PTID, TNAME, TDUR, RK\#$):

$$\begin{aligned} \text{Let } T_i' &= \cup_{r \in S_i} \{ cde \mid (\exists a)(\exists b)(\exists f) \text{Tasks}(abcdef) \wedge b = p \wedge f = r \} \\ \text{Let } T_i &= \{ cde \mid (\exists a)(\exists b)(\exists f) \text{Tasks}(abcdef) \wedge b = p \wedge f = \text{NULL} \wedge \neg(\exists g)(\exists h)(\exists i)T_i'(ghi) \wedge g = c \} \end{aligned}$$

Recall the relation schema Assign ($P\#, PTID, R\#, RK\#$):

$$\begin{aligned} \text{Let } A_i' &= \cup_{r \in S_i} \{ bc \mid (\exists a)(\exists d) \text{Assign}(abcd) \wedge a = p \wedge d = r \} \\ \text{Let } A_i &= \{ bc \mid (\exists a)(\exists d) \text{Assign}(abcd) \wedge a = p \wedge d = \text{NULL} \wedge \neg(\exists e)(\exists f)A_i'(ef) \wedge e = b \} \end{aligned}$$

Recalling the relation schema TRel ($TR\#, P\#, PTID, TSUCC, RK\#$):

$$\begin{aligned} \text{Let } TR_i' &= \cup_{r \in S_i} \{ cd \mid (\exists a)(\exists b)(\exists e) \text{TRel}(abcde) \wedge b = p \wedge e = r \} \\ \text{Let } TR_i &= \{ cd \mid (\exists a)(\exists b)(\exists e) \text{TRel}(abcde) \wedge b = p \wedge e = \text{NULL} \wedge \neg(\exists f)(\exists g)TR_i'(fg) \wedge f = c \wedge g = d \} \end{aligned}$$

Recall the relation schema TSkill ($P\#, PTID, S\#, TSLVL, WEIGHT$):

$$\text{Let } TS_i = \{ bcde \mid (\exists a) \text{TSkill}(abcde) \wedge a = p \}$$

Scaling Task Durations

A number of methods might be proposed to scale tasks according to the skill levels of the assigned resource, and furthermore, other alternatives of task scaling that do not rely exclusively on such criteria are certainly possible. The method proposed here utilizes qualitative assessments of both a resource's level of expertise and the ideal skill level required to preserve the initial idealized estimate of the tasks duration as an actual duration, but more sophisticated methods could feasibly be developed that utilize some objective measure of skill

(determined by testing or performance reviews) and historical data used to develop objectively defined relationships between levels of expertise and the work efficiency in certain types of tasks. The limitations of such approaches in general and the deficiencies of standardized testing in particular are well known, but could provide some benefit in this context.

The means suggested here are admittedly simplistic, and were developed with the intent of illustrating the possibilities of such an approach, rather than defining a canonical methodology for such evaluations. Practical implementations of this framework might include some facility for the definition of customizable functions to determine scaling functions, or at least provide the user with a rich feature set that enables the selection of the most appropriate function for a particular context. Practical implementations might also provide a high level of granularity in the application of the possible scaling functions, determining which tasks may be scaled and the specific method of scaling deemed appropriate for that type of task.

For our purposes of illustration, we propose the calculation of a general scaling factor for each task which is then applied to the ideal duration of the task. Scaling factors are calculated for each of a task's required skills and are weighted according to the relative importance of that skill. The unweighted scaling factors are proportional to the difference between the ideal skill level defined for the task and the level of expertise in that skill possessed by the assigned resource. The weighted scaling factors are then summed to produce a general scaling factor for the task.

In our example, we define the range of skill levels for tasks and resources alike as the integers 1..5 with 1 representing beginner status, 5 representing expert status, and the others representing proportionately distributed intermediate skill levels between these extremes. The choice of a range of skill levels in this discussion is arbitrary, and could be substituted with others of a finer level of granularity.

Given the relations of a risk scenario's tasks T_i and assignments A_j , and the relation of resources to skills RSkill and tasks to skills TSkill as described above, we proceed as follows.

Recall the relation schemas:

1. RSkill(R#, S#, SKLVL)
2. T_i(PTID, TNAME, TDUR)
3. A_i(PTID, R#)
4. TS_i(PTID, S#, TSLVL, WEIGHT)

We first define a function $f(x) = y$, such that x is the difference between a task's required skill level for a particular skill and the assigned resource's level of expertise for that skill. $f(x) = y$ is given by:

$$\{ xy \mid y = 1.25 \text{ if } x > 0, y = 0.75 \text{ if } x < 0, y = 1.0 \text{ if } x = 0 \}$$

Again this choice of scaling functions serves a primarily illustrative purpose, and translates to the assumption that resources working on a task above or below their skill level will take 25% longer or shorter than an ideally skillful resource.

We now define a weighted scaling factor function, $wsfactor(x,y) = z$ such that x is a project task ID in the task relation T_i , and y is skill ID in TS_i , and defined by the relation given by

$$\{ xyz \mid (\exists a)(\exists b)(\exists c)(\exists d)(A_i(xa) \wedge RSkill(ayb) \wedge TS_i(xycd) \wedge z = d * f(c - b)) \}$$

Let $X_i = \{ xy \mid (\exists a)(\exists b)TS_i(xyab) \}$. We define the general scaling function $gfactor(x) = y$, where x is a project task ID in T_i , given by:

$$gfactor(x) = \sum_{z \in \{z \mid \exists i(xz)\}} wsfactor(x,y)$$

Finally we can define the relation of scaled tasks T_i^{scaled} with schema $T_i^{scaled}(PTID, TNAME, TDUR)$ given by:

$$T_i^{scaled} = \{ xyz \mid (\exists a)Ti(xya) \wedge z = gfactor(x) * a \}$$

Project Networks

For each risk scenario S_i , we may construct a project network G_i from the task relationships relation TR_i . For a description of an algorithmic means of creating a project network see *Computer Construction of Project Networks*, Fisher, et al [7]. The inputs to Fisher's algorithm can be readily prepared by means of the TR_i relation described above. For the purposes of this discussion, we will assume G_i to be a CPM project network capturing the task relationships defined in the relation TR_i .

Project Schedule

For each risk scenario S_i , we may also construct a project schedule which is a relation $Schedule_i$ defined as follows:

$Schedule_i$ (PTID, ES, EF)

1. PTID – task identifier relative to the associated project
2. ES – early start time of the task
3. EF – early finish time of the task

The creation of an appropriate schedule relation may be accomplished by a number of means, which are outside the scope of this discussion. For a description of relevant scheduling methods see *Heuristics for Resource Constrained Scheduling*, Elsayed and Nasr [6].

For our purposes, we assume that the schedule produced is constrained such that a resource may not have more than one task assigned at any given time during the project.

Time and Cost

There is a minimum cost and a minimum time associated with each risk scenario. In order to calculate the cost we first define the mapping functions $assignment(x) = y$ where x is a task identifier, $rate(x) = y$ where x is a resource identifier, and $duration(x) = y$ where x is a project task identifier.

Recalling the relation schemas...

1. Resource(R#, RNAME, RATE)

2. $A_i(PTID, R\#)$
3. $T_i(PTID, TNAME, TDUR)$
4. $Schedule_i(PTID, ES, EF)$

We specify $Assignment(x) = y$ with the relation $\{ xy \mid A_i(xy) \}$, $Rate(x) = y$ with the relation $\{ xy \mid (\exists z)Resource(xzy) \}$ and $Duration(x) = y$ with the relation $\{ xy \mid (\exists z)T_i(xzy) \}$.

Let U_i be the set of task identifiers of tasks in the schedule relation $Schedule_i$, given by $U_i = \{ u \mid (\exists v)(\exists w)Schedule_i(uvw) \}$. Let V_i be the set of the early finishes of all tasks in the schedule, $Schedule_i$, given by $V_i = \{ v \mid (\exists t)(\exists u)Schedule_i(tuv) \}$. Let w be the number of hours in a work unit (e.g. $w = 8$ for an eight hour work day using days as the work unit)

The cost of the risk scenario's schedule can now be defined as follows:

$$\begin{aligned} cost(S_i) &= \sum_{u \in U_i} Rate(Assignment(u)) * duration(u) * w \\ time(S_i) &= \max(V_i) \end{aligned}$$

Comparison of Project Plans

Different project plans can be created to achieve the same goal. These plans may consist of different tasks, resources, and assignments. Discrete, non-uniform, minimum time and minimum cost distributions can be created for a project plan and its risk scenarios, since each scenario is a discrete event with an associated probability. Subsequently, project plans designed to achieve the same goal can be compared, by calculating and comparing the expected value of the plans (across all risk scenarios) with respect to minimum time and cost.

An analysis of a project schedule with defined risks and established contingency plans for realized risks can be characterized as a problem in decision making under uncertainty with the opponents being the project manager given a set of possible project plans (of which the project manager must choose one) as pure strategies, and the state of nature being a combinatorial enumeration of the realized risks. Arranged in a table with the project plans on one axis with the risk scenarios on the other (Table 3-1), the intersections represent the

outcomes of utilizing a specific schedule in opposition to a specific combination of realized risks. In game theoretical terms, each possible outcome may be assigned a utility ranking, based on the estimates of cost and/or completion time for that combination [12].

Table 3-1 Cost outcomes of two projects with four risk scenarios

	S1	S2	S3	S4
Project 1	\$20,000	\$25,000	\$22,000	\$28,000
Project 2	\$19,000	\$22,000	\$20,000	\$25,000

We can now calculate the expected value of a project p , with set of risks RK^p and risk scenarios $RS^p = \{ S_i \mid S_i \in *RK^p \}$. The expected project time $EVT(p)$ is given by

$$EVT(p) = \sum_{i=1 \text{ to } |RS^p|} \text{sprob}(S_i) * \text{time}(S_i)$$

and similarly the expected project cost $EVC(p)$ is given by

$$EVC(p) = \sum_{i=1 \text{ to } |RS^p|} \text{sprob}(S_i) * \text{cost}(S_i)$$

Project x may be considered ‘preferred’ over a project y if $EVT(x) < EVT(y)$ or $EVC(x) < EVC(y)$ if project time or project cost is deemed more significant, respectively.

4 Discussion

Analysis Example Utilizing the PM Eye Application

Consider the following project scenario: A consulting company has contracted to design and develop a simple client-server database application. The project manager has estimated the tasks and assignments listed in Table 4-1. Required skills and ideal skill levels for the tasks are listed in Table 4-2. Available staff members for the project and their skills are listed in Table 4-3.

Table 4-1 Tasks and Assignments

Task	Assigned Resource
Requirements Elicitation	Business Analyst
Design	System Architect
Specifications	System Architect
Build Server Development Environment	System Administrator
Build Testing and Integration Environment	System Administrator
Develop Data Model	DBA A
Prepare Test Data	DBA A
Prepare Database Scripts	DBA A
Create Test Database	DBA A
Develop Stored Procedures	DBA A
Client GUI Interface Design	GUI Designer
Implement Server Daemon	Programmer A
Implement Server Database Access Layer	Programmer A
Implement Transaction Handlers	Programmer A
Server Unit Testing and Debugging	Programmer A
Client Server Integration	Programmer A
Client Server Testing and Debugging	Programmer A
Implement Client Application Framework	Programmer B
Implement Simulated Client Server Communication	Programmer B
Implement Core Client Objects	Programmer B
Client Component Integration	Programmer B
Client Unit Testing and Debugging	Programmer B
Implement Client Network Communications	Programmer C
Implement Client GUI	Programmer D
Quality Assurance Testing	QA

Table 4-2 Skill Requirements

Task	Skills	Weight	Ideal Skill Level
Requirements Elicitation	UML	0.2	3
	Requirements Analysis	0.8	3
Design	Data Modeling	0.1	2
	Systems Analysis	0.4	4
	UML	0.1	4
	Requirements Analysis	0.4	4
Specifications	UML	0.2	4
	Data Modeling	0.1	2
	Requirements Analysis	0.4	4
	Systems Analysis	0.3	4
Build Server Development Environment	Oracle 9i	0.1	3
	UNIX	0.4	3
	Server Hardware	0.4	3
	Networking	0.1	3
Build Testing and Integration Environment	Server Hardware	0.4	3
	Networking	0.1	3
	UNIX	0.4	3
	Oracle 9i	0.1	3
Develop Data Model	Oracle 9i	0.2	4
	PL/SQL	0.2	4
	Requirements Analysis	0.2	3
	Data Modeling	0.3	4
	UNIX	0.05	3
	UML	0.05	3
Prepare Test Data	PL/SQL	0.3	3
	Requirements Analysis	0.3	3
	UNIX	0.1	3
	Oracle 9i	0.3	3
Prepare Database Scripts	UNIX	0.1	2
	PL/SQL	0.45	3
	Oracle 9i	0.45	2
Create Test Database	UNIX	0.1	2
	Oracle 9i	0.9	3
Develop Stored Procedures	UNIX	0.1	2
	PL/SQL	0.4	4
	Requirements Analysis	0.2	3
	Oracle 9i	0.3	4
Implement Server Daemon	Systems Analysis	0.2	3
	Network Programming	0.4	4
	C++	0.3	3
	UNIX	0.1	2
Implement Server Database Access Layer	Systems Analysis	0.2	3
	PL/SQL	0.3	3
	UNIX	0.1	2
	C++	0.4	3
Implement Transaction Handlers	UNIX	0.1	2
	Systems Analysis	0.2	3
	C++	0.3	3
	Network Programming	0.4	4
Server Unit Testing and Debugging	UNIX	0.1	2
	PL/SQL	0.3	3
	Network Programming	0.3	3
	C++	0.3	3
Client GUI Interface Design	Usability	0.2	4
	Graphic Design	0.2	3
	UML	0.2	2
	Requirements Analysis	0.4	3
Implement Client Application Framework	Usability	0.1	3
	C++	0.3	3
	Systems Analysis	0.3	3
	UML	0.3	2

Task	Skills	Weight	Ideal Skill Level
Implement Simulated Client Server Communication	Systems Analysis	0.2	3
	Network Programming	0.4	3
	C++	0.4	3
Implement Client Network Communications	Systems Analysis	0.2	3
	C++	0.4	3
	Network Programming	0.4	3
Implement Client GUI	Usability	0.4	3
	C++	0.6	3
Implement Core Client Objects	Systems Analysis	0.4	3
	C++	0.4	3
	UML	0.2	2
Client Component Integration	Systems Analysis	0.6	3
	C++	0.4	3
Client Unit Testing and Debugging	Systems Analysis	0.6	3
	C++	0.4	3
Client Server Integration	Systems Analysis	0.3	4
	Network Programming	0.2	3
	UNIX	0.1	3
	PL/SQL	0.1	3
	C++	0.3	3
Client Server Testing and Debugging	Systems Analysis	0.3	4
	Network Programming	0.2	3
	PL/SQL	0.1	3
	C++	0.3	3
	UNIX	0.1	3
Quality Assurance Testing	Usability	0.4	3
	QA Testing	0.6	3

Table 4-3 Skill Profiles of Project Team Members

Resource	Skill	Level
Business Analyst	UML	2
	Requirements Analysis	3
System Architect	Systems Analysis	4
	UML	3
	Data Modeling	2
	Requirements Analysis	4
System Administrator	Oracle 9i	2
	UML	2
	Data Modeling	1
	Networking	4
	UNIX	4
	Server Hardware	4
	PL/SQL	3
	Requirements Analysis	2
DBA A	Oracle 9i	5
	UML	2
	Data Modeling	5
	UNIX	3
	XML	3
	PL/SQL	5
	Requirements Analysis	3
GUI Designer	Graphic Design	3
	Usability	4
	UML	1
	Requirements Analysis	2
Programmer A	UNIX	4
	XML	4
	C++	4
	PL/SQL	3

Resource	Skill	Level
	Network Programming	5
	Systems Analysis	4
	UML	3
	Requirements Analysis	3
	Data Modeling	2
Programmer B	Usability	1
	UNIX	2
	XML	2
	C++	4
	PL/SQL	2
	Network Programming	2
	Systems Analysis	3
	UML	1
	Requirements Analysis	2
Programmer C	UNIX	4
	XML	2
	C++	2
	Network Programming	5
	Systems Analysis	2
	UML	1
	Requirements Analysis	2
Programmer D	Usability	4
	UNIX	1
	C++	1
	Systems Analysis	1
	Requirements Analysis	2
QA	Usability	3
	QA Testing	5

The development of the client and server will take place in parallel, with two technical leads, Programmer A and Programmer B, the most skilled team members, taking the lead in the development of the client and server respectively. However, the project manager anticipates some complications while scheduling the project. It is somewhat likely that two team members, DBA A and Programmer B, will be assigned to a higher priority project by IT management and may be unavailable to work on the client-server database application.

As a backup plan for this eventuality, the project manager plans to reassign DBA A's tasks to the technical lead for the server application, Programmer A, since Programmer A is the only staff member with sufficient expertise to take on DBA A's responsibilities. Programmer A is not as proficient in database technologies as the DBA, and the project manager expects the reassigned tasks to require additional time as a result. Similarly, in the event that Programmer B is unavailable, his tasks will be reassigned to Programmer C, who has the right skill set for the tasks, although a lower level of proficiency. Similarly to the other reassignment, some resulting delays are expected here as well.

There is also the possibility that a particular stakeholder from the client company, well known at the consulting firm, for micromanaging the design of the GUI and delaying the sign-off on the design, will play a prominent role in the development effort. Historically speaking, the representative for the client company for the project has previously introduced significant delays by requesting modifications to the graphical user interface of previous applications and the project manager estimates that delays of approximately two weeks in the development of the client application could be expected in the event that this particular individual is assigned to represent the client in this project. Subsequently, the project manager defines the risks and contingency plans listed in Figure 4-1, as being pertinent to the project at hand.

From a scheduling perspective, the contingency plans for the availability risks of the resources have the potential to impact the schedule significantly since the backup resources are not as skilled as the preferred resources for the tasks. Additionally, some rescheduling might be required because of concurrent task assignments for those resources, which are already scheduled for several tasks during the project. Consequently, the project manager decides to explore the possibility of obtaining additional team members for the project. The project manager develops skill profiles (Table 4-4), based on two recently interviewed applicants, for two new team members to take the place of the unavailable resources.

Table 4-4 Skill Profiles of Additional Team Members

Resource	Skill	Level
DBA B	Oracle 9i	4
	UNIX	3
	XML	3
	PL/SQL	4
	UML	2
	Data Modeling	4
	Requirements Analysis	3
Programmer E	Usability	1
	UNIX	2
	XML	2
	C++	3
	PL/SQL	2
	Network Programming	2
	Systems Analysis	3
	UML	1
	Requirements Analysis	2

The project manager then defines a second version of the original project, with the only difference being a change in the contingency plans to reassign tasks to the two potential team members, instead of Programmer A and Programmer C. By performing an analysis and comparison of both versions of the project, the project manager hopes to determine the potential impact of these scheduling and staffing decisions, in light of the risks involved.

Figure 4-1 Risks and Contingency Plans

Project v1		Project v2	
Realized Risks	Contingency Plan	Realized Risks	Contingency Plan
DBA A is unavailable	Reassign tasks to Programmer A	DBA A is unavailable	Reassign tasks to DBA B
Executive sign-off on GUI is delayed	Accommodate delay in project schedule	Executive sign-off on GUI is delayed	Accommodate delay in project schedule
Programmer B is unavailable	Reassign tasks to Programmer C	Programmer B is unavailable	Reassign tasks to Programmer E

Given the three project risks, PM Eye generates a total of eight risk scenarios shown in Figure 4-2, including the base scenario with no realized risks. The assigned probabilities of each risk are arrived at through discussion with the project staff, and the probabilities of the scenarios are calculated as described in the results section above.

Based on the project data stored in a relational database (see Appendix B – Example Database for a full description of the project data), PM Eye generates project networks for each risk scenario of both projects. Figure 4-3 shows the project network generated for the base scenario of the first version of the project - Table 4-5 and Table 4-6 show the associated CPM calculations and schedule. Full analysis results for all scenarios of both projects are listed in Appendix A – Full Example Analysis.

Base Scenario	
Realized Risks	Probability
None	N/A
Scenario Probability:	0.105

Scenario 1	
Realized Risks	Probability
DBA A is unavailable	0.5
Scenario Probability:	0.105

Scenario 2	
Realized Risks	Probability
Programmer B is unavailable	0.3
Scenario Probability:	0.045

Scenario 3	
Realized Risks	Probability
Executive sign-off on GUI is delayed	0.7
Scenario Probability:	0.245

Scenario 4	
Realized Risks	Probability
DBA A is unavailable	0.5
Programmer B is unavailable	0.3
Scenario Probability:	0.045

Scenario 5	
Realized Risks	Probability
DBA A is unavailable	0.5
Executive sign-off on GUI is delayed	0.7
Scenario Probability:	0.245

Scenario 6	
Realized Risks	Probability
Executive sign-off on GUI is delayed	0.7
Programmer B is unavailable	0.3
Scenario Probability:	0.105

Scenario 7	
Realized Risks	Probability
DBA A is unavailable	0.5
Executive sign-off on GUI is delayed	0.7
Programmer B is unavailable	0.3
Scenario Probability:	0.105

Figure 4-2 Risk Scenarios and Probabilities

Figure 4-3 Project Network of the Base Scenario

Table 4-5 CPM Data for the Base Scenario

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	145.5	137.4	157.9	12.4	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	159.5	130.9	165.4	5.9	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	178.1	193.1	45.1	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	224.9	232.9	91.9	91.9	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	158.1	133	158.1	0	0	25.1	\$25,125.00	DBA A	Develop Data Model
*	158.1	166.6	158.1	166.6	0	0	8.5	\$8,500.00	DBA A	Prepare Test Data
*	166.6	174.1	166.6	174.1	0	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
*	174.1	177.1	174.1	177.1	0	0	3	\$3,000.00	DBA A	Create Test Database
*	177.1	193.1	177.1	193.1	0	0	16	\$16,000.00	DBA A	Develop Stored Procedures
*	193.1	209.6	193.1	209.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	209.6	224.6	209.6	224.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	224.6	232.9	224.6	232.9	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	165.4	196.9	5.9	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	145.5	165.5	157.9	177.9	12.4	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	175.9	196.9	30.4	24.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	177.9	196.9	12.4	6.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	191	209	196.9	214.9	5.9	0	18	\$14,400.00	Programmer B	Client Component Integration
	209	227	214.9	232.9	5.9	5.9	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	232.9	241.4	232.9	241.4	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	241.4	258.4	241.4	258.4	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	258.4	275.4	258.4	275.4	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 275.4 days
										Total Cost: \$427525.00

Table 4-6 Schedule for Base Scenario

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	158.1	DBA A	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
158.1	166.6	DBA A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
166.6	174.1	DBA A	Prepare Database Scripts
191	209	Programmer B	Client Component Integration
174.1	177.1	DBA A	Create Test Database
209	227	Programmer B	Client Unit Testing and Debugging
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
232.9	241.4	Programmer A	Client Server Integration
241.4	258.4	Programmer A	Client Server Testing and Debugging
258.4	275.4	QA	Quality Assurance Testing
			Project Length (adjusted): 275.4 days
			Total Cost: \$427525.00

Figure 4-4 shows a comparison of the costs, completion times, and expected values of the projects. A glance at the expected values calculated for each project clearly shows that some significant time and cost savings for the project can be expected, with the addition of the two new team members in project 2. The difference in expected costs and completion time between project 1 and project 2 are \$23,240.00 and 18.5 days respectively. The difference between the worst and best time and cost outcomes of project 1, are 38.9 days and \$44,535.00 respectively, while project 2's best and worst are a significantly less worrisome 12.1 days and \$10,025.00. According to the analysis, it is likely that the project manager could make a convincing case for the acquisition of the additional resources. The fact that one of the worst outcomes in both time and cost is associated with Risk Scenario 5, which has an approximately 25% probability of being realized, adds extra weight to the desirability of taking the course of action described by project 2.

Time Comparison:									
	S0	S1	S2	S3	S4	S5	S6	S7	EV
Proj 1	275.4	314.3	309.5	283.5	314.3	314.3	309.5	314.3	301.9 days
Proj 2	275.4	284.1	275.4	283.5	284.1	284.1	287.5	287.5	283.4 days

Cost Comparison:									
	S0	S1	S2	S3	S4	S5	S6	S7	EV
Proj 1	427525	468260	423725	427525	464460	468260	423725	464460	\$446,752.50
Proj 2	427525	422500	422525	427525	417500	422500	422525	417500	\$423,512.50

Figure 4-4 Project Comparisons

Figure 4-5 Risk Scenario Distribution

Figure 4-6 Project Time Comparisons Graph

Figure 4-7 Project Cost Comparisons Graph

Figure 4-8 Best and Worst Case Time Comparisons

Figure 4-9 Best and Worst Case Cost Comparisons

Figure 4-10 Screenshot of PM Eye Interface

Figure 4-11 Time, Cost, and Probability Comparison Chart View for Project 1

Figure 4-12 Time, Cost, and Probability Comparison Chart View for Project 2

Figure 4-13 Gantt Chart View of Project 2

Future Studies

There are a number of potential extensions to the analysis framework and its implementation as a decision support application, that may be worthy of further investigation.

1. PERT-style Probabilistic Analysis – The framework, as described in this paper, suffers from some rigidity in the calculation of completion time estimates. The integration of PERT-like probabilistic time estimates could provide more flexibility and upper/lower bounds for project completion time.
2. Monte Carlo Analysis and Project Simulation – In addition to the deterministic analysis offered by the framework, the integration of Monte Carlo analysis tools, along with the probabilistic PERT time estimates, could provide the ability to perform simulations of projects and generate cost and time outcomes by these means.
3. Provision of additional scheduling heuristics – There are many scheduling heuristics that could be utilized in the scheduling step of the analysis, of which the one used in the PM Eye application, MINSLK, is one of the simplest. The use of more sophisticated scheduling heuristics could generate schedules that are more true to the real-life scheduling decisions that a project manager would be inclined to make in a hand-crafted schedule, thereby providing a more realistic estimate of the completion time a project.
4. Allow the assignment of multiple resources to tasks – The current implementation of the framework, only allows one-to-one assignments of resources and tasks. A more practical implementation could permit multiple assignments, and perform the necessary calculations to scale the duration of tasks to account the corresponding increase in productivity.
5. Interactive creation and comparison of project variations – Allowing the user to interactively create variations of projects in the database could enable the rapid evaluation of what-if scenarios, and increase the potential for gleaning useful insights.

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6 Appendix A – Full Example Analysis

Project Networks

Client Server Application v1 - Base Scenario Project Network

Figure 6-1 Client Server Application v1 - Base Scenario Project Network

Client Server Application v1 - Scenario 1 Project Network

Figure 6-2 Client Server Application v1 - Scenario 1 Project Network

Client Server Application v1 - Scenario 2 Project Network

Figure 6-3 Client Server Application v1 - Scenario 2 Project Network

Client Server Application v1 - Scenario 3 Project Network

Figure 6-4 Client Server Application v1 - Scenario 3 Project Network

Client Server Application v1 - Scenario 4 Project Network

Figure 6-5 Client Server Application v1 - Scenario 4 Project Network

Client Server Application v1 - Scenario 5 Project Network

Figure 6-6 Client Server Application v1 - Scenario 5 Project Network

Client Server Application v1 - Scenario 6 Project Network

Figure 6-7 Client Server Application v1 - Scenario 6 Project Network

Client Server Application v1 - Scenario 7 Project Network

Figure 6-8 Client Server Application v1 - Scenario 7 Project Network

Client Server Application v2 - Base Scenario Project Network

Figure 6-9 Client Server Application v2 - Base Scenario Project Network

Client Server Application v2 - Scenario 1 Project Network

Figure 6-10 Client Server Application v2 - Scenario 1 Project Network

Client Server Application v2 - Scenario 2 Project Network

Figure 6-11 Client Server Application v2 - Scenario 2 Project Network

Client Server Application v2 - Scenario 3 Project Network

Figure 6-12 Client Server Application v2 - Scenario 3 Project Network

Client Server Application v2 - Scenario 4 Project Network

Figure 6-13 Client Server Application v2 - Scenario 4 Project Network

Client Server Application v2 - Scenario 5 Project Network

Figure 6-14 Client Server Application v2 - Scenario 5 Project Network

Client Server Application v2 - Scenario 6 Project Network

Figure 6-15 Client Server Application v2 - Scenario 6 Project Network

Client Server Application v2 - Scenario 7 Project Network

Figure 6-16 Client Server Application v2 - Scenario 7 Project Network

CPM Data and Schedules

Client Server Application v1 - Base Scenario CPM Data and Schedule

Table 6-1 Client Server Application v1 - Base Scenario CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	145.5	137.4	157.9	12.4	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	159.5	130.9	165.4	5.9	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	178.1	193.1	45.1	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	224.9	232.9	91.9	91.9	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	158.1	133	158.1	0	0	25.1	\$25,125.00	DBA A	Develop Data Model
*	158.1	166.6	158.1	166.6	0	0	8.5	\$8,500.00	DBA A	Prepare Test Data
*	166.6	174.1	166.6	174.1	0	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
*	174.1	177.1	174.1	177.1	0	0	3	\$3,000.00	DBA A	Create Test Database
*	177.1	193.1	177.1	193.1	0	0	16	\$16,000.00	DBA A	Develop Stored Procedures
*	193.1	209.6	193.1	209.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	209.6	224.6	209.6	224.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	224.6	232.9	224.6	232.9	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	165.4	196.9	5.9	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	145.5	165.5	157.9	177.9	12.4	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	175.9	196.9	30.4	24.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	177.9	196.9	12.4	6.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	191	209	196.9	214.9	5.9	0	18	\$14,400.00	Programmer B	Client Component Integration
	209	227	214.9	232.9	5.9	5.9	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	232.9	241.4	232.9	241.4	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	241.4	258.4	241.4	258.4	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	258.4	275.4	258.4	275.4	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 275.4 days
										Total Cost: \$427525.00

Table 6-2 Client Server Application v1 - Base Scenario Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	158.1	DBA A	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
158.1	166.6	DBA A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
166.6	174.1	DBA A	Prepare Database Scripts
191	209	Programmer B	Client Component Integration
174.1	177.1	DBA A	Create Test Database
209	227	Programmer B	Client Unit Testing and Debugging
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
232.9	241.4	Programmer A	Client Server Integration
241.4	258.4	Programmer A	Client Server Testing and Debugging
258.4	275.4	QA	Quality Assurance Testing
			Project Length (adjusted): 275.4 days
			Total Cost: \$427525.00

Client Server Application v1 – Scenario 1 CPM Data and Schedule

Table 6-3 Client Server Application v1 – Scenario 1 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	145.5	161.3	181.8	36.3	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	159.5	154.8	189.3	29.8	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	202.1	217.1	69.1	69.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	248.8	256.8	115.8	115.8	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	167.9	133	167.9	0	0	34.9	\$41,850.00	Programmer A	Develop Data Model
*	167.9	178.4	167.9	178.4	0	0	10.5	\$12,600.00	Programmer A	Prepare Test Data
*	178.4	189.3	178.4	189.3	0	0	10.9	\$13,050.00	Programmer A	Prepare Database Scripts
*	189.3	194.1	189.3	194.1	0	0	4.8	\$5,760.00	Programmer A	Create Test Database
*	194.1	217.1	194.1	217.1	0	0	23	\$27,600.00	Programmer A	Develop Stored Procedures
*	217.1	233.6	217.1	233.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	233.6	248.6	233.6	248.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	248.6	256.8	248.6	256.8	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	189.3	220.8	29.8	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	145.5	165.5	181.8	201.8	36.3	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	199.8	220.8	54.3	24.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	201.8	220.8	36.3	6.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	191	209	220.8	238.8	29.8	0	18	\$14,400.00	Programmer B	Client Component Integration
	209	227	238.8	256.8	29.8	29.8	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	256.8	265.3	256.8	265.3	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	265.3	282.3	265.3	282.3	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	282.3	299.3	282.3	299.3	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 299.3 days
										Total Cost: \$468260.00

Table 6-4 Client Server Application v1 – Scenario 1 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	167.9	Programmer A	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
167.9	182.9	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
182.9	193.4	Programmer A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
193.4	204.3	Programmer A	Prepare Database Scripts
191	209	Programmer B	Client Component Integration
204.3	209.1	Programmer A	Create Test Database
209	227	Programmer B	Client Unit Testing and Debugging
209.1	232.1	Programmer A	Develop Stored Procedures
232.1	248.6	Programmer A	Implement Server Database Access Layer
248.6	263.6	Programmer A	Implement Transaction Handlers
263.6	271.8	Programmer A	Server Unit Testing and Debugging
271.8	280.3	Programmer A	Client Server Integration
280.3	297.3	Programmer A	Client Server Testing and Debugging
297.3	314.3	QA	Quality Assurance Testing
			Project Length (adjusted): 314.3 days
			Total Cost: \$468260.00

Client Server Application v1 – Scenario 2 CPM Data and Schedule

Table 6-5 Client Server Application v1 – Scenario 2 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	150	125	150	0	0	25	\$15,000.00	Programmer C	Implement Client Application Framework
	125	159.5	130	164.5	5	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	133	138.1	146.1	13.1	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	191.3	206.3	58.3	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	238	246	105	105	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	158.1	146.1	171.3	13.1	0	25.1	\$25,125.00	DBA A	Develop Data Model
	158.1	166.6	171.3	179.8	13.1	0	8.5	\$8,500.00	DBA A	Prepare Test Data
	166.6	174.1	179.8	187.3	13.1	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
	174.1	177.1	187.3	190.3	13.1	0	3	\$3,000.00	DBA A	Create Test Database
	177.1	193.1	190.3	206.3	13.1	0	16	\$16,000.00	DBA A	Develop Stored Procedures
	193.1	209.6	206.3	222.8	13.1	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	209.6	224.6	222.8	237.8	13.1	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	224.6	232.9	237.8	246	13.1	13.1	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	164.5	196	5	5	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	150	171	150	171	0	0	21	\$12,600.00	Programmer C	Implement Simulated Client Server Communication
	150	171	175	196	25	25	21	\$12,600.00	Programmer C	Implement Client Network Communications
*	171	196	171	196	0	0	25	\$15,000.00	Programmer C	Implement Core Client Objects
*	196	221	196	221	0	0	25	\$15,000.00	Programmer C	Client Component Integration
*	221	246	221	246	0	0	25	\$15,000.00	Programmer C	Client Unit Testing and Debugging
*	246	254.5	246	254.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	254.5	271.5	254.5	271.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	271.5	288.5	271.5	288.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 288.5 days
										Total Cost: \$423725.00

Table 6-6 Client Server Application v1 – Scenario 2 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	150	Programmer C	Implement Client Application Framework
125	159.5	GUI Designer	Client GUI Interface Design
125	133	System Administrator	Build Server Development Environment
150	171	Programmer C	Implement Simulated Client Server Communication
159.5	191	Programmer D	Implement Client GUI
133	158.1	DBA A	Develop Data Model
171	192	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
192	217	Programmer C	Implement Core Client Objects
158.1	166.6	DBA A	Prepare Test Data
217	242	Programmer C	Client Component Integration
166.6	174.1	DBA A	Prepare Database Scripts
242	267	Programmer C	Client Unit Testing and Debugging
174.1	177.1	DBA A	Create Test Database
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
267	275.5	Programmer A	Client Server Integration
275.5	292.5	Programmer A	Client Server Testing and Debugging
292.5	309.5	QA	Quality Assurance Testing
			Project Length (adjusted): 309.5 days
			Total Cost: \$423725.00

Client Server Application v1 – Scenario 3 CPM Data and Schedule

Table 6-7 Client Server Application v1 – Scenario 3 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	159.5	125	159.5	0	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	145.5	145.5	166	20.5	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	133	133.1	141.1	8.1	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	186.3	201.3	53.3	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	233	241	100	100	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	158.1	141.1	166.3	8.1	0	25.1	\$25,125.00	DBA A	Develop Data Model
	158.1	166.6	166.3	174.8	8.1	0	8.5	\$8,500.00	DBA A	Prepare Test Data
	166.6	174.1	174.8	182.3	8.1	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
	174.1	177.1	182.3	185.3	8.1	0	3	\$3,000.00	DBA A	Create Test Database
	177.1	193.1	185.3	201.3	8.1	0	16	\$16,000.00	DBA A	Develop Stored Procedures
	193.1	209.6	201.3	217.8	8.1	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	209.6	224.6	217.8	232.8	8.1	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	224.6	232.9	232.8	241	8.1	8.1	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	145.5	165.5	166	186	20.5	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	184	205	38.5	38.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	186	205	20.5	20.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
*	159.5	173.5	159.5	173.5	0	0	14	\$0.00	delay	GUI sign-off delay
*	173.5	205	173.5	205	0	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	205	223	205	223	0	0	18	\$14,400.00	Programmer B	Client Component Integration
*	223	241	223	241	0	0	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	241	249.5	241	249.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	249.5	266.5	249.5	266.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	266.5	283.5	266.5	283.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 283.5 days
										Total Cost: \$427525.00

Table 6-8 Client Server Application v1 – Scenario 3 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	159.5	GUI Designer	Client GUI Interface Design
125	133	System Administrator	Build Server Development Environment
125	145.5	Programmer B	Implement Client Application Framework
159.5	173.5	delay	GUI sign-off delay
133	158.1	DBA A	Develop Data Model
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
173.5	205	Programmer D	Implement Client GUI
158.1	166.6	DBA A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
205	223	Programmer B	Client Component Integration
166.6	174.1	DBA A	Prepare Database Scripts
223	241	Programmer B	Client Unit Testing and Debugging
174.1	177.1	DBA A	Create Test Database
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
241	249.5	Programmer A	Client Server Integration
249.5	266.5	Programmer A	Client Server Testing and Debugging
266.5	283.5	QA	Quality Assurance Testing
			Project Length (adjusted): 283.5 days
			Total Cost: \$427525.00

Client Server Application v1 – Scenario 4 CPM Data and Schedule

Table 6-9 Client Server Application v1 – Scenario 4 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	150	135.8	160.8	10.8	0	25	\$15,000.00	Programmer C	Implement Client Application Framework
	125	159.5	140.8	175.3	15.8	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	202.1	217.1	69.1	69.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	248.8	256.8	115.8	115.8	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	167.9	133	167.9	0	0	34.9	\$41,850.00	Programmer A	Develop Data Model
*	167.9	178.4	167.9	178.4	0	0	10.5	\$12,600.00	Programmer A	Prepare Test Data
*	178.4	189.3	178.4	189.3	0	0	10.9	\$13,050.00	Programmer A	Prepare Database Scripts
*	189.3	194.1	189.3	194.1	0	0	4.8	\$5,760.00	Programmer A	Create Test Database
*	194.1	217.1	194.1	217.1	0	0	23	\$27,600.00	Programmer A	Develop Stored Procedures
*	217.1	233.6	217.1	233.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	233.6	248.6	233.6	248.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	248.6	256.8	248.6	256.8	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	175.3	206.8	15.8	5	31.5	\$25,200.00	Programmer D	Implement Client GUI
	150	171	160.8	181.8	10.8	0	21	\$12,600.00	Programmer C	Implement Simulated Client Server Communication
	150	171	185.8	206.8	35.8	25	21	\$12,600.00	Programmer C	Implement Client Network Communications
	171	196	181.8	206.8	10.8	0	25	\$15,000.00	Programmer C	Implement Core Client Objects
	196	221	206.8	231.8	10.8	0	25	\$15,000.00	Programmer C	Client Component Integration
	221	246	231.8	256.8	10.8	10.8	25	\$15,000.00	Programmer C	Client Unit Testing and Debugging
*	256.8	265.3	256.8	265.3	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	265.3	282.3	265.3	282.3	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	282.3	299.3	282.3	299.3	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 299.3 days
										Total Cost: \$464460.00

Table 6-10 Client Server Application v1 – Scenario 4 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	150	Programmer C	Implement Client Application Framework
125	159.5	GUI Designer	Client GUI Interface Design
133	167.9	Programmer A	Develop Data Model
150	171	Programmer C	Implement Simulated Client Server Communication
159.5	191	Programmer D	Implement Client GUI
171	192	Programmer C	Implement Client Network Communications
167.9	182.9	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
182.9	193.4	Programmer A	Prepare Test Data
192	217	Programmer C	Implement Core Client Objects
193.4	204.3	Programmer A	Prepare Database Scripts
217	242	Programmer C	Client Component Integration
204.3	209.1	Programmer A	Create Test Database
242	267	Programmer C	Client Unit Testing and Debugging
209.1	232.1	Programmer A	Develop Stored Procedures
232.1	248.6	Programmer A	Implement Server Database Access Layer
248.6	263.6	Programmer A	Implement Transaction Handlers
263.6	271.8	Programmer A	Server Unit Testing and Debugging
271.8	280.3	Programmer A	Client Server Integration
280.3	297.3	Programmer A	Client Server Testing and Debugging
297.3	314.3	QA	Quality Assurance Testing
			Project Length (adjusted): 314.3 days
			Total Cost: \$464460.00

Client Server Application v1 – Scenario 5 CPM Data and Schedule

Table 6-11 Client Server Application v1 – Scenario 5 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	159.5	140.8	175.3	15.8	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	145.5	161.3	181.8	36.3	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	202.1	217.1	69.1	69.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	248.8	256.8	115.8	115.8	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	167.9	133	167.9	0	0	34.9	\$41,850.00	Programmer A	Develop Data Model
*	167.9	178.4	167.9	178.4	0	0	10.5	\$12,600.00	Programmer A	Prepare Test Data
*	178.4	189.3	178.4	189.3	0	0	10.9	\$13,050.00	Programmer A	Prepare Database Scripts
*	189.3	194.1	189.3	194.1	0	0	4.8	\$5,760.00	Programmer A	Create Test Database
*	194.1	217.1	194.1	217.1	0	0	23	\$27,600.00	Programmer A	Develop Stored Procedures
*	217.1	233.6	217.1	233.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	233.6	248.6	233.6	248.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	248.6	256.8	248.6	256.8	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	145.5	165.5	181.8	201.8	36.3	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	199.8	220.8	54.3	38.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	201.8	220.8	36.3	20.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	159.5	173.5	175.3	189.3	15.8	0	14	\$0.00	delay	GUI sign-off delay
	173.5	205	189.3	220.8	15.8	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	205	223	220.8	238.8	15.8	0	18	\$14,400.00	Programmer B	Client Component Integration
	223	241	238.8	256.8	15.8	15.8	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	256.8	265.3	256.8	265.3	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	265.3	282.3	265.3	282.3	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	282.3	299.3	282.3	299.3	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 299.3 days
										Total Cost: \$468260.00

Table 6-12 Client Server Application v1 – Scenario 5 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	167.9	Programmer A	Develop Data Model
159.5	173.5	delay	GUI sign-off delay
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
167.9	182.9	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
182.9	193.4	Programmer A	Prepare Test Data
173.5	205	Programmer D	Implement Client GUI
165.5	184.5	Programmer B	Implement Core Client Objects
193.4	204.3	Programmer A	Prepare Database Scripts
205	223	Programmer B	Client Component Integration
204.3	209.1	Programmer A	Create Test Database
223	241	Programmer B	Client Unit Testing and Debugging
209.1	232.1	Programmer A	Develop Stored Procedures
232.1	248.6	Programmer A	Implement Server Database Access Layer
248.6	263.6	Programmer A	Implement Transaction Handlers
263.6	271.8	Programmer A	Server Unit Testing and Debugging
271.8	280.3	Programmer A	Client Server Integration
280.3	297.3	Programmer A	Client Server Testing and Debugging
297.3	314.3	QA	Quality Assurance Testing
			Project Length (adjusted): 314.3 days
			Total Cost: \$468260.00

Client Server Application v1 – Scenario 6 CPM Data and Schedule

Table 6-13 Client Server Application v1 – Scenario 6 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	159.5	125	159.5	0	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	150	134	159	9	0	25	\$15,000.00	Programmer C	Implement Client Application Framework
	125	133	147.1	155.1	22.1	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	200.3	215.3	67.3	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	247	255	114	114	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	158.1	155.1	180.3	22.1	0	25.1	\$25,125.00	DBA A	Develop Data Model
	158.1	166.6	180.3	188.8	22.1	0	8.5	\$8,500.00	DBA A	Prepare Test Data
	166.6	174.1	188.8	196.3	22.1	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
	174.1	177.1	196.3	199.3	22.1	0	3	\$3,000.00	DBA A	Create Test Database
	177.1	193.1	199.3	215.3	22.1	0	16	\$16,000.00	DBA A	Develop Stored Procedures
	193.1	209.6	215.3	231.8	22.1	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	209.6	224.6	231.8	246.8	22.1	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	224.6	232.9	246.8	255	22.1	22.1	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	150	171	159	180	9	0	21	\$12,600.00	Programmer C	Implement Simulated Client Server Communication
	150	171	184	205	34	34	21	\$12,600.00	Programmer C	Implement Client Network Communications
	171	196	180	205	9	9	25	\$15,000.00	Programmer C	Implement Core Client Objects
*	159.5	173.5	159.5	173.5	0	0	14	\$0.00	delay	GUI sign-off delay
*	173.5	205	173.5	205	0	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	205	230	205	230	0	0	25	\$15,000.00	Programmer C	Client Component Integration
*	230	255	230	255	0	0	25	\$15,000.00	Programmer C	Client Unit Testing and Debugging
*	255	263.5	255	263.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	263.5	280.5	263.5	280.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	280.5	297.5	280.5	297.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 297.5 days
										Total Cost: \$423725.00

Table 6-14 Client Server Application v1 – Scenario 6 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	159.5	GUI Designer	Client GUI Interface Design
125	150	Programmer C	Implement Client Application Framework
125	133	System Administrator	Build Server Development Environment
159.5	173.5	delay	GUI sign-off delay
150	171	Programmer C	Implement Simulated Client Server Communication
133	158.1	DBA A	Develop Data Model
171	192	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
173.5	205	Programmer D	Implement Client GUI
192	217	Programmer C	Implement Core Client Objects
158.1	166.6	DBA A	Prepare Test Data
217	242	Programmer C	Client Component Integration
166.6	174.1	DBA A	Prepare Database Scripts
242	267	Programmer C	Client Unit Testing and Debugging
174.1	177.1	DBA A	Create Test Database
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
267	275.5	Programmer A	Client Server Integration
275.5	292.5	Programmer A	Client Server Testing and Debugging
292.5	309.5	QA	Quality Assurance Testing
			Project Length (adjusted): 309.5 days
			Total Cost: \$423725.00

Client Server Application v1 – Scenario 7 CPM Data and Schedule

Table 6-15 Client Server Application v1 – Scenario 7 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	159.5	126.8	161.3	1.8	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	150	135.8	160.8	10.8	0	25	\$15,000.00	Programmer C	Implement Client Application Framework
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	202.1	217.1	69.1	69.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	248.8	256.8	115.8	115.8	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	167.9	133	167.9	0	0	34.9	\$41,850.00	Programmer A	Develop Data Model
*	167.9	178.4	167.9	178.4	0	0	10.5	\$12,600.00	Programmer A	Prepare Test Data
*	178.4	189.3	178.4	189.3	0	0	10.9	\$13,050.00	Programmer A	Prepare Database Scripts
*	189.3	194.1	189.3	194.1	0	0	4.8	\$5,760.00	Programmer A	Create Test Database
*	194.1	217.1	194.1	217.1	0	0	23	\$27,600.00	Programmer A	Develop Stored Procedures
*	217.1	233.6	217.1	233.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	233.6	248.6	233.6	248.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	248.6	256.8	248.6	256.8	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	150	171	160.8	181.8	10.8	0	21	\$12,600.00	Programmer C	Implement Simulated Client Server Communication
	150	171	185.8	206.8	35.8	34	21	\$12,600.00	Programmer C	Implement Client Network Communications
	171	196	181.8	206.8	10.8	9	25	\$15,000.00	Programmer C	Implement Core Client Objects
	159.5	173.5	161.3	175.3	1.8	0	14	\$0.00	delay	GUI sign-off delay
	173.5	205	175.3	206.8	1.8	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	205	230	206.8	231.8	1.8	0	25	\$15,000.00	Programmer C	Client Component Integration
	230	255	231.8	256.8	1.8	1.8	25	\$15,000.00	Programmer C	Client Unit Testing and Debugging
*	256.8	265.3	256.8	265.3	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	265.3	282.3	265.3	282.3	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	282.3	299.3	282.3	299.3	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 299.3 days
										Total Cost: \$464460.00

Table 6-16 Client Server Application v1 – Scenario 7 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	150	Programmer C	Implement Client Application Framework
133	167.9	Programmer A	Develop Data Model
159.5	173.5	delay	GUI sign-off delay
150	171	Programmer C	Implement Simulated Client Server Communication
171	192	Programmer C	Implement Client Network Communications
167.9	182.9	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
182.9	193.4	Programmer A	Prepare Test Data
173.5	205	Programmer D	Implement Client GUI
192	217	Programmer C	Implement Core Client Objects
193.4	204.3	Programmer A	Prepare Database Scripts
217	242	Programmer C	Client Component Integration
204.3	209.1	Programmer A	Create Test Database
242	267	Programmer C	Client Unit Testing and Debugging
209.1	232.1	Programmer A	Develop Stored Procedures
232.1	248.6	Programmer A	Implement Server Database Access Layer
248.6	263.6	Programmer A	Implement Transaction Handlers
263.6	271.8	Programmer A	Server Unit Testing and Debugging
271.8	280.3	Programmer A	Client Server Integration
280.3	297.3	Programmer A	Client Server Testing and Debugging
297.3	314.3	QA	Quality Assurance Testing
			Project Length (adjusted): 314.3 days
			Total Cost: \$464460.00

Client Server Application v2 – Base Scenario CPM Data and Schedule

Table 6-17 Client Server Application v2 – Base Scenario CPM

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	145.5	137.4	157.9	12.4	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	159.5	130.9	165.4	5.9	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	178.1	193.1	45.1	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	224.9	232.9	91.9	91.9	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	158.1	133	158.1	0	0	25.1	\$25,125.00	DBA A	Develop Data Model
*	158.1	166.6	158.1	166.6	0	0	8.5	\$8,500.00	DBA A	Prepare Test Data
*	166.6	174.1	166.6	174.1	0	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
*	174.1	177.1	174.1	177.1	0	0	3	\$3,000.00	DBA A	Create Test Database
*	177.1	193.1	177.1	193.1	0	0	16	\$16,000.00	DBA A	Develop Stored Procedures
*	193.1	209.6	193.1	209.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	209.6	224.6	209.6	224.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	224.6	232.9	224.6	232.9	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	165.4	196.9	5.9	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	145.5	165.5	157.9	177.9	12.4	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	175.9	196.9	30.4	24.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	177.9	196.9	12.4	6.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	191	209	196.9	214.9	5.9	0	18	\$14,400.00	Programmer B	Client Component Integration
	209	227	214.9	232.9	5.9	5.9	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	232.9	241.4	232.9	241.4	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	241.4	258.4	241.4	258.4	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	258.4	275.4	258.4	275.4	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 275.4 days
										Total Cost: \$427525.00

Table 6-18 Client Server Application v2 – Base Scenario Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	158.1	DBA A	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
158.1	166.6	DBA A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
166.6	174.1	DBA A	Prepare Database Scripts
191	209	Programmer B	Client Component Integration
174.1	177.1	DBA A	Create Test Database
209	227	Programmer B	Client Unit Testing and Debugging
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
232.9	241.4	Programmer A	Client Server Integration
241.4	258.4	Programmer A	Client Server Testing and Debugging
258.4	275.4	QA	Quality Assurance Testing
			Project Length (adjusted): 275.4 days
			Total Cost: \$427525.00

Client Server Application v2 – Scenario 1 CPM Data and Schedule

Table 6-19 Client Server Application v2 – Scenario 1 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	145.5	146.1	166.6	21.1	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	159.5	139.6	174.1	14.6	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	186.9	201.9	53.9	53.9	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	233.6	241.6	100.6	100.6	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	163.4	133	163.4	0	0	30.4	\$24,300.00	DBA B	Develop Data Model
*	163.4	171.9	163.4	171.9	0	0	8.5	\$6,800.00	DBA B	Prepare Test Data
*	171.9	179.4	171.9	179.4	0	0	7.5	\$6,000.00	DBA B	Prepare Database Scripts
*	179.4	182.4	179.4	182.4	0	0	3	\$2,400.00	DBA B	Create Test Database
*	182.4	201.9	182.4	201.9	0	0	19.5	\$15,600.00	DBA B	Develop Stored Procedures
*	201.9	218.4	201.9	218.4	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	218.4	233.4	218.4	233.4	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	233.4	241.6	233.4	241.6	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	174.1	205.6	14.6	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	145.5	165.5	166.6	186.6	21.1	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	184.6	205.6	39.1	24.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	186.6	205.6	21.1	6.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	191	209	205.6	223.6	14.6	0	18	\$14,400.00	Programmer B	Client Component Integration
	209	227	223.6	241.6	14.6	14.6	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	241.6	250.1	241.6	250.1	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	250.1	267.1	250.1	267.1	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	267.1	284.1	267.1	284.1	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 284.1 days
										Total Cost: \$422500.00

Table 6-20 Client Server Application v2 – Scenario 1 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	163.4	DBA B	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
163.4	171.9	DBA B	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
171.9	179.4	DBA B	Prepare Database Scripts
191	209	Programmer B	Client Component Integration
179.4	182.4	DBA B	Create Test Database
209	227	Programmer B	Client Unit Testing and Debugging
182.4	201.9	DBA B	Develop Stored Procedures
201.9	218.4	Programmer A	Implement Server Database Access Layer
218.4	233.4	Programmer A	Implement Transaction Handlers
233.4	241.6	Programmer A	Server Unit Testing and Debugging
241.6	250.1	Programmer A	Client Server Integration
250.1	267.1	Programmer A	Client Server Testing and Debugging
267.1	284.1	QA	Quality Assurance Testing
			Project Length (adjusted): 284.1 days
			Total Cost: \$422500.00

Client Server Application v2 – Scenario 2 CPM Data and Schedule

Table 6-21 Client Server Application v2 – Scenario 2 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	147	127.9	149.9	2.9	0	22	\$14,960.00	Programmer E	Implement Client Application Framework
	125	159.5	126.9	161.4	1.9	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	178.1	193.1	45.1	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	224.9	232.9	91.9	91.9	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	158.1	133	158.1	0	0	25.1	\$25,125.00	DBA A	Develop Data Model
*	158.1	166.6	158.1	166.6	0	0	8.5	\$8,500.00	DBA A	Prepare Test Data
*	166.6	174.1	166.6	174.1	0	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
*	174.1	177.1	174.1	177.1	0	0	3	\$3,000.00	DBA A	Create Test Database
*	177.1	193.1	177.1	193.1	0	0	16	\$16,000.00	DBA A	Develop Stored Procedures
*	193.1	209.6	193.1	209.6	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	209.6	224.6	209.6	224.6	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	224.6	232.9	224.6	232.9	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	161.4	192.9	1.9	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	147	169	149.9	171.9	2.9	0	22	\$14,960.00	Programmer E	Implement Simulated Client Server Communication
	147	168	171.9	192.9	24.9	23	21	\$12,600.00	Programmer C	Implement Client Network Communications
	169	190	171.9	192.9	2.9	1	21	\$14,280.00	Programmer E	Implement Core Client Objects
	191	211	192.9	212.9	1.9	0	20	\$13,600.00	Programmer E	Client Component Integration
	211	231	212.9	232.9	1.9	1.9	20	\$13,600.00	Programmer E	Client Unit Testing and Debugging
*	232.9	241.4	232.9	241.4	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	241.4	258.4	241.4	258.4	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	258.4	275.4	258.4	275.4	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 275.4 days
										Total Cost: \$422525.00

Table 6-22 Client Server Application v2 – Scenario 2 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	147	Programmer E	Implement Client Application Framework
133	158.1	DBA A	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
147	169	Programmer E	Implement Simulated Client Server Communication
147	168	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
158.1	166.6	DBA A	Prepare Test Data
169	190	Programmer E	Implement Core Client Objects
166.6	174.1	DBA A	Prepare Database Scripts
191	211	Programmer E	Client Component Integration
174.1	177.1	DBA A	Create Test Database
211	231	Programmer E	Client Unit Testing and Debugging
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
232.9	241.4	Programmer A	Client Server Integration
241.4	258.4	Programmer A	Client Server Testing and Debugging
258.4	275.4	QA	Quality Assurance Testing
			Project Length (adjusted): 275.4 days
			Total Cost: \$422525.00

Client Server Application v2 – Scenario 3 CPM Data and Schedule

Table 6-23 Client Server Application v2 – Scenario 3 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	159.5	125	159.5	0	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	145.5	145.5	166	20.5	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
	125	133	133.1	141.1	8.1	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	186.3	201.3	53.3	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	233	241	100	100	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	158.1	141.1	166.3	8.1	0	25.1	\$25,125.00	DBA A	Develop Data Model
	158.1	166.6	166.3	174.8	8.1	0	8.5	\$8,500.00	DBA A	Prepare Test Data
	166.6	174.1	174.8	182.3	8.1	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
	174.1	177.1	182.3	185.3	8.1	0	3	\$3,000.00	DBA A	Create Test Database
	177.1	193.1	185.3	201.3	8.1	0	16	\$16,000.00	DBA A	Develop Stored Procedures
	193.1	209.6	201.3	217.8	8.1	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	209.6	224.6	217.8	232.8	8.1	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	224.6	232.9	232.8	241	8.1	8.1	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	145.5	165.5	166	186	20.5	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	184	205	38.5	38.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	186	205	20.5	20.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
*	159.5	173.5	159.5	173.5	0	0	14	\$0.00	delay	GUI sign-off-delay
*	173.5	205	173.5	205	0	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	205	223	205	223	0	0	18	\$14,400.00	Programmer B	Client Component Integration
*	223	241	223	241	0	0	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	241	249.5	241	249.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	249.5	266.5	249.5	266.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	266.5	283.5	266.5	283.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 283.5 days
										Total Cost: \$427525.00

Table 6-24 Client Server Application v2 – Scenario 3 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	159.5	GUI Designer	Client GUI Interface Design
125	133	System Administrator	Build Server Development Environment
125	145.5	Programmer B	Implement Client Application Framework
159.5	173.5	delay	GUI sign-off delay
133	158.1	DBA A	Develop Data Model
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
173.5	205	Programmer D	Implement Client GUI
158.1	166.6	DBA A	Prepare Test Data
165.5	184.5	Programmer B	Implement Core Client Objects
205	223	Programmer B	Client Component Integration
166.6	174.1	DBA A	Prepare Database Scripts
223	241	Programmer B	Client Unit Testing and Debugging
174.1	177.1	DBA A	Create Test Database
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
241	249.5	Programmer A	Client Server Integration
249.5	266.5	Programmer A	Client Server Testing and Debugging
266.5	283.5	QA	Quality Assurance Testing
			Project Length (adjusted): 283.5 days
			Total Cost: \$427525.00

Client Server Application v2 – Scenario 4 CPM Data and Schedule

Table 6-25 Client Server Application v2 – Scenario 4 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	147	136.6	158.6	11.6	0	22	\$14,960.00	Programmer E	Implement Client Application Framework
	125	159.5	135.6	170.1	10.6	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	186.9	201.9	53.9	53.9	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	233.6	241.6	100.6	100.6	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	163.4	133	163.4	0	0	30.4	\$24,300.00	DBA B	Develop Data Model
*	163.4	171.9	163.4	171.9	0	0	8.5	\$6,800.00	DBA B	Prepare Test Data
*	171.9	179.4	171.9	179.4	0	0	7.5	\$6,000.00	DBA B	Prepare Database Scripts
*	179.4	182.4	179.4	182.4	0	0	3	\$2,400.00	DBA B	Create Test Database
*	182.4	201.9	182.4	201.9	0	0	19.5	\$15,600.00	DBA B	Develop Stored Procedures
*	201.9	218.4	201.9	218.4	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	218.4	233.4	218.4	233.4	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	233.4	241.6	233.4	241.6	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	159.5	191	170.1	201.6	10.6	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	147	169	158.6	180.6	11.6	0	22	\$14,960.00	Programmer E	Implement Simulated Client Server Communication
	147	168	180.6	201.6	33.6	23	21	\$12,600.00	Programmer C	Implement Client Network Communications
	169	190	180.6	201.6	11.6	1	21	\$14,280.00	Programmer E	Implement Core Client Objects
	191	211	201.6	221.6	10.6	0	20	\$13,600.00	Programmer E	Client Component Integration
	211	231	221.6	241.6	10.6	10.6	20	\$13,600.00	Programmer E	Client Unit Testing and Debugging
*	241.6	250.1	241.6	250.1	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	250.1	267.1	250.1	267.1	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	267.1	284.1	267.1	284.1	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 284.1 days
										Total Cost: \$417500.00

Table 6-26 Client Server Application v2 – Scenario 4 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	147	Programmer E	Implement Client Application Framework
133	163.4	DBA B	Develop Data Model
159.5	191	Programmer D	Implement Client GUI
147	169	Programmer E	Implement Simulated Client Server Communication
147	168	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
163.4	171.9	DBA B	Prepare Test Data
169	190	Programmer E	Implement Core Client Objects
171.9	179.4	DBA B	Prepare Database Scripts
191	211	Programmer E	Client Component Integration
179.4	182.4	DBA B	Create Test Database
211	231	Programmer E	Client Unit Testing and Debugging
182.4	201.9	DBA B	Develop Stored Procedures
201.9	218.4	Programmer A	Implement Server Database Access Layer
218.4	233.4	Programmer A	Implement Transaction Handlers
233.4	241.6	Programmer A	Server Unit Testing and Debugging
241.6	250.1	Programmer A	Client Server Integration
250.1	267.1	Programmer A	Client Server Testing and Debugging
267.1	284.1	QA	Quality Assurance Testing
			Project Length (adjusted): 284.1 days
			Total Cost: \$417500.00

Client Server Application v2 – Scenario 5 CPM Data and Schedule

Table 6-27 Client Server Application v2 – Scenario 5 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
	125	159.5	125.6	160.1	0.6	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	145.5	146.1	166.6	21.1	0	20.5	\$16,400.00	Programmer B	Implement Client Application Framework
*	125	133	125	133	0	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	186.9	201.9	53.9	53.9	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	233.6	241.6	100.6	100.6	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
*	133	163.4	133	163.4	0	0	30.4	\$24,300.00	DBA B	Develop Data Model
*	163.4	171.9	163.4	171.9	0	0	8.5	\$6,800.00	DBA B	Prepare Test Data
*	171.9	179.4	171.9	179.4	0	0	7.5	\$6,000.00	DBA B	Prepare Database Scripts
*	179.4	182.4	179.4	182.4	0	0	3	\$2,400.00	DBA B	Create Test Database
*	182.4	201.9	182.4	201.9	0	0	19.5	\$15,600.00	DBA B	Develop Stored Procedures
*	201.9	218.4	201.9	218.4	0	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
*	218.4	233.4	218.4	233.4	0	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
*	233.4	241.6	233.4	241.6	0	0	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	145.5	165.5	166.6	186.6	21.1	0	20	\$16,000.00	Programmer B	Implement Simulated Client Server Communication
	145.5	166.5	184.6	205.6	39.1	38.5	21	\$12,600.00	Programmer C	Implement Client Network Communications
	165.5	184.5	186.6	205.6	21.1	20.5	19	\$15,200.00	Programmer B	Implement Core Client Objects
	159.5	173.5	160.1	174.1	0.6	0	14	\$0.00	delay	GUI sign-off-delay
	173.5	205	174.1	205.6	0.6	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
	205	223	205.6	223.6	0.6	0	18	\$14,400.00	Programmer B	Client Component Integration
	223	241	223.6	241.6	0.6	0.6	18	\$14,400.00	Programmer B	Client Unit Testing and Debugging
*	241.6	250.1	241.6	250.1	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	250.1	267.1	250.1	267.1	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	267.1	284.1	267.1	284.1	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 284.1 days
										Total Cost: \$422500.00

Table 6-28 Client Server Application v2 – Scenario 5 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	133	System Administrator	Build Server Development Environment
125	159.5	GUI Designer	Client GUI Interface Design
125	145.5	Programmer B	Implement Client Application Framework
133	163.4	DBA B	Develop Data Model
159.5	173.5	delay	GUI sign-off delay
145.5	165.5	Programmer B	Implement Simulated Client Server Communication
145.5	166.5	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
163.4	171.9	DBA B	Prepare Test Data
173.5	205	Programmer D	Implement Client GUI
165.5	184.5	Programmer B	Implement Core Client Objects
171.9	179.4	DBA B	Prepare Database Scripts
205	223	Programmer B	Client Component Integration
179.4	182.4	DBA B	Create Test Database
223	241	Programmer B	Client Unit Testing and Debugging
182.4	201.9	DBA B	Develop Stored Procedures
201.9	218.4	Programmer A	Implement Server Database Access Layer
218.4	233.4	Programmer A	Implement Transaction Handlers
233.4	241.6	Programmer A	Server Unit Testing and Debugging
241.6	250.1	Programmer A	Client Server Integration
250.1	267.1	Programmer A	Client Server Testing and Debugging
267.1	284.1	QA	Quality Assurance Testing
			Project Length (adjusted): 284.1 days
			Total Cost: \$422500.00

Client Server Application v2 – Scenario 6 CPM Data and Schedule

Table 6-29 Client Server Application v2 – Scenario 6 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	159.5	125	159.5	0	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	147	140	162	15	0	22	\$14,960.00	Programmer E	Implement Client Application Framework
	125	133	137.1	145.1	12.1	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	190.3	205.3	57.3	45.1	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	237	245	104	104	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	158.1	145.1	170.3	12.1	0	25.1	\$25,125.00	DBA A	Develop Data Model
	158.1	166.6	170.3	178.8	12.1	0	8.5	\$8,500.00	DBA A	Prepare Test Data
	166.6	174.1	178.8	186.3	12.1	0	7.5	\$7,500.00	DBA A	Prepare Database Scripts
	174.1	177.1	186.3	189.3	12.1	0	3	\$3,000.00	DBA A	Create Test Database
	177.1	193.1	189.3	205.3	12.1	0	16	\$16,000.00	DBA A	Develop Stored Procedures
	193.1	209.6	205.3	221.8	12.1	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	209.6	224.6	221.8	236.8	12.1	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	224.6	232.9	236.8	245	12.1	12.1	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	147	169	162	184	15	0	22	\$14,960.00	Programmer E	Implement Simulated Client Server Communication
	147	168	184	205	37	37	21	\$12,600.00	Programmer C	Implement Client Network Communications
	169	190	184	205	15	15	21	\$14,280.00	Programmer E	Implement Core Client Objects
*	159.5	173.5	159.5	173.5	0	0	14	\$0.00	delay	GUI sign-off-delay
*	173.5	205	173.5	205	0	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	205	225	205	225	0	0	20	\$13,600.00	Programmer E	Client Component Integration
*	225	245	225	245	0	0	20	\$13,600.00	Programmer E	Client Unit Testing and Debugging
*	245	253.5	245	253.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	253.5	270.5	253.5	270.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	270.5	287.5	270.5	287.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 287.5 days
										Total Cost: \$422525.00

Table 6-30 Client Server Application v2 – Scenario 6 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	159.5	GUI Designer	Client GUI Interface Design
125	133	System Administrator	Build Server Development Environment
125	147	Programmer E	Implement Client Application Framework
159.5	173.5	delay	GUI sign-off delay
133	158.1	DBA A	Develop Data Model
147	169	Programmer E	Implement Simulated Client Server Communication
147	168	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
173.5	205	Programmer D	Implement Client GUI
158.1	166.6	DBA A	Prepare Test Data
169	190	Programmer E	Implement Core Client Objects
205	225	Programmer E	Client Component Integration
166.6	174.1	DBA A	Prepare Database Scripts
225	245	Programmer E	Client Unit Testing and Debugging
174.1	177.1	DBA A	Create Test Database
177.1	193.1	DBA A	Develop Stored Procedures
193.1	209.6	Programmer A	Implement Server Database Access Layer
209.6	224.6	Programmer A	Implement Transaction Handlers
224.6	232.9	Programmer A	Server Unit Testing and Debugging
245	253.5	Programmer A	Client Server Integration
253.5	270.5	Programmer A	Client Server Testing and Debugging
270.5	287.5	QA	Quality Assurance Testing
			Project Length (adjusted): 287.5 days
			Total Cost: \$422525.00

Client Server Application v2 – Scenario 7 CPM Data and Schedule

Table 6-31 Client Server Application v2 – Scenario 7 CPM Data

CP	ES	EF	LS	LF	TS	FS	DUR	COST	RESOURCE	TASK NAME
*	0	0	0	0	0	0	0	\$0.00	start	start
*	0	42	0	42	0	0	42	\$33,600.00	Business Analyst	Requirements Elicitation
*	42	83	42	83	0	0	41	\$41,000.00	System Architect	Design
*	83	125	83	125	0	0	42	\$42,000.00	System Architect	Specifications
*	125	159.5	125	159.5	0	0	34.5	\$20,700.00	GUI Designer	Client GUI Interface Design
	125	147	140	162	15	0	22	\$14,960.00	Programmer E	Implement Client Application Framework
	125	133	128.4	136.4	3.4	0	8	\$6,400.00	System Administrator	Build Server Development Environment
	133	148	190.3	205.3	57.3	53.9	15	\$18,000.00	Programmer A	Implement Server Daemon
	133	141	237	245	104	104	8	\$6,400.00	System Administrator	Build Testing and Integration Environment
	133	163.4	136.4	166.8	3.4	0	30.4	\$24,300.00	DBA B	Develop Data Model
	163.4	171.9	166.8	175.3	3.4	0	8.5	\$6,800.00	DBA B	Prepare Test Data
	171.9	179.4	175.3	182.8	3.4	0	7.5	\$6,000.00	DBA B	Prepare Database Scripts
	179.4	182.4	182.8	185.8	3.4	0	3	\$2,400.00	DBA B	Create Test Database
	182.4	201.9	185.8	205.3	3.4	0	19.5	\$15,600.00	DBA B	Develop Stored Procedures
	201.9	218.4	205.3	221.8	3.4	0	16.5	\$19,800.00	Programmer A	Implement Server Database Access Layer
	218.4	233.4	221.8	236.8	3.4	0	15	\$18,000.00	Programmer A	Implement Transaction Handlers
	233.4	241.6	236.8	245	3.4	3.4	8.3	\$9,900.00	Programmer A	Server Unit Testing and Debugging
	147	169	162	184	15	0	22	\$14,960.00	Programmer E	Implement Simulated Client Server Communication
	147	168	184	205	37	37	21	\$12,600.00	Programmer C	Implement Client Network Communications
	169	190	184	205	15	15	21	\$14,280.00	Programmer E	Implement Core Client Objects
*	159.5	173.5	159.5	173.5	0	0	14	\$0.00	delay	GUI sign-off-delay
*	173.5	205	173.5	205	0	0	31.5	\$25,200.00	Programmer D	Implement Client GUI
*	205	225	205	225	0	0	20	\$13,600.00	Programmer E	Client Component Integration
*	225	245	225	245	0	0	20	\$13,600.00	Programmer E	Client Unit Testing and Debugging
*	245	253.5	245	253.5	0	0	8.5	\$10,200.00	Programmer A	Client Server Integration
*	253.5	270.5	253.5	270.5	0	0	17	\$20,400.00	Programmer A	Client Server Testing and Debugging
*	270.5	287.5	270.5	287.5	0	0	17	\$6,800.00	QA	Quality Assurance Testing
										Project Length (non-adjusted): 287.5 days
										Total Cost: \$417500.00

Table 6-32 Client Server Application v2 – Scenario 7 Schedule

ES	EF	RESOURCE	TASK NAME
0	0	start	start
0	42	Business Analyst	Requirements Elicitation
42	83	System Architect	Design
83	125	System Architect	Specifications
125	159.5	GUI Designer	Client GUI Interface Design
125	133	System Administrator	Build Server Development Environment
125	147	Programmer E	Implement Client Application Framework
159.5	173.5	delay	GUI sign-off delay
133	163.4	DBA B	Develop Data Model
147	169	Programmer E	Implement Simulated Client Server Communication
147	168	Programmer C	Implement Client Network Communications
133	148	Programmer A	Implement Server Daemon
133	141	System Administrator	Build Testing and Integration Environment
173.5	205	Programmer D	Implement Client GUI
163.4	171.9	DBA B	Prepare Test Data
169	190	Programmer E	Implement Core Client Objects
205	225	Programmer E	Client Component Integration
171.9	179.4	DBA B	Prepare Database Scripts
225	245	Programmer E	Client Unit Testing and Debugging
179.4	182.4	DBA B	Create Test Database
182.4	201.9	DBA B	Develop Stored Procedures
201.9	218.4	Programmer A	Implement Server Database Access Layer
218.4	233.4	Programmer A	Implement Transaction Handlers
233.4	241.6	Programmer A	Server Unit Testing and Debugging
245	253.5	Programmer A	Client Server Integration
253.5	270.5	Programmer A	Client Server Testing and Debugging
270.5	287.5	QA	Quality Assurance Testing
			Project Length (adjusted): 287.5 days
			Total Cost: \$417500.00

Gantt Charts

Client Server Application v1 - Base Scenario Gantt Chart

Approximated Gantt (Scale # = 3 days)

0-----30-----60-----90-----120-----150-----180-----210-----240-----270

```
##### start -- start
##### Business Analyst -- Requirements Elicitation
##### System Architect -- Design
##### System Architect -- Specifications
##### System Administrator -- Build Server Development Environment
##### GUI Designer -- Client GUI Interface Design
##### Programmer B -- Implement Client Application Framework
##### DBA A -- Develop Data Model
##### Programmer D -- Implement Client GUI
##### Programmer B -- Implement Simulated Client Server Communication
##### Programmer C -- Implement Client Network Communications
##### Programmer A -- Implement Server Daemon
##### System Administrator -- Build Testing and Integration Environment
##### DBA A -- Prepare Test Data
##### Programmer B -- Implement Core Client Objects
##### DBA A -- Prepare Database Scripts
##### Programmer B -- Client Component Integration
##### DBA A -- Create Test Database
##### Programmer B -- Client Unit Testing and Debugging
##### DBA A -- Develop Stored Procedures
##### Programmer A -- Implement Server Database Access Layer
##### Programmer A -- Implement Transaction Handlers
##### Programmer A -- Server Unit Testing and Debugging
##### Programmer A -- Client Server Integration
##### Programmer A -- Client Server Testing and Debugging
##### QA -- Quality Assurance Testing
```


Client Server Application v1 - Scenario 2 Gantt Chart

Approximated Gantt (Scale # = 3 days)

Client Server Application v1 - Scenario 3 Gantt Chart

Approximated Gantt (Scale # = 3 days)

Client Server Application v1 - Scenario 4 Gantt Chart

Approximated Gantt (Scale # = 3 days)

[illegible]

Client Server Application v1 - Scenario 6 Gantt Chart

Approximated Gantt (Scale # = 3 days)

Client Server Application v2 – Base Scenario Gantt Chart

Approximated Gantt (Scale # = 3 days)

Client Server Application v2 – Scenario 1 Gantt Chart

Approximated Gantt (Scale # = 3 days)

Client Server Application v2 – Scenario 2 Gantt Chart

Approximated Gantt (Scale # = 3 days)

[illegible]

7 Appendix B – Example Database

DS_PROJECTS

PROJ_ID	PROJ_NAME	PROJ_END_DATE	PROJ_START_DATE
1	Simple Project 1	0	0
2	Simple Project 2	0	0
3	Client Server Application v1	0	0
4	Client Server Application v2	0	0

DS_SKILLS

SKILL_ID	SKILL_NAME
1	NA
2	s1
3	s2
4	Systems Analysis
5	Requirements Analysis
6	Graphic Design
7	Usability
8	Network Programming
9	UNIX
10	Networking
11	Oracle 9i
12	Server Hardware
13	Data Modeling
14	PL/SQL
15	C++
16	UML
17	XML
18	QA Testing

DS_RESOURCES

RES_ID	RES_NAME	RES_RATE
1	start	\$0.00
2	delay	\$0.00
3	r1	\$35.00
4	r2	\$35.00
5	Business Analyst	\$100.00
6	System Architect	\$125.00
7	System Administrator	\$100.00
8	DBA A	\$125.00
9	GUI Designer	\$75.00
10	Programmer A	\$150.00
11	Programmer B	\$100.00
12	Programmer C	\$75.00
13	Programmer D	\$100.00
14	QA	\$50.00
15	DBA B	\$100.00
16	Programmer E	\$85.00

DS_RISKS

RISK_ID	PROJ_ID	RISK_TYPE_ID	RISK_DESCRIPTION	RISK_PROBABILITY
1	3	1	DBA A is unavailable	0.5
2	3	1	Programmer B is unavailable	0.3
3	3	2	Executive Sign-off on GUI is delayed	0.7
4	4	1	DBA A is unavailable	0.5
5	4	1	Programmer B is unavailable	0.3
6	4	2	Executive Sign-off on GUI is delayed	0.7

DS_RISK_TYPE

RISK_TYPE_ID	RISK_TYPE_NAME
1	Resource Unavailable
2	Delay

DS_TASKS

TASK_INDEX	TASK_ID	PROJ_ID	TASK_NAME	TASK_DURATION	IS_CONTINGENCY	RISK_ID	IS_RES_SCALABLE
1	1	1	start	0	FALSE		FALSE
2	2	1	a	1	FALSE		TRUE
3	3	1	b	1	FALSE		TRUE
4	4	1	c	2	FALSE		TRUE
5	5	1	d	1	FALSE		TRUE
6	1	2	start	0	FALSE		FALSE
7	2	2	a	1	FALSE		TRUE
8	3	2	b	1	FALSE		TRUE
9	4	2	c	2	FALSE		TRUE
10	5	2	d	1	FALSE		TRUE
11	1	3	start	0	FALSE		FALSE
12	2	3	Requirements Elicitation	40	FALSE		TRUE
13	3	3	Design	40	FALSE		TRUE
14	4	3	Specifications	40	FALSE		TRUE
15	5	3	Build Server Development Environment	10	FALSE		TRUE
16	6	3	Build Testing and Integration Environment	10	FALSE		TRUE
17	7	3	Develop Data Model	30	FALSE		TRUE
18	8	3	Prepare Test Data	10	FALSE		TRUE
19	9	3	Prepare Database Scripts	10	FALSE		TRUE
20	10	3	Create Test Database	4	FALSE		TRUE
21	11	3	Develop Stored Procedures	20	FALSE		TRUE
22	12	3	Implement Server Daemon	20	FALSE		TRUE
23	13	3	Implement Server Database Access Layer	20	FALSE		TRUE
24	14	3	Implement Transaction Handlers	20	FALSE		TRUE
25	15	3	Server Unit Testing and Debugging	10	FALSE		TRUE
26	16	3	Client GUI Interface Design	30	FALSE		TRUE
27	17	3	Implement Client Application Framework	20	FALSE		TRUE
28	18	3	Implement Simulated Client Server Communication	20	FALSE		TRUE
29	19	3	Implement Client Network Communications	20	FALSE		TRUE
30	20	3	Implement Client GUI	30	FALSE		TRUE
31	21	3	Implement Core Client Objects	20	FALSE		TRUE
32	22	3	Client Component Integration	20	FALSE		TRUE
33	23	3	Client Unit Testing and Debugging	20	FALSE		TRUE
34	24	3	Client Server Integration	10	FALSE		TRUE
35	25	3	Client Server Testing and Debugging	20	FALSE		TRUE
36	26	3	Quality Assurance Testing	20	FALSE		TRUE
37	1	4	start	0	FALSE		FALSE
38	2	4	Requirements Elicitation	40	FALSE		TRUE
39	3	4	Design	40	FALSE		TRUE
40	4	4	Specifications	40	FALSE		TRUE
41	5	4	Build Server Development Environment	10	FALSE		TRUE
42	6	4	Build Testing and Integration Environment	10	FALSE		TRUE
43	7	4	Develop Data Model	30	FALSE		TRUE
44	8	4	Prepare Test Data	10	FALSE		TRUE
45	9	4	Prepare Database Scripts	10	FALSE		TRUE
46	10	4	Create Test Database	4	FALSE		TRUE
47	11	4	Develop Stored Procedures	20	FALSE		TRUE
48	12	4	Implement Server Daemon	20	FALSE		TRUE
49	13	4	Implement Server Database Access Layer	20	FALSE		TRUE
50	14	4	Implement Transaction Handlers	20	FALSE		TRUE
51	15	4	Server Unit Testing and Debugging	10	FALSE		TRUE
52	16	4	Client GUI Interface Design	30	FALSE		TRUE
53	17	4	Implement Client Application Framework	20	FALSE		TRUE
54	18	4	Implement Simulated Client Server Communication	20	FALSE		TRUE
55	19	4	Implement Client Network Communications	20	FALSE		TRUE

TASK_INDEX	TASK_ID	PROJ_ID	TASK_NAME	TASK_DURATION	IS_CONTINGENCY	RISK_ID	IS_RES_SCALABLE
56	20	4	Implement Client GUI	30	FALSE		TRUE
57	21	4	Implement Core Client Objects	20	FALSE		TRUE
58	22	4	Client Component Integration	20	FALSE		TRUE
59	23	4	Client Unit Testing and Debugging	20	FALSE		TRUE
60	24	4	Client Server Integration	10	FALSE		TRUE
61	25	4	Client Server Testing and Debugging	20	FALSE		TRUE
62	26	4	Quality Assurance Testing	20	FALSE		TRUE
63	27	3	GUI sign-off delay	14	TRUE	3	FALSE
64	27	4	GUI sign-off-delay	14	TRUE	6	FALSE

DS_TASK_RELATIONSHIPS

TREL_ID	PROJ_ID	TASK_ID	TASK_SUCC_ID	IS_CONTINGENCY	RISK_ID
1	1	1	2	FALSE	
2	1	2	3	FALSE	
3	1	2	4	FALSE	
4	1	3	5	FALSE	
5	1	4		FALSE	
6	1	5		FALSE	
7	2	1	2	FALSE	
8	2	2	3	FALSE	
9	2	2	4	FALSE	
10	2	3	5	FALSE	
11	2	4		FALSE	
12	2	5		FALSE	
13	3	1	2	FALSE	
14	3	2	3	FALSE	
15	3	3	4	FALSE	
16	3	4	5	FALSE	
17	3	5	6	FALSE	
18	3	5	7	FALSE	
19	3	7	8	FALSE	
20	3	8	9	FALSE	
21	3	5	10	FALSE	
22	3	9	10	FALSE	
23	3	10	11	FALSE	
24	3	5	12	FALSE	
25	3	11	13	FALSE	
26	3	12	13	FALSE	
27	3	13	14	FALSE	
28	3	14	15	FALSE	
29	3	4	16	FALSE	
30	3	4	17	FALSE	
31	3	17	18	FALSE	
32	3	17	19	FALSE	
33	3	16	20	FALSE	
34	3	18	21	FALSE	
35	3	17	22	FALSE	
36	3	18	22	FALSE	
37	3	19	22	FALSE	
38	3	20	22	FALSE	
39	3	21	22	FALSE	
40	3	22	23	FALSE	
41	3	6	24	FALSE	
42	3	15	24	FALSE	
43	3	23	24	FALSE	
44	3	24	25	FALSE	
45	3	25	26	FALSE	
46	3	26		FALSE	
47	4	1	2	FALSE	
48	4	2	3	FALSE	
49	4	3	4	FALSE	
50	4	4	5	FALSE	
51	4	5	6	FALSE	
52	4	5	7	FALSE	
53	4	7	8	FALSE	
54	4	8	9	FALSE	
55	4	5	10	FALSE	
56	4	9	10	FALSE	
57	4	10	11	FALSE	
58	4	5	12	FALSE	
59	4	11	13	FALSE	
60	4	12	13	FALSE	
61	4	13	14	FALSE	
62	4	14	15	FALSE	
63	4	4	16	FALSE	
64	4	4	17	FALSE	
65	4	17	18	FALSE	
66	4	17	19	FALSE	
67	4	16	20	FALSE	
68	4	18	21	FALSE	

TREL_ID	PROJ_ID	TASK_ID	TASK_SUCC_ID	IS_CONTINGENCY	RISK_ID
69	4	17	22	FALSE	
70	4	18	22	FALSE	
71	4	19	22	FALSE	
72	4	20	22	FALSE	
73	4	21	22	FALSE	
74	4	22	23	FALSE	
75	4	6	24	FALSE	
76	4	15	24	FALSE	
77	4	23	24	FALSE	
78	4	24	25	FALSE	
79	4	25	26	FALSE	
80	4	26		FALSE	
81	3	16	27	TRUE	3
82	3	27	20	TRUE	3
83	4	16	27	TRUE	6
84	4	27	20	TRUE	6

DS_ASSIGNMENTS

PROJ_ID	TASK_ID	RES_ID	IS_CONTINGENCY	RISK_ID
1	1	1	FALSE	
2	1	1	FALSE	
3	1	1	FALSE	
4	1	1	FALSE	
3	27	2	TRUE	3
4	27	2	TRUE	6
1	3	3	FALSE	
1	5	3	FALSE	
2	3	3	FALSE	
2	4	3	FALSE	
1	2	4	FALSE	
1	4	4	FALSE	
2	2	4	FALSE	
2	5	4	FALSE	
3	2	5	FALSE	
4	2	5	FALSE	
3	3	6	FALSE	
3	4	6	FALSE	
4	3	6	FALSE	
4	4	6	FALSE	
3	5	7	FALSE	
3	6	7	FALSE	
4	5	7	FALSE	
4	6	7	FALSE	
3	7	8	FALSE	
3	8	8	FALSE	
3	9	8	FALSE	
3	10	8	FALSE	
3	11	8	FALSE	
4	7	8	FALSE	
4	8	8	FALSE	
4	9	8	FALSE	
4	10	8	FALSE	
4	11	8	FALSE	
3	16	9	FALSE	
4	16	9	FALSE	
3	12	10	FALSE	
3	13	10	FALSE	
3	14	10	FALSE	
3	15	10	FALSE	
3	24	10	FALSE	
3	25	10	FALSE	
4	12	10	FALSE	
4	13	10	FALSE	
4	14	10	FALSE	
4	15	10	FALSE	
4	24	10	FALSE	
4	25	10	FALSE	
3	7	10	TRUE	1
3	8	10	TRUE	1
3	9	10	TRUE	1
3	10	10	TRUE	1
3	11	10	TRUE	1
3	17	11	FALSE	
3	18	11	FALSE	
3	21	11	FALSE	
3	22	11	FALSE	
3	23	11	FALSE	
4	17	11	FALSE	
4	18	11	FALSE	
4	21	11	FALSE	
4	22	11	FALSE	
4	23	11	FALSE	
3	19	12	FALSE	
4	19	12	FALSE	
3	17	12	TRUE	2
3	18	12	TRUE	2

PROJ_ID	TASK_ID	RES_ID	IS_CONTINGENCY	RISK_ID
3	21	12	TRUE	2
3	22	12	TRUE	2
3	23	12	TRUE	2
3	20	13	FALSE	
4	20	13	FALSE	
3	26	14	FALSE	
4	26	14	FALSE	
4	7	15	TRUE	4
4	8	15	TRUE	4
4	9	15	TRUE	4
4	10	15	TRUE	4
4	11	15	TRUE	4
4	17	16	TRUE	5
4	18	16	TRUE	5
4	21	16	TRUE	5
4	22	16	TRUE	5
4	23	16	TRUE	5

DS_RES_SKILLS

RES_ID	SKILL_ID	RES_SKILL_LVL
1	1	3
2	1	3
3	2	4
3	3	2
4	2	2
4	3	4
5	5	3
5	16	2
6	4	4
6	5	4
6	13	2
6	16	3
7	5	2
7	9	4
7	10	4
7	11	2
7	12	4
7	13	1
7	14	3
7	16	2
8	5	3
8	9	3
8	11	5
8	13	5
8	14	5
8	16	2
8	17	3
9	5	2
9	6	3
9	7	4
9	16	1
10	4	4
10	5	3
10	8	5
10	9	4
10	13	2
10	14	3
10	15	4
10	16	3
10	17	4
11	4	3
11	5	2
11	7	1
11	8	2
11	9	2
11	14	2
11	15	4
11	16	1
11	17	2
12	4	2
12	5	2
12	8	5
12	9	4
12	15	2
12	16	1
12	17	2
13	4	1
13	5	2
13	7	4
13	9	1
13	15	1
14	7	3
14	18	5
15	5	3
15	9	3
15	11	4
15	13	4
15	14	4

RES_ID	SKILL_ID	RES_SKILL_LVL
15	16	2
15	17	3
16	4	3
16	5	2
16	7	1
16	8	2
16	9	2
16	14	2
16	15	3
16	16	1
16	17	2

DS_TASK_SKILLS

PROJ_ID	TASK_ID	SKILL_ID	TASK_SKILL_LVL	TASK_SKILL_WEIGHT
1	1	1	3	1
1	2	3	3	1
1	3	2	3	1
1	4	3	3	1
1	5	2	3	1
2	1	1	3	1
2	2	3	3	1
2	3	2	3	1
2	4	3	3	1
2	5	3	3	1
3	1	1	3	1
3	2	5	3	0.8
3	2	16	3	0.2
3	3	4	4	0.4
3	3	5	4	0.4
3	3	13	2	0.1
3	3	16	4	0.1
3	4	4	4	0.3
3	4	5	4	0.4
3	4	13	2	0.1
3	4	16	4	0.2
3	5	9	3	0.4
3	5	10	3	0.1
3	5	11	3	0.1
3	5	12	3	0.4
3	6	9	3	0.4
3	6	10	3	0.1
3	6	11	3	0.1
3	6	12	3	0.4
3	7	5	3	0.2
3	7	9	3	0.05
3	7	11	4	0.2
3	7	13	4	0.3
3	7	14	4	0.2
3	7	16	3	0.05
3	8	5	3	0.3
3	8	9	3	0.1
3	8	11	3	0.3
3	8	14	3	0.3
3	9	9	2	0.1
3	9	11	2	0.45
3	9	14	3	0.45
3	10	9	2	0.1
3	10	11	3	0.9
3	11	5	3	0.2
3	11	9	2	0.1
3	11	11	4	0.3
3	11	14	4	0.4
3	12	4	3	0.2
3	12	8	4	0.4
3	12	9	2	0.1
3	12	15	3	0.3
3	13	4	3	0.2
3	13	9	2	0.1
3	13	14	3	0.3
3	13	15	3	0.4
3	14	4	3	0.2
3	14	8	4	0.4
3	14	9	2	0.1
3	14	15	3	0.3
3	15	8	3	0.3
3	15	9	2	0.1
3	15	14	3	0.3
3	15	15	3	0.3
3	16	5	3	0.4
3	16	6	3	0.2
3	16	7	4	0.2
3	16	16	2	0.2

PROJ_ID	TASK_ID	SKILL_ID	TASK_SKILL_LVL	TASK_SKILL_WEIGHT
3	17	4	3	0.3
3	17	7	3	0.1
3	17	15	3	0.3
3	17	16	2	0.3
3	18	4	3	0.2
3	18	8	3	0.4
3	18	15	3	0.4
3	19	4	3	0.2
3	19	8	3	0.4
3	19	15	3	0.4
3	20	7	3	0.4
3	20	15	3	0.6
3	21	4	3	0.4
3	21	15	3	0.4
3	21	16	2	0.2
3	22	4	3	0.6
3	22	15	3	0.4
3	23	4	3	0.6
3	23	15	3	0.4
3	24	4	4	0.3
3	24	8	3	0.2
3	24	9	3	0.1
3	24	14	3	0.1
3	24	15	3	0.3
3	25	4	4	0.3
3	25	8	3	0.2
3	25	9	3	0.1
3	25	14	3	0.1
3	25	15	3	0.3
3	26	7	3	0.4
3	26	18	3	0.6
4	1	1	3	1
4	2	5	3	0.8
4	2	16	3	0.2
4	3	4	4	0.4
4	3	5	4	0.4
4	3	13	2	0.1
4	3	16	4	0.1
4	4	4	4	0.3
4	4	5	4	0.4
4	4	13	2	0.1
4	4	16	4	0.2
4	5	9	3	0.4
4	5	10	3	0.1
4	5	11	3	0.1
4	5	12	3	0.4
4	6	9	3	0.4
4	6	10	3	0.1
4	6	11	3	0.1
4	6	12	3	0.4
4	7	5	3	0.2
4	7	9	3	0.05
4	7	11	4	0.2
4	7	13	4	0.3
4	7	14	4	0.2
4	7	16	3	0.05
4	8	5	3	0.3
4	8	9	3	0.1
4	8	11	3	0.3
4	8	14	3	0.3
4	9	9	2	0.1
4	9	11	2	0.45
4	9	14	3	0.45
4	10	9	2	0.1
4	10	11	3	0.9
4	11	5	3	0.2
4	11	9	2	0.1
4	11	11	4	0.3
4	11	14	4	0.4
4	12	4	3	0.2

PROJ_ID	TASK_ID	SKILL_ID	TASK_SKILL_LVL	TASK_SKILL_WEIGHT
4	12	8	4	0.4
4	12	9	2	0.1
4	12	15	3	0.3
4	13	4	3	0.2
4	13	9	2	0.1
4	13	14	3	0.3
4	13	15	3	0.4
4	14	4	3	0.2
4	14	8	4	0.4
4	14	9	2	0.1
4	14	15	3	0.3
4	15	8	3	0.3
4	15	9	2	0.1
4	15	14	3	0.3
4	15	15	3	0.3
4	16	5	3	0.4
4	16	6	3	0.2
4	16	7	4	0.2
4	16	16	2	0.2
4	17	4	3	0.3
4	17	7	3	0.1
4	17	15	3	0.3
4	17	16	2	0.3
4	18	4	3	0.2
4	18	8	3	0.4
4	18	15	3	0.4
4	19	4	3	0.2
4	19	8	3	0.4
4	19	15	3	0.4
4	20	7	3	0.4
4	20	15	3	0.6
4	21	4	3	0.4
4	21	15	3	0.4
4	21	16	2	0.2
4	22	4	3	0.6
4	22	15	3	0.4
4	23	4	3	0.6
4	23	15	3	0.4
4	24	4	4	0.3
4	24	8	3	0.2
4	24	9	3	0.1
4	24	14	3	0.1
4	24	15	3	0.3
4	25	4	4	0.3
4	25	8	3	0.2
4	25	9	3	0.1
4	25	14	3	0.1
4	25	15	3	0.3
4	26	7	3	0.4
4	26	18	3	0.6

8 Appendix C – Source Code

The PM Eye Risk Projection Application

```
use Project::Schedule;
use Project::Sets qw(is_emptyset set_compare generate_powerset set_difference set_intersection set_union);
use Project::Logger qw(log_structs);
use Tk;
use Tk::Graph;
use Tk::ProgressBar;
use Tk::Pane;
use Tk::NoteBook;
use Graph::Directed;
use DBI;
use Data::Dumper;

use warnings;
use strict;

my $projnum; # Project from the database to use
my $projname;
my %risks;

#-----#
# database initializations
#-----#

my $driver = "ODBC";
my $dbstring = "DBI:ODBC:DS_PROJECT";

#-----#
# interface initializations
#-----#

# MAIN WINDOW
my $top = MainWindow->new;
my $menubar = $top->Menu( -borderwidth => 2, -relief => 'groove' );
my $toolbar = $top->Frame()->pack( -side => 'top', -fill => 'x' );
my $notebook = $top->NoteBook()->pack( -side => 'top', -expand => 1, -fill => 'both' );

my $image = $top->Photo( -file => "pmeye24x24.bmp" );
$top->Icon( -image => $image );
$top->title("PM Eye Risk Projector");
$top->configure( -menu => $menubar );

# FONTS
my $textfont = $top->fontCreate( -family => 'Courier', -size => 8 );
my $headingfont = $top->fontCreate( -family => 'Courier', -size => 8, -weight => 'bold' );
my $menufont = $top->fontCreate( -family => 'MS Sans Serif', -size => 6 );

# TOOLBAR
my $percentdone = 0;
my $progressbar = $toolbar->ProgressBar(
    -colors => [ 0, 'green' ],
    -from => 0,
    -to => 100,
    -blocks => 26,
    -closeenough => 1,
    -anchor => 'w',
    -relief => 'sunken',
    -borderwidth => 2,
    -variable => \%percentdone
)->pack( -side => 'right' );

#-----#
# application top-level menu initializations
#-----#

my $file_mb = $menubar->cascade(
    -label => '~File',
    -font => $menufont,
    -tearoff => 0
);

my $open_mb = $file_mb->cascade(
    -label => '~Open Project',
    -font => $menufont,
    -tearoff => 0
);

my $view_mb = $menubar->cascade(
    -label => '~View',
    -font => $menufont,
    -tearoff => 0
);
```



```

my $options_mb = $menubar->cascade(
    -label => '~Options',
    -font  => $menufont,
    -tearoff => 0
);

my $help_mb = $menubar->cascade(
    -label => '~Help',
    -font  => $menufont,
    -tearoff => 0
);

#-----#
# application core data structure initializations
#-----#
my %appdata;
#-----#
# general application data
#-----#
$appdata{ 'dbstring' } = $dbstring;
$appdata{ 'risks' } = \%risks;
$appdata{ 'projects' } = get_projects( $dbstring );
$appdata{ 'skills' } = get_skills( $dbstring );
$appdata{ 'currentproject' } = 0;
$appdata{ 'nextproject' } = 0;
#-----#
# Interface Elements
#-----#
$appdata{ 'textfont' } = $textfont;
$appdata{ 'menufont' } = $menufont;
$appdata{ 'headingfont' } = $headingfont;

$appdata{ 'top' } = $top;
$appdata{ 'menubar' } = $menubar;
$appdata{ 'toolbar' } = $toolbar;
$appdata{ 'progressbar' } = $progressbar;
$appdata{ 'openbutton' } = $open_mb;
$appdata{ 'viewmenu' } = $view_mb;

$appdata{ 'notebook' } = $notebook;
$appdata{ 'comptop' } = undef;
$appdata{ 'compbook' } = undef;
$appdata{ 'pnettop' } = undef;
$appdata{ 'pnetbook' } = undef;
$appdata{ 'gantttop' } = undef;
$appdata{ 'ganttbook' } = undef;

$appdata{ 'percentdone' } = \%percentdone;
$appdata{ 'compcount' } = 0;
#-----#
# Option state data
#-----#
$appdata{ 'rscaling' } = 1;
$appdata{ 'schedheuristic' } = 'MINSLK';
$appdata{ 'logging' } = 0;
$appdata{ 'graphswitch' } = 0;
#-----#
# per project application data => $appdata{ key }[projindex]
#-----#
$appdata{ 'projname' } = undef;
$appdata{ 'projnum' } = undef;

$appdata{ 'appframe' } = undef;
$appdata{ 'textbar' } = undef;
$appdata{ 'graphbar' } = undef;
$appdata{ 'page' } = undef;
$appdata{ 'text' } = undef;

$appdata{ 'timegraph' } = undef;
$appdata{ 'costgraph' } = undef;
$appdata{ 'probgraph' } = undef;

$appdata{ 'timedistribution' } = undef;
$appdata{ 'costdistribution' } = undef;

$appdata{ 'timedata' } = undef;
$appdata{ 'costdata' } = undef;
$appdata{ 'probddata' } = undef;

$appdata{ 'scenariocount' } = undef;
$appdata{ 'scenariodata' } = undef;
$appdata{ 'scenariosort' } = undef;
$appdata{ 'riskscenarios' } = undef;
$appdata{ 'basescenario' } = undef;
#-----#
# keys relating to document management

```

```

#-----#
$appdata{ 'dockkeys' } = [
    'scenarioaccount',
    'scenariodata',
    'scenariosort',
    'timedistribution',
    'costdistribution',
    'timedata',
    'costdata',
    'probddata',
    'page',
    'appframe',
    'textbar',
    'graphbar',
    'text',
    'timegraph',
    'costgraph',
    'probggraph',
    'riskscenarios',
    'basescenario',
    'projname',
    'projnum'
];

#-----#
# file menu initializations
#-----#
$file_mb->separator;

create_project_button(
    $open_mb,
    $appdata{ 'menufont' },
    $appdata{ 'projects' }->[$_][0],
    $appdata{ 'projects' }->[$_][1],
    \%appdata ) foreach (0 .. scalar @{$appdata{ 'projects' }} - 1);

my $close = $file_mb->command(
    -label      => 'Close Project',
    -underline  => 1,
    -font       => $menufont,
    -command    => sub { close_project( \%appdata ); }
);

my $dump = $file_mb->command(
    -label      => 'Dump Application Data',
    -underline  => 1,
    -font       => $menufont,
    -command    => sub { log_structs( ".\\Data\\datalog.txt", \%appdata ); }
);

$file_mb->separator;

my $exit = $file_mb->command(
    -label      => 'Exit',
    -underline  => 1,
    -font       => $menufont,
    -command    => \%exit
);

my $showcomp_cb = $view_mb->command(
    -label      => 'Compare Open Projects',
    -font       => $menufont,
    -command    => sub { &launch_comp( \%appdata ); }
);

my $showpnet = $view_mb->command(
    -label      => 'Show Project Network',
    -font       => $menufont,
    -command    => sub { &launch_pnet( \%appdata ); }
);

my $showgantt = $view_mb->command(
    -label      => 'Show Project Gantt Charts',
    -font       => $menufont,
    -command    => sub { &launch_gantt( \%appdata ); }
);

my $shownarr = $view_mb->command(
    -label      => 'Show Project Scheduling Narratives',
    -font       => $menufont,
    -command    => sub { &launch_narr( \%appdata ); }
);

$view_mb->separator;

#-----#
# options menu initializations
#-----#

```

```

my $rscale_cb = $options_mb->checkboxbutton(
    -label      => 'Use Skill Level Scaling',
    -font       => $menufont,
    -variable   => \$appdata{ 'rscaling' },
    -onvalue    => 1,
    -offvalue   => 0
);

my $sheuristic_mb = $options_mb->cascade(
    -label      => 'Scheduling Heuristic',
    -font       => $menufont,
    -tearoff    => 0
);

my $minslk_rb = $sheuristic_mb->radiobutton(
    -label      => 'MINSLK',
    -value      => 'MINSLK',
    -font       => $menufont,
    -variable   => \$appdata{ 'schedheuristic' }
);

#-----#
# help menu initializations
#-----#
my $about = $help_mb->command(
    -label      => 'About Risk Projector',
    -underline  => 0,
    -font       => $menufont
);

MainLoop;
exit;

#-----#
# get_projects
#-----#
sub get_projects {

    my ( $dbstring ) = @_;
    my $projectarrayref;
    my $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

    # Get the name of the project
    my $sth = $dbh->prepare( "SELECT PROJ_ID, PROJ_NAME FROM DS_PROJECTS" );
    $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
    $projectarrayref = $sth->fetchall_arrayref;

    $dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";

    return $projectarrayref;
}

#-----#
# get_skills
#-----#
sub get_skills {

    my ( $dbstring ) = @_;
    my %skillhash;
    my ( $skill_id, $skill_name );
    my $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

    my $sth = $dbh->prepare( "SELECT SKILL_ID, SKILL_NAME FROM DS_SKILLS" );
    $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
    $sth->bind_col( 1, \$skill_id );
    $sth->bind_col( 2, \$skill_name );
    $skillhash{ $skill_id } = $skill_name while ( $sth->fetch );

    $dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";

    return \%skillhash;
}

#-----#
# read_project - read the project from the database
#-----#
sub read_project {

    my (
        $projnum,
        $dbstring,
        $tasktable,
        $assntable,
        $taskreltable,
        $tasksetref,
        $reshashref,
        $PRef,
        $Sref,
    )

```

```

$startdateref,
$enddateref,
$contflag ) = @_;

my $taskid; # -1 is used as a flag when no rows are returned from the select
my $taskdur;
my $taskname;
my $rscalable;
my $cscalable;
my $skill_id;
my $skill_lvl;
my $skill_weight;
my $resid;
my $resname;
my $resrate;

my $tmppre = "tmp_"; # prefix for temporarily created tables
my $tmpname = ""; # name of current temporary table

my $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";
my $sth; # Database statement handle
my $datasetref;
my $querystr = "";

my $i = 0;

#-----#
# get the project information
#-----#

$sth = $dbh->prepare(
    "SELECT PROJ_START_DATE, PROJ_END_DATE FROM DS_PROJECTS WHERE PROJ_ID = $projnum"
);

$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
$sth->bind_col( 1, $startdateref );
$sth->bind_col( 2, $enddateref );
$sth->fetch();

#-----#
# create a set of the tasks to transform into a project network
#-----#

# No need to worry about contingency column if the table
# is a transformation of the base case in a temporary table

$querystr = "SELECT x.TASK_ID, x.TASK_DURATION, y.RES_ID, x.TASK_NAME, x.IS_RES_SCALABLE " .
    "FROM $tasktable x, $assntable y " .
    "WHERE x.PROJ_ID = $projnum AND x.PROJ_ID = y.PROJ_ID AND x.TASK_ID = y.TASK_ID" .
    "(( $contflag )? "" : " AND y.IS_CONTINGENCY = 0 AND x.IS_CONTINGENCY = 0) ";

$sth = $dbh->prepare( $querystr );
$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";

$sth->bind_col( 1, \$taskid );
$sth->bind_col( 2, \$taskdur );
$sth->bind_col( 3, \$resid );
$sth->bind_col( 4, \$taskname );
$sth->bind_col( 5, \$rscalable );

while ($sth->fetch){
    $tasksetref->{ $taskid }{ "duration" } = $taskdur;
    $tasksetref->{ $taskid }{ "resource" } = $resid;
    $tasksetref->{ $taskid }{ "task_name" } = $taskname;
    $tasksetref->{ $taskid }{ "rscalable" } = $rscalable;
}

#-----#
# get the tasks' required skills
#-----#

foreach ( keys %$tasksetref ) {

    $sth = $dbh->prepare(
        "SELECT SKILL_ID, TASK_SKILL_LVL, TASK_SKILL_WEIGHT " .
        "FROM DS_TASK_SKILLS " .
        "WHERE PROJ_ID = $projnum AND TASK_ID = $_"
    );

    $sth->execute();
    $sth->bind_col( 1, \$skill_id );
    $sth->bind_col( 2, \$skill_lvl );
    $sth->bind_col( 3, \$skill_weight );
    @{$tasksetref->{ $_ }{ 'skills' }}{ $skill_id }{ 'level', 'weight' } =
        ( $skill_lvl, $skill_weight ) while ( $sth->fetch );
}

#-----#

```

```

# create precedence relation sets PR(a) -> PR(s)
#-----#

foreach my $task (keys %$tasksetref) {

    $querystr = "SELECT DISTINCT TASK_SUCC_ID " .
        "FROM $taskreltable " .
        "WHERE PROJ_ID = $projnum AND TASK_ID = $task AND TASK_SUCC_ID IS NOT NULL" .
        (( $contflag )? "" : " AND IS_CONTINGENCY = 0" );

    $sth = $dbh->prepare($querystr);
    $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
    $datasetref = $sth->fetchall_arrayref;

    if ( scalar @$datasetref ) {

        $PRref->{$task}{$_->[0]} = () foreach ( @$datasetref );
    }
    else {

        $PRref->{$task} = {};
    }
}

#-----#
# STEP I
# I. create sets S[1..n]
#-----#

#prepare table for set S1
$tmptable = $tmppre . "S$i";

$querystr = "SELECT DISTINCT TASK_ID " .
    "INTO $tmptable " .
    "FROM $taskreltable " .
    "WHERE PROJ_ID = $projnum AND TASK_SUCC_ID IS NULL" .
    (( $contflag )? "" : " AND IS_CONTINGENCY = 0" );

$sth = $dbh->prepare($querystr);
$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
$sth = $dbh->prepare("SELECT * FROM $tmptable");
$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";

$datasetref = $sth->fetchall_arrayref;

if ( scalar @$datasetref ) {

    $Sref->[$i]{$_->[0]} = () foreach ( @$datasetref );
}
else {

    $Sref->[$i] = {};
}

my $prevtable;

do {
    $i++;
    $taskid = -1;
    $prevtable = $tmptable;
    $tmptable = $tmppre . "S$i";

    $querystr = "SELECT DISTINCT TASK_ID " .
        "INTO $tmptable FROM $taskreltable " .
        "WHERE PROJ_ID = $projnum " .
        (( $contflag )? "" : " AND IS_CONTINGENCY = 0" ) .
        "AND TASK_SUCC_ID IN (SELECT * FROM $prevtable)";

    $sth = $dbh->prepare($querystr);
    $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
    $querystr = "SELECT * FROM $tmptable";
    $sth = $dbh->prepare($querystr);
    $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";

    $datasetref = $sth->fetchall_arrayref;

    if ( scalar @$datasetref ) {

        $Sref->[$i]{$_->[0]} = () foreach ( @$datasetref );
    }
    else {

        $Sref->[$i] = {};
    }
} while ( scalar @$datasetref );

# clean up temp tables

```

```

for my $n ($[..$i]) {

    $sth = $dbh->prepare("DROP TABLE " . $tmppre . "$n");
    $sth->execute();
}

#-----#
# get the project resources
#-----#

$sth = $dbh->prepare( "SELECT RES_ID, RES_NAME, RES_RATE " .
    "FROM DS_RESOURCES" );

$sth->execute();
$sth->bind_col( 1, \$resid );
$sth->bind_col( 2, \$resname );
$sth->bind_col( 3, \$resrate );

@{$reshashref->{ $resid }}{ 'name', 'rate' } = ( $resname, $resrate )
    while ( $sth->fetch );

#-----#
# get the resource skills
#-----#

$sth = $dbh->prepare( "SELECT RES_ID, SKILL_ID, RES_SKILL_LVL " .
    "FROM DS_RES_SKILLS" );

$sth->execute();
$sth->bind_col( 1, \$resid );
$sth->bind_col( 2, \$skill_id );
$sth->bind_col( 3, \$skill_lvl );

while ( $sth->fetch ) {

    $reshashref->{ $resid }{ 'skills' }{ $skill_id } = $skill_lvl
        if ( exists $reshashref->{ $resid } );
}

$dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";
}

#-----#
# open_projects
#-----#
sub open_project {

    my ( $projnum, $projname, $appdataref ) = @_ ;

    my $thisproj      = $appdataref->{ 'nextproject' };
    my $dbstring      = $appdataref->{ 'dbstring' };
    my $stop          = $appdataref->{ 'top' };
    my $view_mb       = $appdataref->{ 'viewmenu' };
    my $open_mb       = $appdataref->{ 'openbutton' };
    my $menufont       = $appdataref->{ 'menufont' };
    my $textfont       = $appdataref->{ 'textfont' };
    my $headingfont    = $appdataref->{ 'headingfont' };
    my $timedata       = $appdataref->{ 'timedata' }[$thisproj] = {};
    my $costdata       = $appdataref->{ 'costdata' }[$thisproj] = {};
    my $probddata      = $appdataref->{ 'probddata' }[$thisproj] = {};
    my $notebook       = $appdataref->{ 'notebook' };

    $appdataref->{ 'projname' }[$thisproj] = $projname;
    $appdataref->{ 'projnum' }[$thisproj] = $projnum;
    $appdataref->{ 'nextproject' }++;
    $appdataref->{ 'currentproject' } = $thisproj;

    my %risks;
    my $riskarrayref;

    #-----#
    # set up the interface for the new project
    #-----#

    my $page = $notebook->add(
        "$thisproj",
        -label    => "$projname",
        -anchor   => 'e',
        -raisecmd => sub { $appdataref->{ 'currentproject' } = $thisproj; }
    );

    my $appframe = $page->Frame(
        -relief    => 'groove'
    )->pack(
        -side      => 'bottom',
        -expand    => 1,
        -fill      => 'both'
    );

```

```

);

my $graphbar = $appframe->Scrolled(
    "Pane",
    -scrollbars => 's'
)->pack(
    -side => 'top',
    -expand => 1,
    -fill => 'both'
);

my $textbar = $appframe->Frame()->pack(
    -side => 'bottom',
    -expand => 1,
    -fill => 'both'
);

my $text = $textbar->Scrolled(
    "Text",
    -scrollbars => 'se'
)->pack(
    -side => 'bottom',
    -expand => 1,
    -fill => 'both'
);

$open_mb->configure( -state => 'disabled' );
$text->configure( -wrap => 'none' );
$BindMouseWheel( $text );

my $timegraph = $graphbar->Graph(
    -type => 'BARS',
    -title => 'Time Comparison',
    -balloon => 1,
    -wire => 'white',
    -headroom => 35,
    -ylabel => "Min Project Duration",
    -fill => 'both',
    -ytick => 15,
    -maxmin => 1,
    -barwidth => 15,
    -yformat => '%d days',
    -xformat => '%s'
)->pack(
    -side => 'left',
    -expand => 1,
    -fill => 'y',
);

my $costgraph = $graphbar->Graph(
    -type => 'BARS',
    -title => 'Cost Comparison',
    -balloon => 1,
    -wire => 'white',
    -headroom => 35,
    -ylabel => "Min Project Cost",
    -fill => 'both',
    -ytick => 10,
    -maxmin => 1,
    -barwidth => 15,
    -yformat => '$%d',
    -xformat => '%s'
)->pack(
    -side => 'left',
    -expand => 1,
    -fill => 'y',
);

my $probgraph = $graphbar->Graph(
    -type => 'BARS',
    -title => 'Scenario Probability',
    -max => 100,
    -balloon => 1,
    -wire => 'white',
    -headroom => 15,
    -ylabel => "Probability",
    -fill => 'both',
    -ytick => 10,
    -maxmin => 1,
    -barwidth => 15,
    -yformat => '%d%%',
    -xformat => '%s'
)->pack(
    -side => 'left',
    -expand => 1,
    -fill => 'y',
);

```

```

$appdataref->{ 'page' }[$thisproj] = $page;
$appdataref->{ 'appframe' }[$thisproj] = $appframe;
$appdataref->{ 'textbar' }[$thisproj] = $textbar;
$appdataref->{ 'graphbar' }[$thisproj] = $graphbar;
$appdataref->{ 'text' }[$thisproj] = $text;
$appdataref->{ 'timegraph' }[$thisproj] = $timegraph;
$appdataref->{ 'costgraph' }[$thisproj] = $costgraph;
$appdataref->{ 'probgraph' }[$thisproj] = $probgraph;

my $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

# Get information about the project risks

my $sth = $dbh->prepare(
    "SELECT x.RISK_ID, x.RISK_DESCRIPTION, y.RISK_TYPE_NAME, x.RISK_PROBABILITY " .
    "FROM DS_RISKS x, DS_RISK_TYPE y " .
    "WHERE x.PROJ_ID = $projnum AND x.RISK_TYPE_ID = y.RISK_TYPE_ID"
);

$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
$riskarrayref = $sth->fetchall_arrayref;

$dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";

foreach ( @$riskarrayref ) {

    $risks{ $_->[0] }{ 'description' } = $_->[1];
    $risks{ $_->[0] }{ 'type' } = $_->[2];
    $risks{ $_->[0] }{ 'probability' } = $_->[3];
}

my $legend;
my $header;

my ( $scenariodataref, $riskscenariosref, $basescenario_id ) =
    risk_projection( $dbstring, $projnum, \%appdata );

$appdataref->{ 'scenariodata' }[$thisproj] = $scenariodataref;
$appdataref->{ 'riskscenarios' }[$thisproj] = $riskscenariosref;
$appdataref->{ 'basescenario' }[$thisproj] = $basescenario_id;

my @scenariosort =
    sort {
        return -1 if ( $a eq $basescenario_id );
        return 1 if ( $b eq $basescenario_id );
        return 0;
    }
    sort {
        my $ab_cmp = 0;
        my ( $acount, $bcount ) = (
            scalar keys %{$riskscenariosref->{ $a }},
            scalar keys %{$riskscenariosref->{ $b }}
        );
        return -1 if ( $acount < $bcount );
        return 1 if ( $acount > $bcount );

        my @asort = sort keys %{$riskscenariosref->{ $a }};
        my @bsort = sort keys %{$riskscenariosref->{ $b }};

        foreach ( 0..@asort-1 ) {
            if ( $asort[$_] > $bsort[$_] ) {
                $ab_cmp = 1;
                last;
            }
            elsif ( $asort[$_] < $bsort[$_] ) {
                $ab_cmp = -1;
                last;
            }
        }
        return $ab_cmp;
    } keys %{$riskscenariosref};

$appdataref->{ 'scenarioscount' }[$thisproj] = scalar @scenariosort;
$appdataref->{ 'scenariosort' }[$thisproj] = \@scenariosort;

# Clear the text widget and fill them with the project information

$text->delete( "1.0", 'end' );

my $i = 0;
foreach my $scenario_id ( @scenariosort ) {

    my $headtag = "scenario$i" . "head";
    my $scenariotag = "scenario$i";

    $text->tagConfigure( $headtag, -font => $headingfont );
    $text->tagConfigure( $scenariotag, -font => $textfont );

```



```

$legend = ($scenario_id eq $basescenario_id)? "Base" : $i;

$header =      "\n$projname Risk Scenario: $legend\n";

$header .=      "Probability of this Scenario : " .
                "$scenario_dataref->{ $scenario_id }{ 'probability' } \n";

$header .=      "Includes the following realized risks:\n";

$header .=      "\n\tRisk Type: $risks{$_}{ 'type' }" .
                "\n\tDescription: $risks{$_}{ 'description' }" .
                "\n\tProbability : $risks{$_}{ 'probability' } \n"
                foreach keys %{ $riskscenariosref->{ $scenario_id } };

$timedata->{ $legend } =
    $scenario_dataref->{ $scenario_id }{ 'schedule' }->adjustedptmin;

$costdata->{ $legend } =
    $scenario_dataref->{ $scenario_id }{ 'schedule' }->cost;

$probdata->{ $legend } =
    $scenario_dataref->{ $scenario_id }{ 'probability' } * 100;

$text->insert( 'end', "\n$header\n\n", $headtag );
$text->insert( 'end', $scenario_dataref->{ $scenario_id }{ 'schedule' }->print_project, $scenariotag );
$i++;
}

my @timedistribution;
my @costdistribution;

push @timedistribution, (
    $scenario_dataref->{ $_ }{ 'schedule' }->adjustedptmin,
    $scenario_dataref->{ $_ }{ 'probability' } )
foreach ( keys %$scenario_dataref );

push @costdistribution, (
    $scenario_dataref->{ $_ }{ 'schedule' }->cost,
    $scenario_dataref->{ $_ }{ 'probability' } )
foreach ( keys %$scenario_dataref );

$text->tagConfigure( 'analysis' );
my $tmpstr =      "\n\nExpected Value (Time) : " . expected_value( @timedistribution );
$tmpstr .=      "\n\nExpected Value (Cost) : " . expected_value( @costdistribution );

$text->insert( 'end', $tmpstr , 'analysis' );

$timegraph->set( $timedata );
$costgraph->set( $costdata );
$probgraph->set( $probdata );

$timegraph->redraw();
$costgraph->redraw();
$probgraph->redraw();

$appdataref->{ 'timedistribution' }[$thisproj] = \@timedistribution;
$appdataref->{ 'costdistribution' }[$thisproj] = \@costdistribution;

$notebook->Resize;
$notebook->raise( "$thisproj" );
$open_mb->configure( -state => 'normal' );

fill_jumpto_menu( $appdataref );
}

#-----#
# risk_projection
#-----#
sub risk_projection {

    my ( $dbstring, $projnum, $appdataref ) = @_;

    #-----#
    # Arbitrary data
    #-----#

    my $startdate;
    my $enddate;
    my $riskid = -1;
    my $riskprobability;
    my $basescenario_id;

    #-----#
    # sets and lists
    #-----#

    my %riskset;      # set of risk ids associated with the project
    my $riskscenarios;

```

```

my $dbh;
my $sth; # Database statement handle

# Read the project risk ids from the database

$dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

$dbh->prepare(
    "SELECT RISK_ID, RISK_PROBABILITY " .
    "FROM DS_RISKS WHERE PROJ_ID = $projnum"
);

$sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
$sth->bind_col( 1, \$riskid );
$sth->bind_col( 2, \$riskprobability );
(($riskid != -1)? $riskset{ $riskid } = $riskprobability : 0 ) while ( $sth->fetch );

$dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";

# Generate the risk scenarios powerset of the risk set

$riskscenarios = generate_powerset( \%riskset );

# Process each risk scenario

my %scenariodata;
my $cummprob = 0; #cumulative probability of all scenarios

my $probability = 1;

my (
    $tasktable,
    $assntable,
    $taskreltable
) = (
    "DS_TASKS",
    "DS_ASSIGNMENTS",
    "DS_TASK_RELATIONSHIPS"
);

my (
    $tmptasktable,
    $tmpassntable,
    $tmptaskreltable
) = (
    "tmp_DS_TASKS",
    "tmp_DS_ASSIGNMENTS",
    "tmp_DS_TASK_RELATIONSHIPS"
);

my $tmpprefix = "tmp_";

my $PRref;
my $Sref; # S1 = { y | y has no followers }, # hash of task preced

# S2 = { y | y has at least one follower in S1 } ..etc
my $tasksetref; # set of all tasks in the project, their durations and assigned resources
my $reshashref; # hash of resources and their rates
my $skillhashref = $appdataref->{'skills'};
my $querystr = "";

my $firstiteration;
my $scheduleref;

my $increment = 100 / ( scalar keys %$riskscenarios );
${$appdataref->{'percentdone'}} = 0;
$appdataref->{'toolbar'}->update;

foreach my $scenario_id ( keys %$riskscenarios ) {

    print "Scenario : ", keys %{$riskscenarios->{ $scenario_id }}, "\n\n";
    # Clear the related sets

    $PRref = {};
    $Sref = [];
    $tasksetref = {};
    $reshashref = {};

    # Transform the original project for the current scenario
    # if there are no risk ids in the scenario it must be the base scenario
    if ( !emptyset( $riskscenarios->{ $scenario_id } ) ) {

        $basescenario_id = $scenario_id; # record the base scenario for return
        read_project(
            $projnum,
            $dbstring,
            $tasktable,
            $assntable,

```

```

        $taskreltable,
        $tasksetref,
        $reshashref,
        $PRref,
        $Sref,
        \ $startdate,
        \ $enddate,
        0
    );
}
else {

    # Generate temporary tables with the transformation
    # of the original project schedule with respect to the risk scenario

    $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

    foreach my $table ( ( $tasktable, $assntable, $taskreltable ) ) {
        $firstiteration = 1;
        foreach $riskid ( keys %{ $riskscenarios->{ $scenario_id } } ) {
            $querystr =
                (( $firstiteration ) ?
                "SELECT * INTO " . $tmpprefix . $table :
                "INSERT INTO " . $tmpprefix . $table . " SELECT *"
                ) . " FROM $table " .
                "WHERE PROJ_ID = $projnum AND IS_CONTINGENCY = 1 AND RISK_ID = $riskid";

            $sth = $dbh->prepare( $querystr );
            print "Scenario : ",
                keys %{ $riskscenarios->{ $scenario_id } },
                " Risk ID $riskid, Table: $table , FirstIteration? $firstiteration\n\n";

            print "$querystr\n\n";

            $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
            $firstiteration = 0;
        }
        $querystr =
            "INSERT INTO " . $tmpprefix . $table .
            " SELECT * FROM $table x " .
            "WHERE PROJ_ID = $projnum AND IS_CONTINGENCY = 0 " .
            "AND NOT EXISTS (SELECT PROJ_ID, TASK_ID FROM " . $tmpprefix . $table . " y " .
            "WHERE y.PROJ_ID = x.PROJ_ID AND y.TASK_ID = x.TASK_ID)";

        $sth = $dbh->prepare( $querystr );
        print "Step 2 : $querystr\n\n";
        $sth->execute() or die "Can't prepare SQL statement, $DBI::errstr\n";
    }

    $dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";

    read_project(
        $projnum,
        $dbstring,
        $tmptasktable,
        $tmpassntable,
        $tmptaskreltable,
        $tasksetref,
        $reshashref,
        $PRref,
        $Sref,
        \ $startdate,
        \ $enddate,
        1
    );

    $dbh = DBI->connect($dbstring) or die "Can't connect, $DBI::errstr\n";

    foreach ( ($tmptasktable, $tmpassntable, $tmptaskreltable) ) {

        $sth = $dbh->prepare("DROP TABLE $_");
        $sth->execute();
    }

    $dbh->disconnect() or warn "Disconnection failed, $DBI::errstr\n";
}

# Perform resource skill level scaling
my $prenarr = "";
$prenarr =
    resource_scaling( $tasksetref, $reshashref, $skillhashref )
    if $appdataref->{ 'rscaling' };

# Initialize schedule data structures and perform scheduling
$scheduleref = $scenariodata{ $scenario_id }{ 'schedule' } = Project::Schedule->new();
$scheduleref->prenarrative( $prenarr );
$scheduleref->taskset( $tasksetref );
$scheduleref->reshash( $reshashref );

```

```

    $schedulerref->startdate( $startdate );
    $schedulerref->enddate( $enddate );
    $schedulerref->precedence( $PRref );
    $schedulerref->ssets( $Sref );
    $schedulerref->execute();

    ${appdataref->{ 'percentdone' }} += $increment;
    $appdataref->{ 'toolbar' }->update;
}

$stop->bell;

$cummprob = 0;
my %baseset;
$baseset{ $basescenario_id } = {};
my $Si = set_difference( \%scenariodata, { $basescenario_id => {} } );

foreach my $scenario_id ( keys %$Si ) {

    my $realized_risks = $riskscenarios->{ $scenario_id };
    my $unrealized_risks = set_difference( \%riskset, $realized_risks );
    my $realprob = 1;
    my $unrealprob = 1;

    #product of the probabilities for all realized risks in this scenario
    map { $realprob *= $riskset{ $_ } } keys %$realized_risks;

    #product of the probabilities for all unrealized risks in this scenario
    map { $unrealprob *= 1 - $riskset{ $_ } } keys %$unrealized_risks;
    $cummprob += $scenariodata{ $scenario_id }{ 'probability' } = $realprob * $unrealprob;

}

$scenariodata{ $basescenario_id }{ 'probability' } = 1 - $cummprob;
return ( \%scenariodata, $riskscenarios, $basescenario_id );
}

#-----#
# resource_scaling - scale task duration by resource skill level
#-----#
sub resource_scaling {

    my ( $tasksetref, $reshashref, $skillhashref ) = @_;
    my $sumfactors;
    my $narr = "Scaling task durations to account for\n" .
        "resource skill level deficiencies/strengths...\n\n";

    TASK: foreach my $taskid ( keys %$tasksetref ) {

        my $taskname = $tasksetref->{ $taskid }{ 'task_name' };
        my $resource = $tasksetref->{ $taskid }{ 'resource' };
        my $resourcename = $reshashref->{ $resource }{ 'name' };

        if ( not $tasksetref->{ $taskid }{ 'rscalable' } ) {

            $narr .= "Task: \"$taskname($resourcename)\" is flagged as non-scalable\n";
            next TASK;
        }

        if ( keys %{ $tasksetref->{ $taskid }{ 'skills' } } ) {

            my $duration = $tasksetref->{ $taskid }{ 'duration' };

            $narr .= "Task: \"$taskname($resourcename)\" is scalable:\n";
            $sumfactors = 0;

            foreach ( keys %{ $tasksetref->{ $taskid }{ 'skills' } } ) {

                my $skillname = $skillhashref->{ $_ };
                my $weight = $tasksetref->{ $taskid }{ 'skills' }{ $_ }{ 'weight' };
                my $tlevel = $tasksetref->{ $taskid }{ 'skills' }{ $_ }{ 'level' };
                my $rlevel = $reshashref->{ $resource }{ 'skills' }{ $_ }{ 'level' };
                my $diff = $tlevel - $rlevel;
                my $sfactor = skill_scale( $diff );
                my $wsfactor = $weight * $sfactor;
                $sumfactors += $wsfactor;

                $narr .= "\tIdeal $skillname lvl = $tlevel\n" .
                    "\tWeight = $weight\n" .
                    "\tResource lvl = $rlevel\n" .
                    "\tScaling factor = $sfactor\n" .
                    "\tWeighted scaling factor = $wsfactor\n";
            }

            my $newduration = $tasksetref->{ $taskid }{ 'duration' } * $sumfactors;
            $narr .= "\n\tInitial task duration = $duration\n" .
                "\tScaled task duration = $newduration\n\n";
        }
    }
}

```

```

        else {
            $narr .= "Task: \"\$taskname(\$resourcename)\"has no skill requirements..skipping.\n";
        }
    }
    return $narr;
}

#-----#
# skill_scale - returns scaling factor given a the difference in
#               skill level between the task and the assigned resource
#-----#
sub skill_scale {
    my $skill_diff = shift @_;
    # if the skill difference is positive then the resource is underqualified
    return 1.25 if $skill_diff > 0;
    # if the skill difference is negative then the resource is overqualified
    return 0.75 if $skill_diff < 0;
    # if the skill difference is zero then the resource is perfectly matched
    return 1;
}

#-----#
# launch_comp
#-----#
sub launch_comp {
    my ( $appdataref ) = @_;
    my $flag = 0;
    my $lastval;

    # If there aren't enough projects open to compare..
    if ( @{$appdataref->{ 'scenariocount' }} < 2 ) {

        #!todo
        # popup here

    }
    # Check all open projects to see if they are comparable
    # in terms of the number of risk scenarios
    else {
        $lastval = $appdataref->{ 'scenariocount' }[0];

        foreach (1..@{$appdataref->{ 'scenariocount' }}-1) {

            last if ( $flag = ( $lastval != $appdataref->{ 'scenariocount' }[$_] ) );

        }

        # if there are at least two open projects with a different number of scenarios..
        if ( $flag ) {

            #popup here
        }
        # otherwise they are comparable
        else {

            do_comparison( $appdataref );

        }
    }
}

#-----#
# do_comparison
#-----#
sub do_comparison {
    my ( $appdataref ) = @_;

    my $projname_arrayref = $appdataref->{ 'projname' };
    my $sdata_arrayref = $appdataref->{ 'scenariodata' };
    my $ssort_arrayref = $appdataref->{ 'scenariosort' };
    my $timedist_arrayref = $appdataref->{ 'timedistribution' };
    my $costdist_arrayref = $appdataref->{ 'costdistribution' };
    my $comptop = $appdataref->{ 'comptop' };
    my $compbook = $appdataref->{ 'compbook' };
    my $compcount = $appdataref->{ 'compcount' };

    my $comptext;
    my $page;

    # if there isn't already a comparison window open..
    if ( not Exists( $comptop ) ) {

        # reset the comparison counter
        $compcount = $appdataref->{ 'compcount' } = 1;
    }
}

```

```

#launch the comparison window
$comptop = $appdataref->{ 'comptop' } = MainWindow->new;
my $image = $comptop->Photo( -file => "pmeve24x24.bmp" );
$comptop->Icon( -image => $image );

$comptop->title( "PM Eye Project Comparisons" );

$compbook = $appdataref->{ 'compbook' } =
    $comptop->NoteBook()->pack(
        -side    => 'top',
        -expand  => 1,
        -fill    => 'both'
    );

# add a new tab and text widget to the notebook and do the comparison
$page = $compbook->add(
    "$compcount",
    -label    => "$compcount",
    -anchor   => 'e'
);

$comptext = $page->Scrolled(
    "Text",
    -scrollbars => 'se'
)->pack(
    -side    => 'bottom',
    -expand  => 1,
    -fill    => 'both'
);

$comptext->configure( -wrap => 'none' );
BindMouseWheel( $comptext );

my @costEVs;
my @timeEVs;
my @times;
my @costs;

my @best_times;
my @best_costs;
my @worst_times;
my @worst_costs;

my $best_tEV;
my $best_cEV;
my $best_time_overall;
my $best_cost_overall;
my $worst_time_overall;
my $worst_cost_overall;

foreach my $i ( 0..@$projname_arrayref - 1 ) {

    push @costEVs, expected_value( @{$costdist_arrayref->[$i]} );
    push @timeEVs, expected_value( @{$timedist_arrayref->[$i]} );

    my $t = [];
    my $c = [];

    foreach ( @{$ssort_arrayref->[$i]} ) {

        push @$t, $sdata_arrayref->[$i]{ $_ }{ 'schedule' }->adjustedptmin;
        push @$c, $sdata_arrayref->[$i]{ $_ }{ 'schedule' }->cost;
    }

    push @best_times, listmin( @$t );
    push @best_costs, listmin( @$c );

    push @worst_times, listmax( @$t );
    push @worst_costs, listmax( @$c );

    push @times, $t;
    push @costs, $c;
}

$best_tEV = listmin( @timeEVs );
$best_cEV = listmin( @costEVs );

$best_time_overall = listmin( @best_times );
$best_cost_overall = listmin( @best_costs );

$worst_time_overall = listmax( @worst_times );
$worst_cost_overall = listmax( @worst_costs );

#prepare tags
my $textfont =
    $comptop->fontCreate( -family => 'Courier', -size => 8 );

```

```

my $bestfont =
    $comptop->fontCreate( -family =>'Courier', -size => 8 );
my $worstfont =
    $comptop->fontCreate( -family =>'Courier', -size => 8 );
my $bestfontbold =
    $comptop->fontCreate( -family =>'Courier', -size => 8, -weight => 'bold' );
my $worstfontbold =
    $comptop->fontCreate( -family =>'Courier', -size => 8, -weight => 'bold' );
my $headingfont =
    $comptop->fontCreate( -family => 'Courier', -size => 8, -weight => 'bold' );

my $headtag = "comphead";
my $texttag = "comptext";
my $besttag = "best";
my $worsttag = "worst";
my $bestbold = "bestbold";
my $worstbold = "worstbold";

$comptext->tagConfigure( $headtag, -font => $headingfont );
$comptext->tagConfigure( $texttag, -font => $textfont );
$comptext->tagConfigure( $besttag, -font => $bestfont, -foreground => 'blue' );
$comptext->tagConfigure( $worsttag, -font => $worstfont, -foreground => 'red' );
$comptext->tagConfigure( $bestbold, -font => $bestfontbold, -foreground => 'blue' );
$comptext->tagConfigure( $worstbold, -font => $worstfontbold, -foreground => 'red' );

#comparison heading
$comptext->insert( 'end', "Comparison of :\n", $headtag );

my $i = 1;
foreach ( @$projname_arrayref ) {
    $comptext->insert( 'end', "$i - $_\n", $headtag );
    $i++;
}

# TIME COMPARISON

$comptext->insert( 'end', "\nTime Comparison:\n" . " " x 8, $headtag );
$comptext->insert( 'end', sprintf( "%10s", "$$_" ), $texttag ) foreach (0 .. @{$ssort_arrayref->[0]}-1);
$comptext->insert( 'end', sprintf( "%10s", "EV\n" ) . "-" x 12 x (@{$ssort_arrayref->[0]}+2) . "\n", $texttag
);

foreach $i ( 0..@$projname_arrayref - 1 ) {

    my $tag = "";
    $comptext->insert( 'end', sprintf( "%8s", "Proj " . ($i + 1) ), $texttag );

    foreach ( @{$times[$i]} ) {

        if ( $_ == $worst_times[$i] ) {

            $tag = ( $_ == $worst_time_overall )? $worstbold : $worsttag;
        }
        elsif ( $_ == $best_times[$i] ) {

            $tag = ( $_ == $best_time_overall )? $bestbold : $besttag;
        }
        else {

            $tag = $texttag;
        }
        $comptext->insert( 'end', sprintf( "%10.1f", $_ ), $tag );
    }

    $tag = ( $timeEVs[$i] == $best_tEV )? $bestbold : $texttag;
    $comptext->insert( 'end', sprintf( "%10.1f days\n", $timeEVs[$i] ), $tag );

}

# COST COMPARISON

$comptext->insert( 'end', "\nCost Comparison:\n" . " " x 8, $headtag );
$comptext->insert( 'end', sprintf( "%12s", "$$_" ), $texttag ) foreach (0 .. @{$ssort_arrayref->[0]}-1);
$comptext->insert( 'end', sprintf( "%12s", "EV\n" ) . "-" x 12 x (@{$ssort_arrayref->[0]}+2) . "\n", $texttag
);

foreach $i ( 0..@$projname_arrayref - 1 ) {

    my $tag = "";
    $comptext->insert( 'end', sprintf( "%8s", "Proj " . ($i + 1) ), $texttag );

    foreach ( @{$costs[$i]} ) {

        if ( $_ == $worst_costs[$i] ) {

            $tag = ( $_ == $worst_cost_overall )? $worstbold : $worsttag;
        }
        elsif ( $_ == $best_costs[$i] ) {

```

```

        $tag = ( $_ == $best_cost_overall )? $bestbold : $besttag;
    }
    else {

        $tag = $texttag;
    }

    $comptext->insert( 'end', sprintf( "%12.2f", $_ ), $tag );
}

$tag = ( $costEVs[$i] == $best_cEV )? $bestbold : $texttag;
$comptext->insert( 'end', sprintf( "%12s\n", sprintf( "\%.0.2f", $costEVs[$i] ) ), $tag );
}

$appdataref->{ 'compcount' }++;
}

#-----#
# destroy_comp
#-----#
sub destroy_comp {

    my ( $appdataref ) = @_ ;
    $appdataref->{ 'comptop' }->destroy;
}

#-----#
# launch_pnet
#-----#
sub launch_pnet {

    my ( $appdataref ) = @_ ;

    my $projname_arrayref = $appdataref->{ 'projname' };
    my $sdata_arrayref = $appdataref->{ 'scenariodata' };
    my $ssort_arrayref = $appdataref->{ 'scenariosort' };
    my $currproj = $appdataref->{ 'currentproject' };
    my $ssortref = $appdataref->{ 'scenariosort' }[$currproj];

    my $pnettop = $appdataref->{ 'pnettop' };
    my $pnetbook = $appdataref->{ 'pnetbook' };

    my $path = ".\\graphs\\";
    my $i = 0;
    my @pics;

    foreach my $scenario_id ( @$ssortref ) {

        my $graph = $sdata_arrayref->[$currproj][$scenario_id]{ 'schedule' }->pgraph;
        my $tasksetref = $sdata_arrayref->[$currproj][$scenario_id]{ 'schedule' }->taskset;
        my $reshashref = $sdata_arrayref->[$currproj][$scenario_id]{ 'schedule' }->reshash;
        my $imgfile = $path . $projname_arrayref->[$currproj] . "(".$i)." .gif";
        my $psfile = $path . $projname_arrayref->[$currproj] . "(".$i)." .eps";
        my $dotfile = $path . $projname_arrayref->[$currproj] . "(".$i)." .txt";
        $dotfile =~ s/\\/ /g;
        $imgfile =~ s/\\/ /g;
        $psfile =~ s/\\/ /g;

        open( FILE, ">$dotfile" ) or die "Couldn't open file: $dotfile\n";
        print FILE Project::Grapher::render2DOT( "g$i", $graph, $tasksetref, $reshashref );
        close( FILE );
        print `dot -Tgif $dotfile -o $imgfile`;
        print `dot -Tps $dotfile -o $psfile`;
        push @pics, $imgfile;
        $i++;
    }

    #launch the comparison window
    $pnettop = MainWindow->new;
    my $image = $pnettop->Photo( -file => "pmeve24x24.bmp" );
    $pnettop->Icon( -image => $image );
    $pnettop->title( "[".$projname_arrayref->[$currproj]] - PM Eye Project Networks" );
    $pnetbook = $pnettop->NoteBook()->pack( -side => 'top', -expand => 1, -fill => 'both' );

    $i = 0;
    foreach my $imgfile ( @pics ) {

        my $scenario = ( $i == 0 )? "Base" : "$i";
        my $pnetimage = $pnettop->Photo( -file => $imgfile );
        my $page = $pnetbook->add( $scenario , -label => $scenario, -anchor => 'e' );
        $page->Label(
            -anchor => 'center',
            -image => $pnetimage,
            -background => 'white'
        )->pack(
            -expand => 'both',
            -fill => 'both'

```



```

    );
    $i++;
}
}

#-----#
# launch_gantt
#-----#
sub launch_gantt {

    my ( $appdataref ) = @_;

    my $projname_arrayref = $appdataref->{ 'projname' };
    my $sdata_arrayref = $appdataref->{ 'scenariodata' };
    my $ssort_arrayref = $appdataref->{ 'scenariosort' };
    my $currproj = $appdataref->{ 'currentproject' };
    my $ssortref = $appdataref->{ 'scenariosort' }[$currproj];

    my $gantttop = $appdataref->{ 'gantttop' };
    my $ganttbook = $appdataref->{ 'ganttbook' };

    #launch the comparison window
    $gantttop = MainWindow->new;
    my $image = $gantttop->Photo( -file => "pmeye24x24.bmp" );
    $gantttop->Icon( -image => $image );
    $gantttop->title( "[${projname_arrayref->[$currproj]} - PM Eye Project Gantt Charts" );
    $ganttbook = $gantttop->NoteBook()->pack( -side => 'top', -expand => 1, -fill => 'both' );
    my $ganttfnt = $gantttop->fontCreate( -family => 'Courier', -size => 8 );
    my $i = 0;

    foreach my $scenario_id ( @$ssortref ) {
        my $gantt = $sdata_arrayref->[$currproj][$scenario_id]{ 'schedule' }->gantt;
        my $scenario = ( $i == 0 )? "Base" : "$i";
        my $page = $ganttbook->add( $scenario , -label => $scenario, -anchor => 'e' );

        my $gantttxt = $page->Scrolled(
            "Text",
            -font          => $ganttfnt,
            -scrollbars    => 'se'
        )->pack(
            -side          => 'bottom',
            -expand        => 1,
            -fill          => 'both'
        );

        $gantttxt->configure( -wrap => 'none' );
        BindMouseWheel( $gantttxt );

        $gantttxt->insert( 'end', $gantt );
        $i++;
    }
}

#-----#
# launch_narr
#-----#
sub launch_narr {

    my ( $appdataref ) = @_;

    my $projname_arrayref = $appdataref->{ 'projname' };
    my $sdata_arrayref = $appdataref->{ 'scenariodata' };
    my $ssort_arrayref = $appdataref->{ 'scenariosort' };
    my $currproj = $appdataref->{ 'currentproject' };
    my $ssortref = $appdataref->{ 'scenariosort' }[$currproj];

    my $narrtop;
    my $narrbook;

    #launch the comparison window
    $narrtop = MainWindow->new;
    my $image = $narrtop->Photo( -file => "pmeye24x24.bmp" );
    $narrtop->Icon( -image => $image );
    $narrtop->title( "[${projname_arrayref->[$currproj]} - PM Eye Project Scheduling Narratives" );
    $narrbook = $narrtop->NoteBook()->pack( -side => 'top', -expand => 1, -fill => 'both' );

    my $i = 0;

    foreach my $scenario_id ( @$ssortref ) {

        my $scenario = ( $i == 0 )? "Base" : "$i";
        my $page = $narrbook->add( $scenario , -label => $scenario, -anchor => 'e' );

        my $narrtxt = $page->Scrolled(
            "Text",
            -scrollbars    => 'e'
        )->pack(
            -side          => 'bottom',

```

```

        -expand      => 1,
        -fill        => 'both'
    );

    $narrtext->configure( -wrap => 'none' );
    BindMouseWheel( $narrtext );

    $narrtext->insert( 'end', $sdata_arrayref->[$currproj]{ $scenario_id }->prenarrative );
    $narrtext->insert( 'end', $sdata_arrayref->[$currproj]{ $scenario_id }->schednarrative );
    $i++;
}
}

#-----#
# create_project_button
#-----#
sub create_project_button {
    my ( $parent, $font, $projnum, $projname, $appdataref ) = @_;
    my $callbacksub = sub {
        open_project( $projnum, $projname, $appdataref );
    };

    my $button = $open_mb->command(
        -label      => $projname,
        -font       => $font,
        -command    => $callbacksub
    );
}

#-----#
# create_jumpto_button
#-----#
sub create_jumpto_button {
    my ( $parent, $textwidget, $i, $font ) = @_;
    my $callbacksub = sub { $textwidget->see( "scenario$i" . "head.first + 10 lines" ); };
    my $button = $parent->command(
        -label      => "Scenario $i",
        -underline   => 9,
        -accelerator => "Ctrl-$i",
        -font       => $font,
        -command    => $callbacksub
    );
    return $button;
}

#-----#
# fill_jumpto_menu
#-----#
sub fill_jumpto_menu {
    my ( $appdataref ) = @_;

    my $currproj = $appdataref->{ 'currentproject' };
    my $view_mb = $appdataref->{ 'viewmenu' };
    my $textwidget = $appdataref->{ 'text' }[$currproj];
    my $scount = $appdataref->{ 'scenariocount' }[$currproj];

    $appdataref->{ 'jumpto' }[$_] = create_jumpto_button( $view_mb, $textwidget, $_, $menufont )
        foreach ( 0..$scount - 1 );
    $view_mb->separator;
}

#-----#
# BindMouseWheel
#-----#
sub BindMouseWheel {
    my ( $w ) = @_;

    if ( $^O eq 'MSWin32' ) {
        $w->bind( '<MouseWheel>' =>
            [ sub { $_[0]->yview( 'scroll', -($_[1] / 120) * 3, 'units' ) }, Ev('D') ]
        );
    }
    else {
        $w->bind( '<4>' => sub { $_[0]->yview( 'scroll', -3, 'units' ) unless $Tk::strictMotif; } );
        $w->bind( '<5>' => sub { $_[0]->yview( 'scroll', +3, 'units' ) unless $Tk::strictMotif; } );
    }
}

#-----#
# pack_graphs
#-----#
sub pack_graphs {

```

```

my ( $appdataref ) = @_;

foreach my $currproj (0..$appdataref->{ 'nextproject' } - 1) {

    my $graphbar = $appdataref->{ 'graphbar' }[$currproj];
    my $timegraph = $appdataref->{ 'timegraph' }[$currproj];
    my $costgraph = $appdataref->{ 'costgraph' }[$currproj];
    my $textbar = $appdataref->{ 'textbar' }[$currproj];
    my $probgraph = $appdataref->{ 'probgraph' }[$currproj];
    my $timedataref = $appdataref->{ 'timedata' }[$currproj];
    my $costdataref = $appdataref->{ 'costdata' }[$currproj];
    my $probdaref = $appdataref->{ 'probdaref' }[$currproj];

    $timegraph->pack(
        -side => 'top',
        -expand => 1,
        -fill => 'y',
    );
    $costgraph->pack(
        -side => 'top',
        -expand => 1,
        -fill => 'y',
    );
    $probgraph->pack(
        -side => 'top',
        -expand => 1,
        -fill => 'y',
    );
    $graphbar->pack(
        -side => 'left',
        -fill => 'both',
        -expand => 1
    );

    $timegraph->set( $timedataref );
    $costgraph->set( $costdataref );
    $probgraph->set( $probdaref );

}

}

#-----#
# unpack_graphs
#-----#
sub unpack_graphs {

    my ( $appdataref ) = @_;

    foreach my $currproj (0..$appdataref->{ 'nextproject' } - 1) {
        $appdataref->{ 'graphbar' }[$currproj]->packForget();
    }

}

#-----#
# close_project
#-----#
sub close_project {

    my ( $appdataref ) = @_;
    my $cproj = $appdataref->{ 'currentproject' };

    $appdataref->{ 'notebook' }->delete("$cproj");
    splice( @{$appdataref->{ '$_'} }, $cproj, 1 ) foreach ( @{$appdataref->{ 'dockkeys' } } );
    my $pcount = scalar @{$appdataref->{ 'page' } };
    $appdataref->{ 'nextproject' } = $pcount;
    $appdataref->{ 'currentproject' } = $cproj = ( $cproj > 0 )? $cproj - 1 : 0;
    $appdataref->{ 'notebook' }->raise("$cproj") if ( $pcount );
    ${$appdataref->{ 'percentdone' }} = 0 unless ( $pcount );
    $appdataref->{ 'toolbar' }->update;

}

#-----#
# expected_value
#-----#
sub expected_value {

    my $total = 0;
    my $outcome;
    my $prob;
    print "\n\noutcome\tprobability\n";
    print "-----\n";

    while ( $outcome = shift ) {

        $prob = shift;
        $total += $outcome * $prob;
        print "$outcome\t$prob = ", $outcome * $prob, "\n";
    }
}

```

```

    }
    print "\nTotal = $total\n";
    return $total;
}

#-----#
# listmax
#-----#
sub listmax {

    my $maxval = shift;
    my $compval;
    while (@_) {
        $compval = shift;
        $maxval = ( $maxval > $compval )? $maxval : $compval;
    }
    return $maxval;
}

#-----#
# listmin
#-----#
sub listmin {

    my $minval = shift;
    my $compval;
    while (@_) {
        $compval = shift;
        $minval = ( $minval < $compval )? $minval : $compval;
    }
    return $minval;
}

```

The Project::Schedule Module

```
package Project::Schedule;

use Project::Grapher;
use Project::Sets qw(is_emptyset set_compare generate_powerset set_difference set_intersection set_union);
use Graph::Directed;
use Data::Dumper;

use warnings;
use strict;

sub new {
    my $proto = shift;
    my $class = ref($proto) || $proto;
    my $self = {};
    $self->{PGRAPH} = Graph::Directed->new;
    $self->{PTMIN} = 0;
    $self->{STARTDATE} = undef;
    $self->{ENDDATE} = undef;
    $self->{TASKSET} = undef;
    $self->{TASKSORT} = undef;
    $self->{RESHASH} = undef;
    $self->{PRECEDENCE} = undef;
    $self->{SSETS} = undef;
    $self->{COST} = undef;
    $self->{ADJUSTEDSCHEDULE} = undef;
    $self->{ADJUSTEDGRAPH} = undef;
    $self->{ADJUSTEDPTMIN} = undef;
    $self->{GANTTCHART} = "";
    $self->{PRENARRATIVE} = "";
    $self->{SCHEDULENARRATIVE} = "";
    $self->{WORKDAY} = 8;
    bless ($self, $class);
    return $self;
}

sub execute {
    my $self = shift @_;

    $self->make_pgraph;
    $self->sort_tasks;
    $self->forward_pass;
    $self->backward_pass;
    $self->free_slack;
    $self->heuristic_schedule;
    $self->make_gantt;
    $self->cost_calc;
}

sub sort_tasks {
    my $self = shift @_;
    my @toposort = $self->{PGRAPH}->toposort;
    $self->{TASKSORT} = ();

    for my $vertex ( @toposort ) {
        my @edges = ();
        @edges = $self->{PGRAPH}->out_edges( $vertex );
        while ( scalar @edges ) {
            my $u = shift @edges;
            my $v = shift @edges;
            push @{$self->{TASKSORT}}, [$u, $v];
        }
    }
}

sub print_project {
    my $self = shift @_;
    my $totalcost = 0;
    my $outstring = "";

    $outstring .= "CPM Calculations Prior to Scheduling\n\n";
    $outstring .= "CP\tes\tef\tls\tlf\tts\tfs\tdur\t COST          RESOURCE -- TASK NAME\n";
    $outstring .= "-----\n";
    $outstring .= "\n";

    foreach my $activity (@{$self->{TASKSORT}}) {
        my ($inode, $jnode) = @{$activity};
        my ($duration, $resource, $taskid) =
            ( $self->{PGRAPH}->get_attribute( 'duration', $inode, $jnode ),
              $self->{PGRAPH}->get_attribute( 'resource_id', $inode, $jnode ),
```

```

    $self->{PGRAPH}->get_attribute( 'task_id', $inode, $jnode );

my $cost = (($resource != -1)?
    $self->{RESHASH}->{$resource}->{'rate'} : 0 ) * $self->{WORKDAY} * $duration;

$outstring .= ( $self->{PGRAPH}->get_attribute( 'total_slack', $inode, $jnode ) == 0 )? "*" : " ";
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'early_start', $inode, $jnode );
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'early_finish', $inode, $jnode );
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'late_start', $inode, $jnode );
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'late_finish', $inode, $jnode );
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'total_slack', $inode, $jnode );
$outstring .= sprintf "%0.1f\t", $self->{PGRAPH}->get_attribute( 'free_slack', $inode, $jnode );
my $tmpstr = $self->{RESHASH}{$resource}{'name'};
$outstring .= sprintf "%0.1f\t", $duration;
$outstring .= sprintf "%9.2f ", (( $resource != -1 )? "$cost" : "n/a" );
$outstring .= sprintf "%s -- %s\n",
    (( $resource != -1 )? "$tmpstr" : "n/a"),
    (( $taskid != -1 )? $self->{TASKSET}{$taskid}{'task_name'} : "dummy task" );

}

$outstring .= "-----\n";
$outstring .= sprintf "Project Length (non-adjusted): %0.1f days\n", $self->{PTMIN};
$outstring .= sprintf "Total Cost: \\\$%0.2f\n", $self->{COST};
$outstring .= "\nAdjusted Schedule:\n\n";
$outstring .= "ES\\tEF\\tRESOURCE -- TASK NAME\n";
$outstring .= "-----\n";
$outstring .= sprintf "%0.1f\\t%0.1f\\t%s -- %s\n", $_->[0], $_->[1], $_->[3], $_->[5]
    foreach ( @{$self->{ADJUSTEDSCHEDULE}} );
$outstring .= "-----\n";
$outstring .= sprintf "Project Length (adjusted): %0.1f days\n", $self->{ADJUSTEDPTMIN};
$outstring .= sprintf "Total Cost: \\\$%0.2f\n", $self->{COST};
return $outstring;
}

sub make_gantt {
    my $self = shift @_;
    my $ptmin = $self->{ADJUSTEDPTMIN};
    my $scale = ($ptmin / 100);
    $scale = ( $scale >= 1 )? int($scale + 0.5) : ( $scale >= 0.5 )? 1 : 0.5;
    my $ganttstr = "";
    my $tmpstr;
    $ganttstr .= "Approximated Gantt (Scale # = $scale days)\n";
    my $sepstr = "";

    for ( my $i = 0; $i <= $ptmin / $scale; ) {
        my $tick = $i * $scale;
        $tmpstr = ( $i % 10 == 0 )? "|$tick" : "-";
        $i += length $tmpstr;
        $sepstr .= $tmpstr;
    }

    $ganttstr .= $sepstr . "\n";
    my $chartlen = length $sepstr;

    foreach ( @{$self->{ADJUSTEDSCHEDULE}} ) {
        $tmpstr = ' ' x ( int( $_->[0] + 0.5 ) / $scale );
        $tmpstr .= '#' x ( int( $_->[1] - $_->[0] + 0.5 ) / $scale );
        $ganttstr .= $tmpstr . ' ' x ( $chartlen - length $tmpstr ) . "\t$_->[3] -- $_->[5]\n";
    }
    $ganttstr .= $sepstr;
    $self->{GANTTCHART} = $ganttstr;
}

sub forward_pass {
    my $self = shift @_;
    $self->{PTMIN} = 0;
    my $activity;

    $self->{PGRAPH}->set_attribute( 'early_occurrence', $_, $self->{STARTDATE} )
        foreach ( $self->{PGRAPH}->vertices );

    foreach $activity ( @{$self->{TASKSORT}} ) {
        my ($inode, $jnode) = @$activity;

        $self->{PGRAPH}->set_attribute( 'early_start', $inode, $jnode,
            $self->{PGRAPH}->get_attribute( 'early_occurrence', $inode ) );

        $self->{PGRAPH}->set_attribute( 'early_finish', $inode, $jnode,
            $self->{PGRAPH}->get_attribute( 'early_start', $inode, $jnode ) +
            $self->{PGRAPH}->get_attribute( 'duration', $inode, $jnode ) );

        if ( $self->{PGRAPH}->get_attribute( 'early_finish', $inode, $jnode ) -
            $self->{PGRAPH}->get_attribute( 'early_occurrence', $jnode ) > 0 ) {

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```

        $self->{PGRAPH}->set_attribute('early_occurrence', $jnode,
            $self->{PGRAPH}->get_attribute('early_finish', $inode, $jnode));
    }
    if ( $self->{PGRAPH}->get_attribute('early_finish', $inode, $jnode) - $self->{PTMIN} > 0 ) {
        $self->{PTMIN} = $self->{PGRAPH}->get_attribute('early_finish', $inode, $jnode);
    }
}
}

sub backward_pass {
    my $self = shift @_;
    my $activity;

    my $lateoccurrence = ( $self->{ENDDATE} == 0 )? $self->{PTMIN} : $self->{ENDDATE};
    $self->{PGRAPH}->set_attribute('late_occurrence', $_, $lateoccurrence)
        foreach ( $self->{PGRAPH}->vertices );

    foreach $activity ( reverse @{$self->{TASKSORT}} ) {
        my ($inode, $jnode) = @$activity;

        $self->{PGRAPH}->set_attribute('late_finish', $inode, $jnode,
            $self->{PGRAPH}->get_attribute('late_occurrence', $jnode));

        $self->{PGRAPH}->set_attribute('late_start', $inode, $jnode,
            $self->{PGRAPH}->get_attribute('late_finish', $inode, $jnode) -
            $self->{PGRAPH}->get_attribute('duration', $inode, $jnode));

        if ( $self->{PGRAPH}->get_attribute('late_start', $inode, $jnode) -
            $self->{PGRAPH}->get_attribute('late_occurrence', $inode) < 0 ) {
            $self->{PGRAPH}->set_attribute('late_occurrence', $inode,
                $self->{PGRAPH}->get_attribute('late_start', $inode, $jnode));
        }
        $self->{PGRAPH}->set_attribute('total_slack', $inode,
            $jnode, $self->{PGRAPH}->get_attribute('late_start', $inode, $jnode) -
            $self->{PGRAPH}->get_attribute('early_start', $inode, $jnode));
    }
}

sub free_slack {
    my $self = shift @_;
    my $activity;

    foreach $activity (@{$self->{TASKSORT}}) {
        my ($inode, $jnode) = @$activity;

        $self->{PGRAPH}->set_attribute('free_slack', $inode, $jnode,
            $self->{PGRAPH}->get_attribute('total_slack', $inode, $jnode) -
            $self->{PGRAPH}->get_attribute('late_occurrence', $jnode) +
            $self->{PGRAPH}->get_attribute('early_occurrence', $jnode));
    }
}

sub heuristic_schedule {
    my $self = shift @_;
    my $d = Data::Dumper->new({$self->{PGRAPH}});
    $d->Purity(1)->Terse(1)->Deepcopy(1);
    my $pgraph = $self->{ADJUSTEDGRAPH} = eval $d->Dump;
    my %resalloc;
    my %lastfinish;
    my %U;
    my @edges;
    my ($inode, $jnode);
    my @F;
    my @C;
    my %clock;
    my %curract;
    my %next;
    my %done;
    my %gantt;
    my $ptmin = 0;

    #reinitialize early occurrence times for all project nodes
    $pgraph->set_attribute('early_occurrence', $_, $self->{STARTDATE}) foreach ( $pgraph->vertices );
    #initialize resource allocation hash
    my $enddate = ( $self->{ENDDATE} == 0 )? $self->{PTMIN} : $self->{ENDDATE};

```

```

@resalloc{ keys %{$self->{RESHASH}} } = ();
$resalloc{ $_ }{ join ':', $self->{STARTDATE}, $enddate * 10 } = () foreach ( keys %resalloc );
@edges = $pgraph->edges;

# place all tasks in set U
while ( @edges ) {
    $inode = shift @edges;
    $jnode = shift @edges;
    $U{ join ':', $inode, $jnode } = ();
}

#get the start task
my ( $starttask ) = denode( $self->term_task( 'start' ) );
my ( $endtask ) = denode( $self->term_task( 'end' ) );

#initialize current activity to the start task and initialize the clock
$curract = $starttask;
$clock = $self->{STARTDATE};

#set start task attributes and reserve time for the task
( $inode, $jnode ) = nodes( $starttask );
my $taskid = $pgraph->get_attribute( 'task_id', nodes( $starttask ) );
my $taskname = $self->{TASKSET}{ $taskid }{ 'task_name' };
my $resource = $pgraph->get_attribute( 'resource_id', nodes( $starttask ) );
my $resourcename = $self->{RESHASH}{ $resource }{ 'name' };
my $earlystart = $self->{STARTDATE};
my $duration = $pgraph->get_attribute( 'duration', nodes( $starttask ) );
my $earlyfinish = $clock + $duration;
$pgraph->set_attribute( 'early_occurrence', $inode, $self->{STARTDATE} );
$pgraph->set_attribute( 'early_start', $inode, $jnode, $self->{STARTDATE} );
$pgraph->set_attribute( 'early_finish', $inode, $jnode, $earlyfinish );
reserve( \%resalloc, $resource, $clock, $duration );
push @gantt, [ $earlystart, $earlyfinish, $resource, $resourcename, $taskid, $taskname ];
$ptmin = $earlyfinish;
$lastfinish{ $_ } = $starttask foreach ( keys %{$self->{RESHASH}} );
#Remove start task from U
delete $U{ $starttask };
$done{ $starttask } = ();

#move start task's successors to F
push @F, denode( get_successors( $pgraph, nodes( $starttask ) ) );

@F = sort { $pgraph->get_attribute( 'total_slack', nodes( $a ) ) <=>
    $pgraph->get_attribute( 'total_slack', nodes( $b ) ) } @F;

delete $U{ $_ } foreach ( @F );
my $cantschedule;

OUTER_PASS: while (1) {
    $cantschedule = 1;
    my $pass = 1;
    while ( $pass <= 2 ) {

        my @unscheduled;
        while ( @F ) {

            my $currtask = shift @F;
            $taskid = $pgraph->get_attribute( 'task_id', nodes( $currtask ) );
            $resource = $pgraph->get_attribute( 'resource_id', nodes( $currtask ) );
            if ( $pass == 1 ) {
                # on the first scheduling pass:
                # set scheduling clock to the maximum of early finish time of the last completed task
                # for the resource assigned to the current task and all of the current task's predecessors
                $clock = max_EF( $pgraph, nodes( $lastfinish{ $resource } ),
                    get_predecessors( $pgraph, nodes( $currtask ) ) );
            }
            else {
                # on the second scheduling pass:
                # set the scheduling clock to the maximum of the early finishes of all completed tasks
                $clock = max_EF( $pgraph, nodes( keys %done ) );
            }
            $duration = $pgraph->get_attribute( 'duration', nodes( $currtask ) );
            $taskname = $self->{TASKSET}{ $taskid }{ 'task_name' };
            $resourcename = $self->{RESHASH}{ $resource }{ 'name' };

            if ( resource_is_available( \%resalloc, $resource, $clock, $duration ) ) {
                $earlystart = $clock;
                $earlyfinish = $clock + $duration;
                reserve( \%resalloc, $resource, $clock, $duration );
                ( $inode, $jnode ) = nodes( $currtask );
                $pgraph->set_attribute( 'early_occurrence', $inode, $clock );
                $pgraph->set_attribute( 'early_start', $inode, $jnode, $clock );
                $pgraph->set_attribute( 'early_finish', $inode, $jnode, $earlyfinish );
                $pgraph->set_attribute( 'early_occurrence', $jnode, $earlyfinish );
                if ( $earlyfinish > $pgraph->get_attribute( 'early_occurrence', $jnode ) );
                $ptmin = ( $earlyfinish > $ptmin ) ? $earlyfinish : $ptmin;
                $self->{SCHEDULENARRATIVE} .=
                    "Scheduling task \"$taskname( $resourcename )\" to start at T = $clock\n";
            }
        }
    }
}

```



```

        push @gantt, [ $earlystart, $earlyfinish, $resource, $resourcename, $taskid, $taskname ];
        push @C, $currtask;
        $done{ $C[-1] } = ();      #add the task to the set of completed tasks
        @C = sort { $pgraph->get_attribute( 'early_finish', nodes( $a ) ) <=>
            $pgraph->get_attribute( 'early_finish', nodes( $b ) ) } @C;
        $lastfinish{ $resource } = $currtask;
        $cantschedule = 0;
    }
    else {
        push @unscheduled, $currtask;
        $self->{SCHEDULENARRATIVE} .=
            "Rescheduling task \"$taskname( $resourcename )\" due to resource conflict at T =
$clock\n";
    }
}
@F = @unscheduled;
@unscheduled = ();
$pass++;
}

if ( $cantschedule ) {
    foreach ( keys %U ) {
        my %predset;
        @predset{ denode( get_predecessors( $pgraph, nodes( $_ ) ) ) } = ();
        my $scomp = set_compare( \%predset, \%done );
        if ( $scomp eq 'proper subset' || $scomp eq 'equal' ) {
            push @F, $_;
            delete $U{ $_ };
        }
    }
    @F = sort { $pgraph->get_attribute( 'total_slack', nodes( $a ) ) <=>
        $pgraph->get_attribute( 'total_slack', nodes( $b ) ) } @F;

    last OUTER_PASS unless ( @F );
}
}
$self->{ADJUSTEDPTMIN} = $ptmin;
$self->{ADJUSTEDSCHEDULE} = \@gantt;
}

sub max_EF {
    my $pgraph = shift;
    my $max = 0;
    my ( $inode, $jnode );

    while ( @_ ) {
        $inode = shift;
        $jnode = shift;
        my $ef = $pgraph->get_attribute( 'early_finish', $inode, $jnode );
        $max = ( $ef > $max ) ? $ef : $max;
    }
    return $max;
}

sub nodes {
    my @edges;
    while ( @_ ) {
        push @edges, split ':', shift @_;
    }
    return @edges;
}

sub denode {
    my @tasks;
    while ( @_ ) {
        push @tasks, ( join ':', shift @_, shift @_ );
    }
    return @tasks;
}

sub get_successors {
    my $pgraph = shift @_;
    my ( $inode, $jnode ) = @_;
    my @succs;
    my @succverts = $pgraph->successors( $jnode );
    push @succs, $jnode, shift @succverts while ( @succverts );
    return @succs;
}

sub get_predecessors {

```

```

my $pgraph = shift @_;
my ( $inode, $jnode ) = @_;
my @preds;
my @predverts = $pgraph->predecessors( $inode );
push @preds, shift @predverts, $inode while ( @predverts );
return @preds;
}

sub term_task {

my $self = shift @_;
my ( $termttype ) = @_;
my $pgraph = $self->{PGRAPH};
my @edges = $pgraph->edges;
my ( $inode, $jnode );
EDGE: while ( @edges ) {

    $inode = shift @edges;
    $jnode = shift @edges;

    if ( $termttype eq 'start' ) {
        last EDGE if ( $pgraph->in_degree($inode) == 0 );
    }
    else {
        last EDGE if ( $pgraph->out_degree($jnode) == 0 );
    }
}
return ( $inode, $jnode );
}

sub resource_is_available {

my ( $resalloc_ref, $resource, $time, $duration ) = @_;

return 1 if ( $resource == -1 );

my ( $start, $finish ) = ( $time, $time + $duration );
my $is_available = 0;
my ( $x, $y );
AVAIL_SCAN: foreach ( keys %{$resalloc_ref->{ $resource }} ) {
    ( $x, $y ) = split ':', $_;
    if ( $start >= $x &&
        $start <= $y &&
        $finish >= $x &&
        $finish <= $y ) {

        $is_available = 1;
        last AVAIL_SCAN;
    }
}
return $is_available;
}

sub reserve {

my ( $resalloc_ref, $resource, $time, $duration ) = @_;

return if ( $resource == -1 );

my ( $start, $finish ) = ( $time, $time + $duration );
my ( $x, $y );
RES_SCAN: foreach ( keys %{$resalloc_ref->{ $resource }} ) {
    ( $x, $y ) = split ':', $_;
    if ( $start >= $x &&
        $start <= $y &&
        $finish >= $x &&
        $finish <= $y ) {

        my $head = $start - $x;
        my $tail = $y - $finish;
        delete $resalloc_ref->{ $resource }{ $_ };
        $resalloc_ref->{ $resource }{ join ':', $x, $start } = () if ( $head > 0 );
        $resalloc_ref->{ $resource }{ join ':', $finish, $y } = () if ( $tail > 0 );
        last RES_SCAN;
    }
}

}

sub make_pgraph {

my $self = shift @_;
my $activity;

$self->{PGRAPH} =
    Project::Grapher::pgraph(
        $self->{TASKSET},
        $self->{PRECEDENCE},
        $self->{SETS},

```

```

        $self->{STARTDATE},
        $self->{ENDDATE}
    );
}

sub cost_calc {
    my $self = shift @_;
    my $totalcost = 0;

    foreach my $activity (@{$self->{TASKSORT}}) {
        my ($inode, $jnode) = @{$activity};

        my ($duration, $resource) =
            ( $self->{PGRAPH}->get_attribute( 'duration', $inode, $jnode ),
              $self->{PGRAPH}->get_attribute( 'resource_id', $inode, $jnode ) );

        my $cost = ( $self->{PGRAPH}->get_attribute( 'resource_id', $inode, $jnode ) != -1 )?
            $self->{WORKDAY} * $self->{RESHASH}{$resource}{ 'rate' } * $duration : 0 ;

        $totalcost += $cost;
    }

    $self->{COST} = $totalcost;
}

sub ptmin {
    my $self = shift;
    if (@_) { $self->{PTMIN} = shift }
    return $self->{PTMIN};
}

sub adjustedptmin {
    my $self = shift;
    if (@_) { $self->{ADJUSTEDPTMIN} = shift }
    return $self->{ADJUSTEDPTMIN};
}

sub pgraph {
    my $self = shift;
    if (@_) { $self->{PGRAPH} = shift }
    return $self->{PGRAPH};
}

sub tasksort {
    my $self = shift;
    if (@_) { $self->{TASKSORT} = shift }
    return $self->{TASKSORT};
}

sub startdate {
    my $self = shift;
    if (@_) { $self->{STARTDATE} = shift }
    return $self->{STARTDATE};
}

sub enddate {
    my $self = shift;
    if (@_) { $self->{ENDDATE} = shift }
    return $self->{ENDDATE};
}

sub taskset {
    my $self = shift;
    if (@_) { $self->{TASKSET} = shift }
    return $self->{TASKSET};
}

sub reshash {
    my $self = shift;
    if (@_) { $self->{RESHASH} = shift }
    return $self->{RESHASH};
}

sub cost {
    my $self = shift;
    if (@_) { $self->{COST} = shift }
    return $self->{COST};
}

sub precedence {
    my $self = shift;
    if (@_) { $self->{PRECEDENCE} = shift }
    return $self->{PRECEDENCE};
}

```

```

}

sub ssets {
    my $self = shift;
    if (@_) { $self->{SSETS} = shift }
    return $self->{SSETS};
}

sub prenarrative {
    my $self = shift;
    if (@_) { $self->{PRENARRATIVE} = shift }
    return $self->{PRENARRATIVE};
}

sub schednarrative {
    my $self = shift;
    if (@_) { $self->{SCHEDULENARRATIVE} = shift }
    return $self->{SCHEDULENARRATIVE};
}

sub gantt {
    my $self = shift;
    if (@_) { $self->{GANTTCHART} = shift }
    return $self->{GANTTCHART};
}

sub workday {
    my $self = shift;
    if (@_) { $self->{WORKDAY} = shift }
    return $self->{WORKDAY};
}

1;

```

The Project::Grapher Module

```

package Project::Grapher;

use Project::Sets qw(is_emptyset set_compare set_difference set_intersection set_union);
use Graph::Directed;
use warnings;
use strict;

# STEP I
# I. create sets S[1..n]

# STEP II
# II. A. number activities in topological order
# II. B. form the binary precedence matrix R
# II. C. convert R to toally redundant precedence matrix Rprime
# II. D. reduce Rprime to the basic precedence matrix without redundancy R2prime

# STEP III
# III. A. Determine nonredundant sets A(i)
# III. B. Determine totally redundant sets A'(i)
# III. C. Determine the sets B(i)

# STEP IV
# IV. Assign integer F(i) to activity i

# STEP V
# V. Assign integer T(i) to activity i

# STEP VI
# VI. Assign a preceding node number P(i) to activity i

# STEP VII
# VII. Assign a succeeding node number Q(i) to activity i

# STEP VIII
# VIII. Create ordered pairs of nodes [Q(i), P(j)]

sub pgraph {

    #-----#
    # Arbitrary data
    #-----#

    $[ = 1; # Changes first array subscript to 1 instead of zero.
    # Just to make the implementation of the alogrithm simpler.
    my $startdate;
    my $enddate;

    #-----#
    # sets and lists
    #-----#

    my $PR; # hash of task precedence relations
    my $S; # S1 = { y | y has no followers }, S2 = { y | y has at least one follower in S1 } ..etc
    my $taskset; # set of all tasks in the project
    my @tsort = (); # topologically sorted list of tasks in the project
    my %tmpset = (); # temporary set used in the topological sort of tasks
    my @R = (); # Precedence matrix
    my @Rprime; # Totally redundant precedence matrix
    my @R2prime; # Basic precedence matrix without redundancy
    my @A; # non redundant sets
    my @Aprime; # totally redundant sets
    my @B; # ?
    my %D; # ?
    my @F; # ?
    my @T; # ?
    my @P; # ?
    my @Q; # ?
    my @dummies; # Dummy activities required for the project network

    #-----#
    # counters, temp variables, and flags
    #-----#

    my $taskid; # -1 is used as a flag when no rows are returned from the select
    my $i = 1; # Initialize general counter
    my $j = 1;
    my $k = 1; # ditto
    my $exhaustiveset = 0; # flag to indicate when exhaustive sets have been produced while creating S[1..n]
    my $flag = 0; # General flag

    my $pg = Graph::Directed->new();

    ($taskset, $PR, $S, $startdate, $enddate) = @_;
    #-----#
    # STEP II

```

```

# II. A. number activities in topological order
#-----#

# perform a topological sort on the tasks

foreach my $k ( reverse 1 .. @{$S}-1 ) {

my @list = sort keys %{{set_difference( $S->[$k], \%tmpset )}};
my @sortlist =
    sort {
my $setcomparison = set_compare ( $PR->{$a}, $PR->{$b} );
return 1 if ( $setcomparison eq "proper subset" );
return -1 if ( $setcomparison eq "proper superset" );
return 0;
    } @list;

push @tsort, @sortlist;
$tmpset{$_} = () foreach @tsort;

    }

#-----#
# II. B. form the binary precedence matrix R
#-----#

# prepare the precedence matrix R

print "\nPrecedence Matrix R\n";

for my $i ( 1 .. @tsort ) {
for my $j ( 1 .. @tsort ) {

    print " ", $R[$i][$j] = ( exists $PR->{$tsort[$i]}{$tsort[$j]} ) ? 1 : 0;

}
print "\n";
}

#-----#
# II. C. convert R to toally redundant precedence matrix Rprime
#-----#

# Initialize R2prime matrix
for my $i ( 1 .. @R ) {
$Rprime[$i] = @{$R[$i]};
}

$ i = scalar keys %$taskset;

do {
if ( $Rprime[$k][$i] == 1 ) {
    foreach ( 1 .. @Rprime )
    { $Rprime[$k][$_] = ( $Rprime[$k][$_] > $Rprime[$i][$_] ) ?
      $Rprime[$k][$_] : $Rprime[$i][$_]; }
}
if ( $k != $i - 1 ) {
    $k++;
}
else {
    if ( $i != 2 ) {
        $i--;
        $k = 1;
    }
    else {
        $flag = 1;
    }
}
} until ( $flag );

print "\nTotally Redundant Precedence Matrix R'\n";

for my $i ( 1 .. @Rprime ) {
for my $j ( 1 .. @Rprime ) {
    print " ", $Rprime[$i][$j];
}
print "\n";
}

#-----#
# II. D. reduce Rprime to the basic precedence matrix without redundancy R2prime
#-----#

# Initialize R2prime matrix
for my $i ( 1 .. @R ) {
$R2prime[$i] = @{$Rprime[$i]};
}

$ j = 1;

```

```

    $k = 2;
    $flag = 0;

    do {
    if ( $R2prime[$j][$k] == 1 ) {
        foreach (1 .. @R2prime)
        { $R2prime[$j][$_] = ( 0 > $R2prime[$j][$_] - $R2prime[$k][$_] ) ?
          0 : $R2prime[$j][$_] - $R2prime[$k][$_] ;}
        }
    if ( $k != @R2prime ) {
        $k++;
    }
    else {
        if ( $j != @R2prime - 1 ) {
            $j++;
            $k = $j + 1;
        }
        else {
            $flag = 1;
        }
    }
    } until ( $flag );

    print "\nBasic Precedence Matrix R''\n";

    for my $i (1 .. @R2prime) {
    for my $j (1 .. @R2prime) {
        print " ", $R2prime[$i][$j];
    }
    print "\n";
    }

    #-----#
    # STEP III
    # III. A. Determine nonredundant sets A(i)
    #-----#

    for my $i (1..@R2prime) {
    $A[$i] = {};
    for my $j (1..@R2prime) {
        $A[$i][$j] = () if ( $R2prime[$i][$j] == 1 );
    }
    }

    #-----#
    # III. B. Determine totally redundant sets A'(i)
    #-----#

    for my $i (1..@Rprime) {
    $Aprime[$i] = {};
    for my $j (1..@Rprime) {
        $Aprime[$i][$j] = () if ( $Rprime[$i][$j] == 1 );
    }
    }

    #-----#
    # III. C. Determine the sets B(i)
    #-----#

    for my $i (1..@Rprime) {
    $B[$i] = {};
    for my $j (1..@Rprime) {
        $B[$i][$j] = () if ( exists $A[$j][$i] );
    }
    }

    #-----#
    # STEP IV
    # IV. Assign integer F(i) to activity i
    #-----#

    $i = 1;
    $flag = 0;

    do {
    my $j;
    my $setcomparison = "";

    if ( not defined $F[$i] ) {

        %D = ();

        for $j (1..@B) {
            $setcomparison = set_compare($B[$j], $B[$i]);
            $D[$j] = () if $setcomparison eq "equal";
        }
        for $j (keys %D) {
            $F[$j] = $i;
        }
    }
    }

```

```

    }
}

if ( $i != @B ) {
    $i++;
}
else {
    $flag = 1;
}

} until ( $flag );

#-----#
# STEP V
# V. Assign integer T(i) to activity i
#-----#

$i = @A;
$flag = 0;

do {
my $j;
my $setcomparison = "";

if ( not defined $T[$i] ) {

    %D = ();

    for $j (1..@B) {
        $setcomparison = set_compare($A[$j], $A[$i]);
        $D{$j} = () if $setcomparison eq "equal";
    }
    for $j (keys %D) {
        $T[$j] = $i;
    }
}

if ( $i != 1 ) {
    $i--;
}
else {
    $flag = 1;
}

} until ( $flag );

#-----#
# STEP VI
# VI. Assign a preceding node number P(i) to activity i
#-----#

$i = 1;
$flag = 0;

do {

my $j;
my $setcomparison = "";

# step VI 2
if ( not is_emptyset($B[$i]) ) {
    # step VI 3
    %D = ();
    my @Aaddrlist = ();
    my @jprime = ();

    @Aaddrlist = map { $A[$_] } keys { $B[$i] };
    if (@Aaddrlist == 1) {

%D = { $Aaddrlist[ $[ ] ];
    }
    else {

%D = { set_intersection( @Aaddrlist ) };
    }
    # step VI 4
    @jprime = grep { set_compare(\%D, $A[$_] ) eq "equal" } keys { $B[$i] };

    if ( scalar @jprime ) {
# step VI 5
$P[$i] = 10 * $T[@jprime[ $[ ] ] + 2;
    }
    else {
# step VI 6
    @Aaddrlist = map { $Aprime[$_] } keys { $B[$i] };

    if (@Aaddrlist == 1) {

```



```

    %D = %{$Aaddrlist[ $[ ] ];
}
else {

    %D = %{ set_intersection( @Aaddrlist ) };
}

# step VI 7
@jprime = grep { set_compare(\%D, $Aprime[$_] eq "equal" ) keys %{$B[$i]};
if (scalar @jprime) {
    # dupe of step VI 5
    $P[$i] = 10 * $T[$jprime[ $[ ] ] + 2;
}
else {
    #dupe of step VI 8
    $P[$i] = 10 * $F[$i] + 1;
}
}
}
else {
    # step VI 8
    $P[$i] = 10 * $F[$i] + 1;
}
}

# step VI 9
if ($i != @A) {

    $i++;
}
else {

    $flag = 1;
}

} until ($flag);

#-----#
# STEP VII
# VII. Assign a succeeding node number Q(i) to activity i
#-----#

$i = @A;
$flag = 0;

do {

if ( not defined $Q[$i] ) {

    my %E = ();
    my $setcomparison = "";

    for $j (1..@A) {
        $setcomparison = set_compare($A[$j], $A[$i]);
        $E[$j] = () if $setcomparison eq "equal";
    }
    for $j (keys %E) {

        if ( not defined $Q[$j] ) {

            my @jprime = ();
            @jprime = grep { $_ != $j and defined $Q[$_] and $P[$_] == $P[$j] } keys %{$B[$i]};

            if ( @jprime ) {

                $Q[$j] = 10 * $j + 2;
            }
            else {

                $Q[$_] = 10 * $i + 2 foreach (keys %E);
            }
        }
    }
}
}
if ( $i != 1 ) {

    $i--;
}
else {

    $flag = 1;
}

} until ($flag);

#-----#
# STEP VIII
# VIII. Create ordered pairs of nodes [Q(i), P(j)]
#-----#

```

```

    $i = 1;
    $flag = 0;

    do {
    if ( not is_emptyset( $A[$i] ) ) {

        for my $j (keys %{ $A[$i] }) {
            my %G = ();
            my %H = ();
            my @jprime = grep { set_compare( $B[$_], $B[$j] ) eq "proper subset" } keys %{ $A[$i] };
            map { $G[$_] = () } @jprime;

            if ( not is_emptyset( \%G ) ) {

                my @klist = grep { $Q[$_] == $Q[$i] and $_ != $i } (1 .. @Q);
                my %kset = ();
                map { $kset{$_} = () } @klist;
                my @Baddrlist = map { $B[$_] } keys %G;
                %H = %{ set_difference( set_union( @Baddrlist ), { $i => [] }, \%kset ) };

                if ( is_emptyset( \%H ) ) {

                    if ( $Q[$i] != $P[$j] ) {

                        push @dummies, [$Q[$i], $P[$j]];
                    }
                    else {
                        my $found = 0;
                        for my $h ( keys %H ) {
                            for my $g ( keys %G ) {

                                $found = ( $Q[$h] == $P[$g] ) ? 1 : $found;
                            }
                        }
                        push @dummies, [$Q[$i], $P[$j]] if not $found;
                    }
                }
            }
            elsif ( $Q[$i] != $P[$j] ) {

                push @dummies, [$Q[$i], $P[$j]];
            }
        }
    }
    if ( $i != @A ) {

        $i++;
    }
    else {

        $flag = 1;
    }
    } until ( $flag );

    #-----#
    # build the project network
    #-----#

    # add tasks and properties to the project network

    foreach my $i ( 1..@tsort ) {
        $pg->add_vertices( $P[$i], $Q[$i] );
        $pg->set_attribute( 'early_occurrence', $P[$i], $startdate );
        $pg->set_attribute( 'early_occurrence', $Q[$i], $startdate );
        $pg->set_attribute( 'late_occurrence', $P[$i], $enddate );
        $pg->set_attribute( 'late_occurrence', $Q[$i], $enddate );
        $pg->add_path( $P[$i], $Q[$i] );
        $pg->set_attribute( 'duration', $P[$i], $Q[$i], $taskset->{ $tsort[$i] }{ "duration" } );
        $pg->set_attribute( 'resource_id', $P[$i], $Q[$i], $taskset->{ $tsort[$i] }{ "resource" } );
        $pg->set_attribute( 'task_id', $P[$i], $Q[$i], $tsort[$i] );
    }

    # add dummy tasks and properties to the project network
    if (@dummies) {
    foreach my $i ( 1..@dummies ) {
        $pg->add_vertices( $dummies[$i][1], $dummies[$i][2] );
        $pg->set_attribute( 'early_occurrence', $dummies[$i][1], $startdate );
        $pg->set_attribute( 'early_occurrence', $dummies[$i][2], $startdate );
        $pg->set_attribute( 'late_occurrence', $dummies[$i][1], $enddate );
        $pg->set_attribute( 'late_occurrence', $dummies[$i][2], $enddate );
        $pg->add_path( $dummies[$i][1], $dummies[$i][2] );
        # dummy tasks have a duration of 0
        $pg->set_attribute( 'duration', $dummies[$i][1], $dummies[$i][2], 0 );
        $pg->set_attribute( 'resource_id', $dummies[$i][1], $dummies[$i][2], -1 );
        # flag to indicate that there is no corresponding task in the database
        $pg->set_attribute( 'task_id', $dummies[$i][1], $dummies[$i][2], -1 );
    }
}

```

```

    }
    $[ = 0;
    return $pg;
}

sub render2DOT {

    my ( $gname, $pgraph, $tasksetref, $reshashref ) = @_;
    my $dotstr = "digraph $gname {\n\tsize=\"8,10\";\n";
    my $attr = "";
    my $startattr = "[shape=circle,peripheries=2,style=filled,label=\"Start\"]";
    my $nodeattr = "[shape=circle]";

    foreach my $node ( $pgraph->vertices ) {
        $attr = ( $pgraph->in_degree( $node ) == 0 )? $startattr : $nodeattr;
        $dotstr .= "\t$node $attr;\n";
    }

    my @edges = $pgraph->edges;
    while ( @edges ) {

        my $inode = shift @edges;
        my $jnode = shift @edges;

        my $resource_id = $pgraph->get_attribute( 'resource_id', $inode, $jnode );
        my $duration = $pgraph->get_attribute( 'duration', $inode, $jnode );
        my $slack = $pgraph->get_attribute( 'total_slack', $inode, $jnode );
        my $taskid = $pgraph->get_attribute( 'task_id', $inode, $jnode );
        my $taskname = ( $taskid == -1 )? "dummy" : $tasksetref->{$taskid}{task_name};
        my $resname = ( $taskid == -1 )? "NA" : $reshashref->{$resource_id}{name};
        my $color = ( $slack == 0 )? ",color=red,style=bold" : ",color=black";
        my $style = ( $taskid == -1 )? "style=dotted," : "";

        my $edgeattr = "[ $style" . "label=\"${taskname}\\nDUR = $duration\\nRES = $resname\"$color]";
        $dotstr .= "\t$inode -> $jnode $edgeattr\n";
    }
    return $dotstr .= "};";
}

1;

```