

Chapter 6: Risk, Feasibility and Benefit/Cost Analysis

What Project Professionals Do To
Minimize Risks, Consider Feasibility and
Assess Benefits in Relation to Costs

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Introduction

We study risk management at this point in our tome because, to be dealt with adequately, it needs thorough consideration in the first and/or second stage of the project lifecycle. Risk management entails the entire lifecycle, but it must be thoroughly identified and planned for in the early stages of the lifecycle. Risk can be both upside and downside in the sense that some managerial decisions/actions/strategies may create upside potential for the firm, while other decisions might result in downside loss for the firm. As we shall illustrate in this chapter, decision tables and trees, risk registers, as well as risk contingency plans can be useful tools for dealing with risk. If a plan of action is thought to have negative or downside risk, decision-makers can pursue avoidance, transferal, or mitigation approaches; if the plan of action is thought to have positive or upside risk, decision-makers can pursue exploitation, sharing and enhancement approaches. If the plan of action is believed to possess both upside and downside risk, the approach can be one of acceptance or contingency. We discuss each of these in what follows.

The plan of action possesses significant upside potential or opportunity.

When risks are thought to possess positive impacts on project objectives, the approach would be to exploit the risk, to share the risk or to enhance the opportunity presented by the upside potential of the risk, or some combination of these. An exploitation approach is one that reduces the uncertainty associated with the strategy by assigning the best resources to the project so it produces a product sooner, by ensuring the best quality goes into the project so the product exceeds quality expectations and so forth. A sharing approach is a more cautious approach that gives other parties an opportunity to participate. The participation of the third party may help reduce uncertainty and increase the likelihood of significant gain. Joint ventures, risk-sharing partnerships, special purpose companies are sharing entities that can help increase the upside potential and reduce the downside. Finally, enhancement approaches can be pursued that will increase the size of the opportunity.

The plan of action possesses significant downside potential or threat.

When risks are thought to possess negative impacts on project objectives, the approach would be to avoid the risk, to transfer the risk or to mitigate the risk, or some combination of these. Risk avoidance involves changing the project management plan to eliminate the threat posed by an adverse risk. Further risk avoidance will endeavor to isolate the project objectives from the impact of the risk, perhaps by extending the schedule or reducing scope. Sometimes risks can be avoided by clarifying requirements, obtaining information, improving communication, or acquiring expertise. Risk transference involves shifting the impact of a threat to a third party. Insurance against bad weather, for example, can be one such approach to transferal. Such an approach simply gives responsibility for management of the risk to another party; it does not eliminate it. As in the case of insurance, a premium is paid to the third party for assuming responsibility of the risk. Other transference tools include the use of performance bonds, warranties, guarantees, etc. Contracts are yet another means to transfer risk. A cost-reimbursement contract transfers cost risk to the buyer, while a fix-price contract places all cost risk firmly upon the seller. Risk mitigation implies a reduction in the probability and/or impact that an adverse risk event will have to an acceptable threshold. This might be accomplished by improving processes, conducting more tests, or choosing a more stable supplier. A mitigating action may involve more thorough prototype development or designing redundancy into the product so that if some component of the product fails, there is a backup in place.

The plan of action possesses both upside opportunity and downside potential.

Most often, when decisions are made, there is both a downside and an upside. The approaches here are acceptance and/or contingency response. Here, the project team knows of no other approach that can be taken. Certainly, it is seldom possible to eliminate all risk from a project. What is not explicitly addressed by an approach such as avoidance or transferal is accepted. Acceptance can be either passive, such as doing nothing, or active, such as providing a contingency reserve of funds, time or resources to accommodate the risk. Contingency responses are explicitly-designed approaches that will be triggered only if a specific risk event occurs. Risk management is explicitly concerned with situations in which there is either significant downside risk or a combination of upside opportunity and downside potential.

Motivation for Risk Management

A major concern for any project manager is the risks associated with the project assigned to him or her. How to anticipate and assess these risks, how to cope with them, how to mitigate them before they ever occur, how to create contingency plans should they occur, how to stay in control, is what this chapter is about. Unfortunately, most industry observers see risk management seldom applied as an explicit project management activity. Most project management maturity surveys will show risk management as one of the knowledge areas in which maturities is lowest.

Consequently, there are a great many project disasters. A survey performed by Barry Boehm indicated that out of 600 firms, over 200 of them had at least one runaway software project (Boehm, 1988). Retrospective assessments have been performed on these projects and from them project professionals have learned that these disasters would have been avoided or strongly reduced if there had been an explicit early concern for identification and resolution of the high-risk elements in the projects. However, Boehm also attributes some of the blame to the methodologies used (Boehm, 1991). In particular he believes the waterfall methodology causes people to over-promise software capabilities in contractually binding requirements specifications before the risk implications are well understood. Furthermore, the evolutionary development model has often created high-risk elements and led the project down the path to disaster, he avows. Indeed, he would avow such; after all, the waterfall and evolutionary development models are not risk driven methodologies, whereas his spiral model is.

Information technology risk management must concern itself with three categories of risk—general risk situations, technical risk situations, and financial risk situations.

General Risk Considerations

Suppose, for the moment that you are a consultant. Perhaps you are aware of a particular IT need that your client has. However, this need does not align well with your team's area of expertise. The client is very impressed with your team's work. You decide to propose doing the work for the client and the client accepts, not realizing that this is a totally different type of project than the one you are currently completing so successfully for him. Now, what kind of disaster have you created for yourself? If this is in a new technology area, all of your people must be trained to do the new project at a considerable additional cost and additional time. Perhaps you can build this additional cost and time into the project proposal and get the client to pay for it. If not, then expect to take a loss on the project. There are other firms out there that have the expertise and could have done the project for less money and more quickly. This could turn out to be an unprofitable project for you and your team. Meanwhile, you have forgone the opportunity to do a profitable project (for another client) that is in your area of expertise. A lack of experience with the hardware, operating system, software packages, computer language tools or the application area all pose risks.

Learning or Experience Curve Effects

This is where the effects of the learning or experience curve begin to have an impact. Consider a small information technology firm that performs projects in which they transition their clients from an old information architecture to a new one. After several such projects they begin to develop an experience base in this type of project. Further, they are able to retain a repository of software developed in previous projects that they can reuse within current and future projects. When they bid on an architectural transition project, their proposed price may be the same or less than was their first such project. However, their actual cost is substantially less, because they are much further along on the experience curve. By now at least some of the custom software is already written. Developers know where to get the reusable components that will save them huge blocks of time and they know how to connect these disparate components.

Now, consider an upstart firm that wants to bid and compete with the experienced firm. If the upstart firm underbids the experienced firm, they will win the contract. But, in the end they will probably lose money on the project because of where they are on the experience or learning curve relative to the firm that has performed many such projects. The upstart firm must be willing to do this if they are to become a player in this line of business. Eventually, after several unprofitable projects, they may be able to reach profitability, as they develop an experience base.

Other General Risk Situations

Occasionally, the working environment is inadequate and a major consideration. A proper development environment is one that is quiet, and free from interruptions. Developers need to spend long periods of time working on their tasks without intervening interruptions. Especially if the development work has to be done at the client's site, this could be a problem. The development computing equipment should be able to provide a fast response to requirements for compilation and execution. Additionally, the required development tools must be in place before the project commences.

Third party sources of the required software, hardware or of the required resources can also be a source of risk. Penalty clauses in suppliers contracts is one way to gain some leverage and control over the possibility of such risks.

Technical Risk Considerations

This is always an issue when an IT firm bids on a new, as yet untried, project. There is always the question of technical feasibility. "Can we actually pull it off, considering that we have never done this type of work before?" Technically, we have seen other firms and individuals do things similar to this, but we have never done it. The question becomes, "Can this type of project be done now by us and if so at what cost?"

Further, consider the first firm mentioned in the section on experience curve effects above. Suppose they decide to start a new business line, Internet application development and interactive web-site creation, say. They will once again find themselves low in terms of experience and losing money on the first few projects. With perseverance, however, they should be able to move this new line of work into the realm of profitability. However, if there is plenty of work to be done in the profitable line of business involving transitioning clients into new information architectures, there is reason to doubt the credibility of the firm's decision to move into Internet development. An obvious opportunity cost is involved here in which the firm gives up profitable business ventures for unprofitable ones for a time.

Financial Risk Considerations

Typically, the client or customer will decide whether your proposal is economically viable. If your proposal is low in terms of cost, the client may not believe your bid and decide to reject it on the basis of a lack of credibility. If your proposal is too high because of your lack of experience, your proposal may again get rejected in favor of lower bids that are credible.

When there are two parties involved as is the case when an outside contractor is used, there are two risk perspectives. From the contractor's point of view, there is the risk that the project will yield a negative return and/or the contractor's reputation is tarnished. From the contracting firm's perspective there are several possible risk scenarios: 1) the project does not get completed on time, 2) the project goes over budget, 3) the project does not get completed with full functionality, and 4) the requirements change.

The Go/No-Go Decision

After the requirements are determined vis-à-vis, the previous chapter, the next step is to decide whether the project is worth doing and feasible. Then additional questions need to be asked. IS IT TECHNICALLY FEASIBLE?, or more appropriately AT WHAT COST CAN THE SYSTEM BE BUILT, and WHAT WILL BE THE BENEFIT/COST? And finally, the project manager must ask IS THIS PROJECT DOABLE NOW BY ME?

Risk Issues

Historically, the information technology community has a terrible reputation for underestimating projects. All too often, project managers and team members live in a DREAM WORLD in which we tacitly assume:

1. There will be no changes.
2. Upper management will do the right things for the project.
3. We will have all the necessary resources.
4. No limits on time or money.
5. No resources or products need be obtained from a third party.
6. The user will agree to the two-step proposal.
7. The hardware manufacturer will deliver the hardware and the new version of the operating systems on time and in working condition and within budget.
8. There is no competition.

The REALITIES are the following:

1. Estimates are by dictated by some stakeholders.
2. Management signs fixed price¹ contract based on your first ballpark estimate.
3. You never get adequate resources.
4. Changes take place in the requirements.
5. Responsibilities remain undefined.
6. Estimates increase after the analysis and the delivery date slips.
7. When the project slips, management assigns additional programmers, who slow the project down even further.
8. User is unsympathetic to problems.
9. Management panics, gets involved.

¹ A fixed-price contract is one in which the price is fixed and the project product will be delivered for that price.

Among other topics, we will present, in this chapter, a general methodology for risk management. In effect, this is a mini-methodology that could fit one traversal of a cycle in the spiral model. The exact mini-methodology chosen by the project manager must fit the nature of the risk itself.

Risk Management Processes

The risk management area within PMBOK (2004) consists of six processes. The general methodological steps to risk management are based on the risk management processes, which are:

1. risk management planning
2. risk identification
3. qualitative risk analysis
4. quantitative risk analysis
5. risk response planning
6. risk monitoring and control

In what follows we discuss each of these steps in detail.

Risk Management Planning

The project manager should spend some time up front of the project assessing and anticipating possible risks. Indeed, this should be done before ever agreeing to assume the position of project manager. Risk management planning involves developing a plan for risk management for the entire lifecycle, which should be accomplished in the planning and budgeting stage of the lifecycle. Better plans result in better processes for each of the remaining five process types.

The goal of risk management planning is to develop a set of risk-mitigating or risk-contingency plans that determine the activities necessary to bring the risk items previously identified under control. Each plan is determined from answering the standard questions of WHY, WHAT, WHEN, WHO, WHERE, HOW, and HOW MUCH. The actual plan might involve benchmarking, modeling, prototyping, simulation, instrumentation or tuning. For example, it is widely known that safety features and fault-tolerance features slow down a product's performance. The question is by HOW MUCH. A prototype of representative features could be constructed and performance tested to determine and reduce the slowing effects on system performance that such enhancements tend to produce.

A most important thing for a PM to do is to get focused on the critical success factors² of the project. Too often projects get focused on activities that are not critical for their success. These include trying to get the requirements **exactly** right, writing detailed boilerplate documents, exploring peripheral issues, or playing politics. In the process, the project fails and nobody wins. The *Top-Ten Risk Item Plan* is intended to keep PMs focused on the important stuff. It is easy for PMs who were previously hot-shot developers to get focused on the day-to-day development that should be performed by the team members and to lose sight of the larger perspective—the project as a whole.

² Any firm will have a set of critical success factors by which success or failure of the project will be gauged. These should be known and explicit from the very beginning. They typically would include the expected product functionality, the anticipated performance of the product in terms of speed, the project schedule and/or the project budget. Still other factors might include ease of use, accommodation of requirements that might be changing, and end-user acceptability.

Software Risk Management Plan

1. Identify the project's top ten risk items
2. Present a plan for resolving each risk item
3. Update a) list of top ten risk items, b) plan, and c) results monthly
4. Highlight risk-item status in project reviews
5. Compare with previous report's rankings, status
6. Initiate appropriate corrective actions

Risk Identification

Lists of project-specific risk items likely to compromise a project's success are produced in this step. Tools used include checklists, examination of decision drivers, comparison with experience and decomposition. A checklist of the top ten risk types is given in Table 6.1 below, together with the solution technique. This list is adapted from work by Boehm (Boehm, 1991). He identifies the risk factor and then gives risk management techniques to address each of them.

Risk Type	Risk Solution Technique
Personnel shortfalls	Staffing with top talent; job matching; team-building; morale building; cross-training; pre-scheduling key people
Unrealistic schedules and budgets	Detailed, multi-source cost and schedule estimation; design-to-cost; incremental development; software reuse; requirements scrubbing
Developing the wrong software functions	Organizational analysis; mission analysis; ops-concept formulation; user surveys; prototyping; early users' manuals
Developing the wrong user interface	Task analysis; prototyping; scenarios; user characterization (functionality, style, workload)
Gold plating	Requirements scrubbing; prototyping; cost-benefit analysis; design to cost
Continuing stream of requirement changes	High change threshold; information hiding; incremental development (defer changes to later increments)
Shortfalls in externally performed tasks	Reference checking; pre-award audits; award-fee contracts; competitive design or prototyping; team-building
Shortfalls in externally furnished components	Benchmarking; inspections; reference checking; compatibility analysis
Real-time performance shortfalls	Simulation; benchmarking; modeling; prototyping; instrumentation; tuning
Straining computer science capabilities	Technical analysis; cost-benefit analysis; prototyping; reference checking

Table 6.1. Top Ten Major Risk Types Together with Recommended Solutions

Identifying the risks involved with a project has always been a difficult and time-consuming process. One cannot overstate the importance that this identification has as part of a successful overall risk management. Before going further though, a definition for project risk needs to be established. Risks are those factors that may prevent the attainment of a set goal. H. Bersoff has defined the goal of a software development process as, "Producing a product that meets or closely matches the needs of the people for whom it is developed. Achieving this goal is called product integrity" (Bersoff, 1984). He goes on to say that product integrity must also

include the additional goals of meeting the planned cost, and meeting the planned schedule for producing that product. Therefore, project risk would involve anything that may compromise the attainment of project integrity. Recently, the importance of risk identification been recognized by most of the engineering community. In the past, risk has always had a negative connotation and thereby encouraged the denial of its existence during development. In his 1991 paper, *Software Risk Management: Principles and Practices*, Barry Boehm suggests that risk management is more important in software development than previously realized (Boehm, 1991). Risk is an inherent factor in any software development activity and needs to be addressed. Risk taking is essential to achieve progress, and failures are, unfortunately, a key part of learning. Conversely, the inevitability of risk does not imply the inability to recognize or manage it. Risk management can help us to minimize potential negative consequences while retaining the opportunities for creating new and better software or other products.

As one might imagine, there are dozens of methods to identify project risk. Most have project success criteria to look for and questionnaires to evaluate the status of those criteria. Checklists developed by the Standish Group and F.W. McFarlan are good examples of these methods (Schwalbe, 2000). Each one has its share of supporters; however, the focus of this paper will be on a key model of risk identification developed by the Software Engineering Institute (SEI) at Carnegie Mellon University in Pittsburgh, Pennsylvania called Taxonomy-Based Risk Identification (Carr, et al., 1993). It is part of a comprehensive and continuous risk management method being developed by the institute to promote better project management practices. The SEI used a model that they call the risk management paradigm to illustrate the different activities that compose the software development risk management process. The paradigm is represented as a circle to emphasize that risk management is a continuous process while the arrows show the logical flow of information between the activities in risk management. Communication is placed in the center of the paradigm because it is both the conduit through which all information flows and is often the major obstacle to the success of risk management.

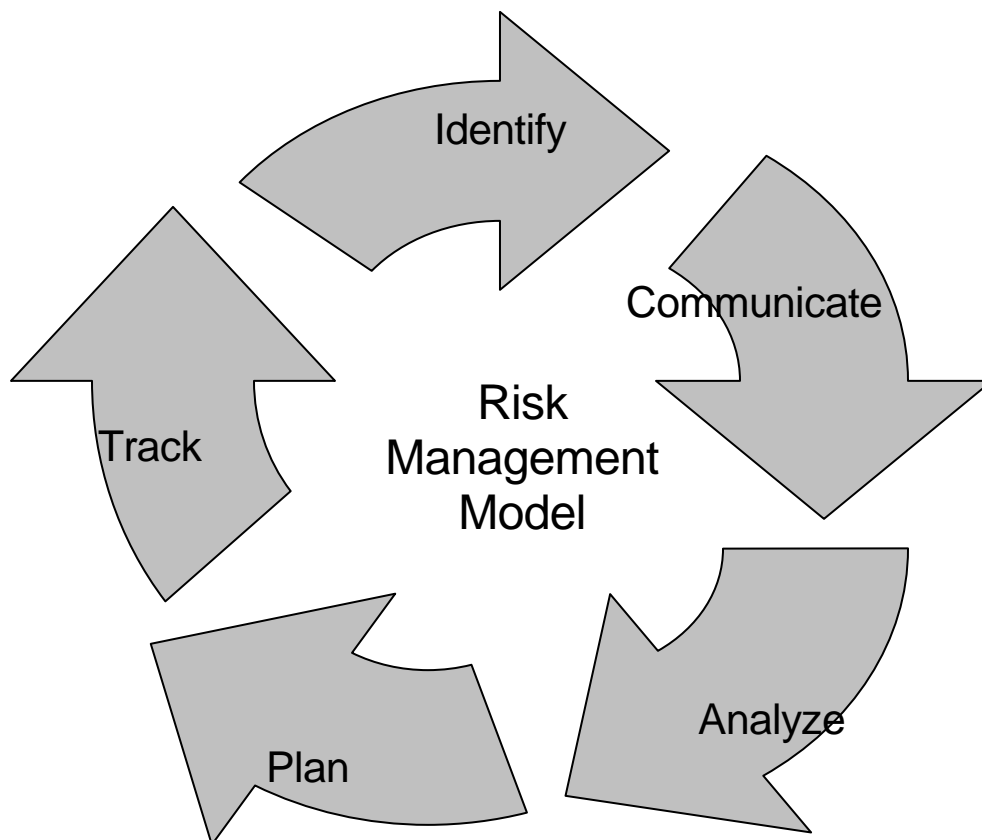


Figure 6.0. SEI Risk Management Model (paradigm) (Carr, et al., 1993)

Qualitative Risk Analysis

As with any problem solving technique; however, the problem must first be identified. By definition, taxonomy is a scheme that partitions a body of knowledge and defines the relationship among the pieces. It is used to classify and understand the body of knowledge. In this case, the body of knowledge is composed of the empirical data of Boehm, Charette, Air Force Systems Command, and the IEEE Standard Glossary of Software Engineering. It also includes SEI staff experience and the analysis of massive amounts of field data. The SEI model recognizes that there are three main types of risk involved in project work today. The first is "known risk." Known risks are risks that at least one of the project's personnel is aware of, even if he is only aware of it as a personal concern. The second type of risk is "unknown risks." Unknown risks are risks that, if given the proper information and conditions, would be discovered by the project staff. The third and final type of risk would be "unknowable risks." Unknowable risks are the risks that even with near perfect information can not be foreseen. This final type of risk, while potentially damaging to the project, will be beyond the ability of any risk identification method. Because of this, the SEI model makes the following assumptions (Carr, et al., 1993):

1. Software development risks are generally known by the project's technical staff but are poorly communicated.
2. A structured and repeatable method of risk identification is necessary for consistent risk management.
3. Effective risk identification must cover all key development and support areas of the project.
4. The risk identification process must create and sustain a non-judgmental and non-attributive risk elicitation environment so that tentative or controversial views are heard.
5. No overall judgment can be made about the success or failure of a project based solely on the number or nature of risks uncovered.

The cornerstone of the Taxonomy-Based Risk Identification system is the Taxonomy-Based Questionnaire (TBQ). This questionnaire consists of a list of non-judgmental questions to elicit issues and concerns in each taxonomic group. The taxonomy, of software development risks, recognizes three main classes of the origin of these risks. The first is the product engineering class, which includes the intellectual and physical activities required in building a product to be delivered to the customer. Its elements include requirements, design, code and unit testing, integration and testing, and engineering specialties. The second is the development environment class. This covers the development process, development system, management process, management methods, and the work environment. The last class is program constraints. These are the factors that are outside the direct control of the project but can still have major effects on its success. The elements of program constraints include resources, contracts, and program interfaces. Each element listed has multiple attributes. It is these attributes that form the basis of the TBQ's questions. (A complete list of the classes, elements, and attributes can be found in appendix A.)

The Taxonomy-Based Questionnaire (TBQ) itself consists of a comprehensive set of questions at the attribute level. Since the TBQ has been design to be so comprehensive, some questions may be irrelevant to a particular situation. In these cases the TBQ has been designed so that the unneeded questions may be omitted without affecting the results. The questions were purposely worded neutrally, in order to gain the subjects honest opinions. It also includes follow-up questions and queues to aid the interviewer in directing the interview and to help the interviewee in understanding it. With all that has gone into the TBQ it is no wonder that it has proven itself to be both effective and efficient in identifying risk.

An additional bonus that was discovered during the field-testing of the TBQ was that it educated workers on how to identify risk on a day-to-day basis. After participating in the interviews, people knew what to look for and how to spot risk early. The complete questionnaire consists of 194 questions but, as explained earlier, it can be customized. Below are included a

sample of the first six questions from the TBQ. Notice how a particular answer prompts the interviewer to ask a follow-up question and even give queues to help focus the participant's state of mind. Implicit in the TBQ is the probing of areas that contain issues, concerns, or risks. That is, the interview protocol requires the interviewer to always follow up on responses that seem to indicate a potential problem. For instance, if the response to a question like, "Has a performance analysis been done?" were "No," then the interviewer would probe for the issues, concerns, or risks to the project due to lack of a performance analysis.

(Sample TBQ Questions -- Carr, et al., 1993)

1. Requirements

a. Stability [Are requirements changing even as the product is being produced?]

[1] Are the requirements stable?

(No) (1.a) What is the effect on the system?

- Quality
- Functionality
- Schedule
- Integration
- Design
- Testing

[2] Are the external interfaces changing?

b. Completeness [Are requirements missing or incompletely specified?]

[3] Are there any 'to-be-determined items' in the specifications?

[4] Are there requirements you know should be in the specification but aren't?

(Yes) (4.a) Will you be able to get these requirements into the system?

[5] Does the customer have unwritten requirements/expectations?

(Yes) (5.a) Is there a way to capture these requirements?

[6] Are the external interfaces completely defined?

Risks are evident at all levels of the development lifecycle, from defining functional requirements to building the product. Luckily, most risks can be mitigated by adherence to project management principles. According to Mundell (1997), in a paper about mitigating project risk, most problems that can be attributed to poor risk identification can be classified into a set of six general risk factors. These factors are:

- failure to identify work products that need to be controlled
- failure to baseline controlled items
- failure to use the correct/complete baseline version
- failure to track problems
- failure to inform management
- failure to use version control tool.

Risk management should be an ongoing process throughout the project development life cycle. It requires active participation from the entire team from management down to the working level. As discussed earlier, when identifying risk you need to identify items or events (such as

changes in customer requirements, new development technologies, or a change in target systems) that may have a significant negative impact on the project. This is where the TBQ is very helpful. Once risks are identified, decision analysis, cost risk analysis, schedule analysis, reliability analysis, and similar techniques and models can be used to analyze the risks. Each risk is then evaluated to assess the potential impact of the risk on the project. Then each risk is rated in two ways: the likelihood that the risk event will actually occur, and the consequences to the project if the risk event occurs. Finally, risk can be prioritized using statistically based decision mechanisms to determine how to best handle the risk thus determining the risk priority. These "risk calculators" can be found at many different web sites or in certain project management software suites. A typical questionnaire has roughly 30 questions for a project manager to answer. After answering the questions it will automatically tell you if your project is potentially high, medium, or low risk and tell you what areas you will need to keep an eye on.

To summarize there are many different methods for identifying the risks in a project. The following provides a short summary of some of the more common methods and tools, according to Boehm, that can be used to support the risk identification process (Boehm, 1988):

Risk Information Sheet:	A form that documents information about a risk, similar to a software trouble or problem report. As information is acquired or collected, it is added to the risk information sheet.
Brainstorming:	A method where project personnel verbally identify risks as they think of the risks. This method provides the opportunity for participants to build on each other's ideas.
Periodic Risk Reporting:	A method requiring mandatory and scheduled reporting of risks by project personnel.
Project Profile Questions:	A tool used to tailor the taxonomy-based questionnaire (TBQ) based on project characteristics.
Risk Form:	A form used to document new risks as they are identified.
TBQ:	A listing of interview questions that are organized according to the software development risk taxonomy.
Short TBQ:	A shortened version of the TBQ, which can be used in conjunction with voluntary or periodic risk reporting. It can also be used during meetings and one-on-one interviews to help identify risks.
TBQ Interviews:	A method where structured peer group interviews are conducted using the TBQ.
Voluntary Risk Reporting:	A method where project personnel voluntarily submit risk forms whenever new risks are identified.

All of the above methods and tools are also applicable to understanding the context of a risk as well, because context is required any time a risk is identified. It is not so important as to how a manager identifies risk, just that he does. Every companies' projects are different and each requires a tailored risk identification method to determine its risk potential. If the culture of a company supports the individual voicing of concerns, risk identification will become second nature to everyone involved. Finally, with a valid risk identification program in place, project problems can be reduced and project successes will undoubtedly increase.

Quantitative Risk Analysis

After generating a list of possible risk types, the PM assigns a Likelihood of Occurrence (LO) to each Risk Type i and a Magnitude of Impact (MI) to each risk type. The LO and MI numbers are arbitrarily picked from a scale of 0 to 10. A Risk Exposure (RE) number is then calculated as the product of the LO and MI numbers. Hence,

$$RE_i = LO_i * MI_i$$

The LO and MI numbers can be determined by use of group-consensus techniques.

Risk Prioritization. The PM should then concentrate on those risk types that have the highest Risk Exposure (RE). The RE quantities also provide a basis for prioritizing verification and validation and related test activities by giving each error class a significance weight. There is often a good deal of uncertainty in estimating the probability or loss associated with an unsatisfactory outcome. A way to reduce this source of risk is to buy information about the actual situation, which can be done by taking another cycle around the spiral by use of a prototyping step, a simulation of the actual situation, or whatever. For example, if performance is a critical issue with a high level of uncertainty relative to overall product architecture, then several architectures can be tested in a simulative environment before a decision is ultimately made.

Risk Response Planning

When a risk is identified, categorized and prioritized, it must be managed in some way. As indicated in the introduction, the approach can be any of the following or some combination: management can endeavor to mitigate the risk, avoid the risk, transfer the risk, share the risk, or accept the risk. Mitigating the risk involves choosing some alternative plan of action. For example, rather than off-shoring IT development where there is some risk of theft of intellectual property, a firm might choose to do the work locally, where it can control this and other risks, such as a departure of a team developer—very probable in off-shore contexts.

As mentioned in the introduction, transferring the risk does not eliminate the risk, but uses a vehicle like insurance to transfer it. Premiums are paid to an insurance firm who will assume the financial consequences should the risk occur. Farmers are accustomed to buying hail insurance to transfer to risk of losing their crop to an insurance company, for example. Construction firms will take out weather insurance to protect them against the possibility of extreme weather that would prevent them from finishing their construction project on time. The insurance policy requires the insurance company to pay for any losses that might occur.

Risk sharing involves bringing other parties into the venture because the costs associated with a non-performing venture are too great. For example, many investors are brought into a project to drill an oil-well because if the well turns out to be a dry-hole, each of their losses will be minimal and able to be assimilated. A similar situation exists for production of movies and films. Many investors are brought into the film venture. If it turns out to be a dud, they can absorb the losses, but if the film is a 'homerun' the investors will each enjoy royalties for years to come.

Risk Monitoring and Control

Risk Resolution

Once the risk-related plans are established, the risk-resolution process can begin. The risk-resolution process consists of implementing whatever prototypes, simulations, benchmarks, surveys, or other risk-reduction techniques are called for in the plans.

Risk Monitoring

Risk monitoring insures that risk-resolution is a closed-loop process by tracking risk-reduction progress and applying whatever corrective action is necessary to keep the risk-resolution process on track. Boehm [2] also recommends the use of *project top-ten risk item tracking*. This technique concentrates management attention on the high-risk, high-leverage, critical success factors that make or break a project. The alternative is to allow the PM's attention to sway from the important stuff to the unimportant stuff—the low-priority detail.

Top-ten risk item tracking involves the following steps:

1. Rank the project's most significant risk items.
2. Establish a regular schedule for higher management review of the project, possibly monthly.
3. Begin each review meeting with a summary of progress on the top-ten risk items.
4. Focus the project review meeting on dealing with any problems in resolving the risk items.

A table like that shown in Table 6.2 should be prepared that exhibits the relative priority of the risk item, its priority last week, the risk-mitigating actions that are being taken and the number of months the item has been on the top-ten list.

Risk Item	Priority	Priority Last Week	Risk-Mitigating Actions
Requirements change	1	1	Build modular, reusable architecture
Project x, on which this project is contingent, not done in time	2	5	Expedite Project x
Helen, chief developer, leaves	3	4	Offer completion bonus to Helen
Knowledge engine not finished on time	4	3	Monitor task diligently, allow overtime
Server performance too slow	5	6	Reassess probable demand traffic; order additional MPP processors if necessary
Hardware contractor doesn't deliver on time	10	2	Hardware has been shipped, should arrive as scheduled

Table 6.2. Top-ten Risk Prioritization Table

Risk Recovery, Reconciliation and Restoration

Risks that do in fact happen, be they anticipated or not, must be managed in some way. This will involve recovery, reconciliation and restoration. Risk recovery begins with the understanding that a particular risk has happened. It is the PM's responsibility to then formulate a plan for recovery. Such a plan might begin by letting all affected parties know. This will include all team members, upper-level management, line managers of the team and the client. When it happened, why it happened, whether it was anticipated or not—all of this needs to be reported, along with the actual risk event itself. Next, the PM must report the formulated plan for recovery. How does the occurrence of the risk affect the critical success factors? If the risk item puts the project behind schedule and this is critical to the success of the project, then the plan must propose a way for getting the project back on schedule.

Models for Risk Assessment

In this section, a formal structure for risk management is explored. The explanation provided here is a simplification of what is provided in those courses, yet without loss of robustness. There are four basic components to any decision problem. They are 1) a collection of decision alternatives that are mutually exclusive³, 2) a collection of future states that are mutually exclusive and collectively exhaustive⁴, 3) for each alternative/state pair, a payoff is assigned, 4) a decision criterion by which a choice amongst the decision alternatives will be made, and finally, in some cases, 5) a set of state probabilities.

Consider the following projects that are being contemplated by a systems integration contractor. Because of resource limitations, only one of these projects can be bid on. Only two future states are possible WIN or LOSE; that is, either the firm will win the bid, or the firm will lose the bid. These are all of the possibilities. If the firm wins the bid, it is contractually obligated to perform the project in conformance to its bid, producing the required deliverables. If the firm loses the bid, it has no further contractual obligations relative to that bid, but it does lose the cost of preparing the bid.

PAYOFF TABLE	WIN	LOSE
Bid Project 1	\$40,000	-\$2,000
Bid Project 2	\$100,000	-\$10,000
Bid Project 3	\$50,000	-\$8,000
Bid Project 4	\$60,000	-\$15,000
Don't bid on anything	0	0

Table 6.3. Payoff table involving choice of one of five decision alternatives, each with uncertain future states

Consider project 2 in relation to project 4. If the outcome is WIN, project 2 is preferred to project 4 because the winnings are greater—\$100,000 versus only \$60,000. If the outcome is LOSE, project 2 is again preferred to project 4 because the losses are less—only \$10,000 versus \$15,000 for project 4. This is a case where project 2 always dominates project 4 and project 4 is considered “dominated” because one would always choose project 2 over project 4. Dominated alternatives can usually be eliminated, but there are exceptions, especially when regret is being considered. Notice in the table above that, for each alternative/state pair, a payoff is defined.

We come next to a consideration of the decision criterion. There are several to choose from, depending mostly on 1) the attitude of the decision maker toward this situation and 2) whether there are probabilities defined for the states. In this case, there are, but there can be situations where these probabilities are unknown. Let's consider first, the decision maker's attitude, which is generally classified as one of the following: PESSIMIST, OPTIMIST, IN-BETWEENIST, REGRETTIST.

Consider the PESSIMIST criterion first. This is the person who wishes to pick the best of all of the “worst-case scenarios.” The worst-case scenario for alternative 1 would be to LOSE the bid, resulting in a \$2,000 loss to the firm. For all alternatives, the worst-case scenario is to LOSE. We can place the payoffs associated with these worst case scenarios in a column to the right. Labeled ROW MINIMUM. We then examine the column labeled ROW MINIMUM and pick the number that is the largest. Its associated decision alternative is “Do Nothing.” In fact, this alternative will get chosen by the PESSIMIST criterion in “almost every decision situation.” For this reason, it is best to leave this criterion out when using the pessimist criterion, if it really is the decision-maker's intention to “do something.”

³ By mutually exclusive, is meant each alternative is independent from all of the others.

⁴ By collectively exhaustive, is meant that all the bases, all possibilities are covered, are enumerated.

PAYOFF TABLE	WIN	LOSE	ROW MINIMUM
Bid Project 1	\$40,000	-\$2,000	-\$2,000
Bid Project 2	\$100,000	-\$10,000	-\$10,000
Bid Project 3	\$50,000	-\$8,000	-\$8,000
Bid Project 4	\$60,000	-\$15,000	-\$15,000
Do Nothing	0	0	0

Table 6.4. Payoff table involving choice of one of five decision alternatives, using the PESSIMIST criterion

PESSIMIST CRITERION

- 1) For each row, find the smallest payoff in the row and record that in a column to the right, labeled ROW MINIMUM;
- 2) Examine the column to the right labeled ROW MINIMUM and pick the alternative with the largest payoff in that column.

The next criterion we want to investigate is the OPTIMIST criterion. This is the person who is always looking for the best of the best. What are the best-case scenarios? What is the best of the best-case scenarios? To apply this criterion, we find the best payoff in each row and record that in a column to the right, labeled ROW MAXIMUM. Then we examine that column and choose the alternative with the highest payoff in that column. Clearly, in this case, the decision alternative that gets selected is “Bid Project 2,” with a “row maximum” of \$100,000, which is the largest payoff in the entire table. In fact, this criterion will always select the alternative with the highest payoff in the payoff table.

PAYOFF TABLE	WIN	LOSE	ROW MAXIMUM
Bid Project 1	\$40,000	-\$2,000	\$40,000
Bid Project 2	\$100,000	-\$10,000	\$100,000
Bid Project 3	\$50,000	-\$8,000	\$50,000
Bid Project 4	\$60,000	-\$15,000	\$60,000
Do Nothing	0	0	0

Table 6.5. Payoff table involving choice of one of five decision alternatives, using the OPTIMIST criterion

OPTIMIST CRITERION

- 1) For each row, find the largest payoff in the row and record that in a column to the right, labeled ROW MAXIMUM;
- 2) Examine the column to the right labeled ROW MAXIMUM and pick the alternative with the largest payoff in that column.

The third criterion to be investigated here is the IN-BETWEENIST criterion. This is the individual that is neither optimistic nor pessimistic but somewhere in between the two. To position such a person properly between the two extremes, we ask the question, “On a scale of zero to one, how close are you to being an optimist, where zero would indicate that you are really an optimist and one would mean that you are a complete pessimist?” Suppose the answer that comes back is .5. We use this number to average the two columns “ROW MIN” and “ROW MAX.” We record the average in a column to the right, labeled COMBINED, as shown below. The specific formula used is

$$\alpha * \text{ROW MIN} + (1 - \alpha) * \text{ROW MAX}$$

In this case the chosen value for α is .5 because that was the decision maker's response to our question. In generally, α can vary from 0 to 1, with 0 indicating that the decision maker is a complete OPTIMIST, while 1 would indicate that the decision maker is a complete PESSIMIST. We then examine this column and pick the alternative with the largest value. Clearly, in this case, the decision alternative that gets selected is "Bid Project 2."

PAYOFF TABLE	WIN	LOSE	ROW MIN	ROW MAX	COMBINED
Bid Project 1	\$40,000	-\$2,000	-\$2,000	\$40,000	\$19,000
Bid Project 2	\$100,000	-\$10,000	-\$10,000	\$100,000	\$45,000
Bid Project 3	\$50,000	-\$8,000	-\$8,000	\$50,000	\$21,000
Bid Project 4	\$60,000	-\$15,000	-\$15,000	\$60,000	\$22,500
Do Nothing	0	0	0	0	0

Table 6.6. Payoff table involving choice of one of five decision alternatives, using the IN-BETWEENIST criterion

IN-BETWEENIST CRITERION

- 1) For each row, combine the smallest payoff in the row with the largest payoff in the row using the formula: $\alpha \cdot \text{ROW MIN} + (1 - \alpha) \cdot \text{ROW MAX}$, record that in a column to the right, labeled COMBINED;
- 2) Examine the column labeled COMBINED to the right and pick the alternative with the largest payoff in that column.

Another criterion that is appropriate for the in-betweenist is the so called RULE OF INSUFFICIENT REASON. It is also a two-step procedure. First, we begin by adding up all of the payoffs along each row and then recording the result of the addition in a column to the right, called "ROW SUM." Second, we examine this column and pick the alternative with the largest ROW SUM. Clearly, in this case, the decision alternative that gets selected is "Bid Project 2."

PAYOFF TABLE	WIN	LOSE	ROW SUM
Bid Project 1	\$40,000	-\$2,000	\$38,000
Bid Project 2	\$100,000	-\$10,000	\$90,000
Bid Project 3	\$50,000	-\$8,000	\$42,000
Bid Project 4	\$60,000	-\$15,000	\$45,000
Do Nothing	0	0	0

Table 6.7. Payoff table involving choice of one of five decision alternatives, using the INSUFFICIENT REASON criterion

RULE OF INSUFFICIENT REASON

- 1) For each row, add-up all of the payoffs in that row and record the result in a column to the right labeled ROW SUM;
- 2) Examine the column labeled ROW SUM to the right and pick the alternative with the largest payoff in that column.

The fifth criterion to be studied is the REGRETTIST criterion. This is appropriate for the person who is often heard lamenting that they had chosen a certain path to take (viz., a decision alternative) in their past that did not turn out just right, a person who is focused on their past and the failed decisions they have taken. To implement this criterion, we examine each column associated with a future state of our payoff table and pick the largest value in that column, recording it in the row "COLUMN MAX." We then form another table that is called a Regret Table. We do this by subtracting each number in a column of our payoff table from the largest

payoff possible in that column. That number represents the amount of regret we will sustain if state WIN occurs and we pick some alternative other than the one that gives us the largest payoff in that column. Unlike the other criteria in which we were interested in *maximizing* some “set of measures,” in this case we are interested in *minimizing* a measure of something called regret. We choose to minimize the worst case regret scenarios. This is again a two-step process. First, we pick the largest regret number in each row and then record that in a column called “row maximum” to the right. Second, we examine this column and pick the alternative with the smallest regret number. Clearly, in this case, the decision alternative that gets selected is “Bid Project 2.”

PAYOFF TABLE	WIN	LOSE
COLUMN MAX	\$100,000	0

REGRET TABLE	WIN	LOSE	ROW MAXIMUM
Bid Project 1	\$60,000	\$2,000	\$60,000
Bid Project 2	\$0	\$10,000	\$10,000
Bid Project 3	\$50,000	\$8,000	\$50,000
Bid Project 4	\$40,000	\$15,000	\$40,000
Do Nothing	\$100,000	0	\$100,000

Table 6.8. Payoff table involving choice of one of five decision alternatives, using the REGRETTIST criterion

REGRETTIST CRITERION

- 1) Form the regret table;
- 2) For each row in the regret table, find the largest regret number in the row and record that in a column to the right labeled ROW MAXIMUM;
- 3) Examine the column labeled ROW MAXIMUM to the right and pick the alternative with the smallest regret in that column.

In examining the regret table above, we should understand that \$60,000 in the column labeled WIN and the row labeled “Bid Project 1” is the amount of regret the regrettist will sustain if “Bid Project 1” is picked and the end result is to win the bid.

All of the criteria above are appropriate for situations in which the probabilities for the future states are unknown. The basic idea is to pick a criterion that best matches the decision maker’s attitude toward the risk and to use only that one criterion. For in-betweenists, there are two possible criteria that are appropriate.

Risk Management with Probability Information

In what follows, we next investigate how to include the probability information into the decision process. The probability information can be found by sifting through accounting records, or by deliberately recording the outcome from each and every instance of this collection of future states. The probabilities of winning and losing are .7 and .3, respectively⁵. Several criteria have been devised to include probability information. The name of this criterion is EXPECTED VALUE WITHOUT ADDITIONAL INFORMATION, or EV for short.

This criterion is again a two-step procedure. First, for each row, we calculate
 $.7 * (\text{payoff of winning}) + .3 * (\text{payoff of losing})$

⁵ This assumes that the probabilities of winning and losing are the same regardless of project choice, which may not be the case.

and record that in a column to the right labeled “EXPECTED VALUE.” Second, we examine this column and pick the alternative with the largest payoff. Clearly, the alternative that wins in this case is “Bid Project 2.”

PAYOFF TABLE	WIN	LOSE	EXPECTED VALUE
Probability DECISION ALTERNATIVES	.7	.3	
Bid Project 1	\$40,000	-\$2,000	\$27,400
Bid Project 2	\$100,000	-\$10,000	\$67,000
Bid Project 3	\$50,000	-\$8,000	\$32,600
Bid Project 4	\$60,000	-\$15,000	\$37,500
Do Nothing	0	0	0

Table 6.9. Payoff table involving choice of one of five decision alternatives, using the Expected Value criterion

Another alternative that frequently gets used in this regard is EXPECTED REGRET. As for the regret criterion, we form a regret table and then apply the probabilities to it, by calculating the average for each row using expected regret, which is

$$.7*(\text{expected regret of winning}) + .3*(\text{expected regret of losing})$$

and recording that in a column to the right labeled “expected regret.” We then examine this column and choose the alternative with the smallest expected regret. You will notice that this criterion picked the exact same alternative as did the expected value criterion, namely “Bid Project 2.” We should remark that it will always do this; that is, the expected regret criterion will always pick the same alternative as the expected value criterion.

REGRET TABLE	WIN	LOSE	EXPECTED REGRET
Probabilities DECISION ALTERNATIVES	.7	.3	
Bid Project 1	\$60,000	\$2,000	\$42,600
Bid Project 2	\$0	\$10,000	\$3,000
Bid Project 3	\$50,000	\$8,000	\$37,400
Bid Project 4	\$40,000	\$15,000	\$32,500
Do Nothing	\$100,000	0	\$70,000

Table 6.10. Payoff table involving choice of one of five decision alternatives, using the Expected Regret criterion

Another possible calculation is the expected payoff of perfect information, EPPI. We calculate this by averaging the largest payoff row using

$$.7*(\text{largest payoff of winning}) + .3*(\text{largest payoff of losing})$$

The result is the absolute best we could do if additional information were “out there somewhere” that we could purchase, that would be able to tell us with certainty which future state would happen. This number is \$70,000. The “value” of such information is the difference between the EPPI and the EV*. Here we use the * on the “EV” to denote it as the optimal EV, the maximal EV. We call the EPPI minus the EV* the EVPI or “Expected Value of Perfect Information”; that is, it is simply $EVPI = EPPI - EV^*$. The EVPI turns out in this case to be \$3,000. The EVPI is a very important number because it tells us the maximum we would be willing to pay for information that is absolutely perfect.

Now, notice the optimal Expected Regret, is the same number as the EVPI. This is yet another reason for calculating the Expected Regret. We could show that the optimal (viz., minimal) expected regret is always the EVPI. Notice something else. If we take the expected regret number and add to it the expected value for any alternative, the result is always the same and equal to the EPPI.

Risky Decisions Involving Additional Information

Frequently, it is possible for decision makers to avail themselves of additional information before making the final primary decision. Potentially, the additional information can help the decision maker choose the best alternative relative to the primary decision. In such situations the decision maker must decide first whether to put money into the purchase or acquisition of the additional information before making the primary decision. In the problem above, the primary decision was which project to bid on. But, the primary decision could be whether or not to launch a particular project, or which of a variety of projects to choose, whether to take on a project as project manager, which person to assign as project manager to a project, etc. In this section, we illustrate how to make sequential decisions in which the decision maker must first decide whether the additional information is worth the cost, and then what to do relative to the primary decision. The additional information is always less than perfect, and for that reason, is called sample information. While an EVPI calculation would certainly give us an upper bound on the worth of the imperfect information, we would like a tighter bound on the information's actual worth, that is more indicative of the maximum amount the decision maker should pay for the information. We shall call this the EVSI, or Expected Value of Sample Information. The EVSI is always less than the EVPI, because the EVPI assumes perfect information, whereas the EVSI assumes imperfect information. The information usually comes with conditional probabilities that show the "forecasting ability" of the information. This information can be had by recourse to a consultant, by taking surveys, by conducting tests of various and sundry types, all of which cost money.

The conditional probabilities that come with the information have to be used to revise the state probabilities regarding the likelihood of the various future states. Let's suppose that the additional information gives one of two predictive outcomes, SUCCESS or FAILURE. Then for each of these predictive outcomes, we must calculate revised future state probabilities and use these to determine our best choice, assuming the additional information we received was SUCCESS or was FAILURE. These revised state probabilities must be calculated using Bayesian revision. We illustrate how to do that with probability trees. Finally, we will use payoff tables to "map-out" the decision sequence and to determine the best decision strategy.

Consider the following scenario⁶. A project manager wishes to assess the level of risk associated with a project that is being contemplated. Based on the firm's experience with projects of this sort, there is a 20% chance of success resulting in a gain of three million dollars over five years. On the other hand, there is a 80% chance of failure resulting in a loss of one million dollars. In this latter case, one million gets spent on the project before it is discovered that the requirements are wrong and the project must be scrapped (terminated). For \$50,000, the firm can hire an outside consultant who will assess the likelihood for success. Based on past experience with projects of this type, the consultant predicted success when the project was successful 75% of the time. The consultant predicted failure for projects that were duds 87.5% of the time. To arrive at these conditional probabilities, the consultant is presented with a number of old projects in which the actual future states are known but not revealed to the consultant. The consultant is allowed to read material related to the project and then to make a "prediction." This prediction is then recorded in relation to whether the project was a success or failure. The project numbers, the actual states associated with these projects, are given in the table below.

⁶ In order to simplify the situation, we change the scenario here, so as to reduce the calculations required to a bare minimum.

Project Number	Actual State	Consultant's Prediction
1	Success	SUCCESS
2	Failure	FAILURE
3	Failure	FAILURE
4	Failure	SUCCESS
5	Failure	FAILURE
6	Failure	FAILURE
7	Success	SUCCESS
8	Failure	FAILURE
9	Failure	FAILURE
10	Failure	SUCCESS
11	Success	SUCCESS
12	Failure	FAILURE
13	Failure	FAILURE
14	Failure	FAILURE
15	Failure	FAILURE
16	Success	FAILURE
17	Failure	FAILURE
18	Failure	FAILURE
19	Failure	FAILURE
20	Failure	FAILURE

Table 6.11. Past cases in which a project has been undertaken together with the actual state and the consultant's prediction

From the above, it is apparent that out of 20 projects, 16 were failures and four were successes. The consultant correctly predicted success, given that the project was a success in actuality three out of four times (see projects 1, 7, 11, and 16). Thus, the conditional probability of a success prediction given a successful project is .75. The consultant correctly predicted failure, given that the project was a failure in actuality, 14 out of 16 times. Thus, the conditional probability of a failure prediction given a failed project was 14/16 or .875. It is also apparent that the conditional probability of a prediction of failure given a successful project was .25, while the conditional probability of a prediction of success given a failed project was 2/16 or .125. If we use the following acrostics, PS, PF, AS, AF for predicted success, predicted failure, actual success and actual failure, respectively, then $P(PS/AS) = .75$, $P(PF/AS) = .25$, $P(PS/AF) = .125$ and $P(PF/AF) = .875$.

Clearly, the decision maker must first decide whether to buy the additional information and then must decide upon the primary question of whether to do the project or not. The probabilities of success and failure associated with the primary decision are .2 for $P(AS)$ or $P(\text{actual success})$ and .8 for $P(AF)$ or $P(\text{actual failure})$, with outcomes of \$3,000,000 and -\$1,000,000. This information can be put into a table as follows.

PAYOFF TABLE	SUCCESS	FAILURE
Probabilities	.2	.8
Do project	\$3,000,000	-\$1,000,000
Don't do project	0	0

Table 6.12. Payoff table involving choice of one of two decision alternatives, together with associated state probabilities

As in the previous problem, we can calculate an expected value for doing the project by averaging out as follows: $.2*(3,000,000) + .8*(-1,000,000)$. This yields a value of -\$200,000. Furthermore, the expected value of doing nothing is $.2*(0) + .8*(0)$ or 0. Obviously, our choice would be to do nothing, since, on average, we can expect to lose \$200,000 every time we do projects of this type. As in the previous section, we can also calculate an EPPI (Expected Payoff of Perfect Information) and an EVPI (Expected Value of Perfect Information). Notice that our

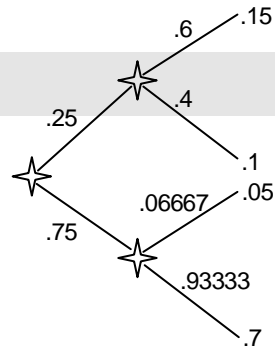
optimal alternative for this problem is “Don’t do project” and that this results in an EV* of 0. So for this problem, EVPI is simply going to be equal to EPPI, as the formula for the EVPI is $EVPI = EPPI - EV^*$. The EPPI for this problem is simply the product of the probabilities in each column times the highest payoff in that column, or $.2*(3,000,000) + .8*(0)$, summing the resulting products. The result is \$600,000. Thus, the EVPI is \$600,000 and this is the maximum we would be willing to pay for perfect information; naturally, we would be willing to pay even less for imperfect information. We can represent all of this in the following table.

PAYOFF TABLE	SUCCESS	FAILURE	EXPECTED VALUE
Probabilities:	.2	.8	
Do Project	\$3,000,000	-\$1,000,000	-\$200,000
Don't do project	0	0	0
Column Maxima	\$3,000,000	0	\$600,000 = EPPI

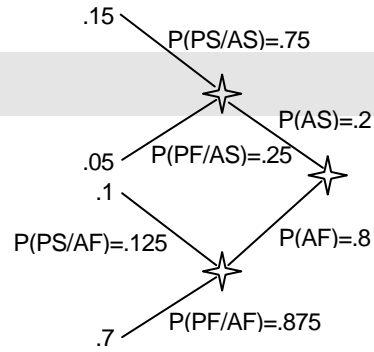
Table 6.13. Payoff table involving choice of one of two decision alternatives, using the expected value criterion

Now, let’s consider the additional information. Two outcomes are forthcoming from the consultant. Either she forecasts the project will be a SUCCESS or she forecasts the project will be a FAILURE. We don’t know what the probabilities of these two outcomes are. Neither do we know what the probabilities of an actual SUCCESS given a forecasted SUCCESS are. In fact, we would like to know the following “revised” probabilities: $P(AS/PS)$, $P(AF/PS)$, $P(AS/PF)$ and $P(AF/PF)$. Notice that these are very different from the conditional probabilities that were calculated based on the consultant’s reaction to twenty old cases. These are revised probabilities because they reflect what the state probabilities, conditioned upon the new information are, coming from the consultant. The original state probabilities were $P(AS)$ and $P(AF)$. Clearly, if the consultant predicts SUCCESS, then $P(AS/PS)$ and $P(AF/PS)$ would revise these actual state probabilities to some other values. At this point we know $P(PS/AS)$, $P(PS/AF)$, $P(PF/AS)$ and $P(PF/AF)$ to be .75, .125, .25 and .875, respectively. But to solve this decision problem we need $P(AS/PS)$, $P(AF/PS)$, $P(AS/PF)$ and $P(AF/PF)$.

The solution requires that we perform Bayesian revision. Bayesian revision is discussed in most text books on statistics and all texts in management science. In this section, we illustrate an easy to remember strategy for doing Bayesian revision, involving probability trees. We construct first a backward looking probability tree in which we emanate from a single node, the actual states of nature. From the resulting endpoints we further emanate the predicted outcomes, as shown below. The backward looking probability tree is like standing in the future and looking backward toward the present. First the actual states are encountered and then the predictive states. Notice how each edge is labeled with a name and its associated probability. We then calculate the probabilities of the very-most end nodes of this tree. These are the joint probabilities associated with a state/outcome pair. Thus the joint probability $P(PS \bullet AS) = P(PS/AS)*P(AS)$. Similarly, for the other joint probabilities; that is, $P(PF \bullet AS) = P(PF/AS)*P(AS)$, $P(PS \bullet AF) = P(PS/AF)*P(AF)$, and $P(PF \bullet AF) = P(PF/AF)*P(AF)$. These calculate out to be .15, .05, .1 and .7, respectively.



Forward Looking Tree



Backward Looking Tree

Figure 6.1. Probability Trees for Bayesian Revision

To solve the forward looking tree, we assume we are standing in the present and looking toward the future. In sequence, we expect to first receive the consultant's outcome (SUCCESS or FAILURE) and then we will be recipients of the actual state, either success or failure. From the root node, we emanate the two predictive outcomes SUCCESS and FAILURE, and from these we emanate the actual states, success and failure. We move the joint probabilities from the backward looking tree over to the forward looking tree and then we are able to calculate the probabilities of the two predictive outcomes, as follows. $P(PS) = P(PS \bullet AS) + P(PS \bullet AF) = .15 + .1 = .25$ and $P(PF) = P(PF \bullet AS) + P(PF \bullet AF) = .05 + .7 = .75$. We can now calculate the required conditional probabilities: $P(AS/PS) = P(AS \bullet PS)/P(PS) = .15/.25 = .6$. Similarly, $P(AF/PS) = P(AF \bullet PS)/P(PS) = .1/.25 = .4$. Given a prediction of FAILURE, PF, we can also calculate $P(AS/PF) = P(AS \bullet PF)/P(PF) = .05/.75 = .06667$. Similarly, $P(AF/PF) = P(AF \bullet PF)/P(PF) = .7/.75 = .93333$.

From the Bayesian revision, we learn that the probability of an actual success, given the consultant predicts success for the project, is .6 and that the probability that the project will be a failure, given that the consultant predicts success is .4. We can now apply these revised probabilities in our payoff table and calculate expected value for the two alternatives.

Payoff Table assuming consultant predicts success	SUCCESS	FAILURE	EXPECTED VALUE
Revised Probabilities	.6	.4	
Do Project	\$3,000,000	-\$1,000,000	\$1,400,000
Don't do project	0	0	0

Table 6.14. Payoff table involving choice of one of two decision alternatives, using the expected value criterion and revised probabilities based on the consultant's prediction of success

Clearly, in this case where the consultant predicted a success we would do the project. Similarly, we consider the case in which the consultant predicts failure. The probability of an actual success, given the consultant predicts failure for the project, is .06667, while the probability that the project is a failure, given the consultant predicts failure for the project, is .93333. We can now apply these revised probabilities in our payoff table and calculate expected value for the two alternatives.

Payoff Table assuming consultant predicts failure	SUCCESS	FAILURE	EXPECTED VALUE
Revised Probabilities	.06667	.93333	
Do Project	\$3,000,000	-\$1,000,000	-\$733,320
Don't do project	0	0	0

Table 6.15. Payoff table involving choice of one of two decision alternatives, using the expected value criterion and revised probabilities based on the consultant's prediction of failure

Evidently, our choice in this case would be to **not do** the project. We now have a simple strategy: *do the project* when the consultant says SUCCESS and *don't do the project* when the consultant says FAILURE. Since, the probabilities of predicting SUCCESS and FAILURE are .25 and .75, respectively, we can calculate the expected value of this strategy. It is $.25 * (\$1,400,000) + .75 * (0)$ which is \$350,000. We can now address the question of how much this imperfect information is worth in actuality. The Expected Payoff of Sample Information, EPSI, in this case is clearly \$350,000. Recall that the expected value, EV^* , without the sample information was 0. The $EVSI = EPSI - EV^*$, which is $\$350,000 - 0$ or \$350,000. Thus, this information has a value to the decision maker of \$350,000, which is less than the calculated value of perfect information. Perfect information, or the EVPI, was worth \$600,000. In any case the decision maker should consider this information a good deal at \$50,000, should go ahead and buy it and then do what the consultant says. If the consultant predicts SUCCESS, do the project; otherwise, not. The net expected return would be $\$350,000 - \$50,000$ or \$300,000, for projects of this type.

After-Tax, Net Present Value Analyses of Proposed Cost

Present value analysis is a technique for mapping all costs associated with project cash outflows for labor costs or procurement to a specific point in time—namely, the present. This permits different payment schedules for different (or the same) systems to be compared. For example, one proposed project may cost \$200,000 initially and \$30,000 per month for the next five years. Another comparable project may cost nothing down and \$50,000 per month for the next five years. This latter project may also be financed outright for \$4,150,000. Which of these project finance strategies is the least expensive?

To answer such questions, it is necessary to give consideration to the after-tax aspects of the cash flows as well as its present-value aspects. The tax effects of a project are such as to lessen the actual cost of the project because of tax savings that will accrue. For example, a project, out-sourced outright for \$200,000 and used in conjunction with one's business, can be depreciated over roughly five years. (Since there are frequent changes in IRS depreciation rules, the assumed depreciation period may change.) In what follows we shall consider the combined effects of present-value and after-tax analysis to determine the real cost of a project.

Net present value analyses require an estimate as to the cost of capital. The cost of capital is essentially the interest rate at which money could be borrowed by a firm. Essentially, two formulas are used. One is the present-value-of-an-annuity (PVA) formula given as follows:

$$PVA = A(1 - (1+R)^{-N})/R$$

where A is the annuity amount, R is the interest rate or cost of capital, and N is the number of pay periods. For example, suppose that you must choose between paying \$1,000 monthly for 60 months for a five-year maintenance agreement or paying an outright amount of \$50,000. On the surface it may seem best to pay the \$50,000 since that is less than $\$1,000 \times 60$ or \$60,000. Assume your cost of capital is 12% a year or 1% a month. However, to render a fair comparison, it is necessary to map all 59 future payments in the amount of \$1,000 back to the present. To do this we use the annuity formula above, in which $A=1,000$, $N=60$, and $R=.01$. Making payments in the amount of \$1,000 each month is analogous to paying an annuity in the same amount each

month. The value of this formula in our case is the following.

$$PVA = \$1,000(1 - (1+0.12)^{-60})/0.12 = \$44,955.04$$

Thus the present value of a \$1,000 a month payment for 60 months is \$44,955 to the nearest dollar. Hence, it would still be better to pay the \$1,000 a month than to pay the \$50,000 outright, assuming a 12% cost of capital.

The other formula is the simple present worth formula given by the following.

$$PV = FW(1+R)^{-N}$$

Here PV is the present value, FW is the future worth, R is the interest rate or cost of capital, and N is the number of periods. Suppose that three years from now you expect to save \$30,000 in taxes from the purchase of computer hardware in the present. What is the present worth of the future tax savings, assuming the cost of capital is 12% a year? We can find out by using the present worth formula with FW=30,000, R=.12 and N=3. The result is the following.

$$PV = \$30,000(1+.12)^{-3} = \$21,353.41$$

Thus the present worth of the \$30,000 in future tax savings is \$21,353 to the nearest dollar. These formulas will enable us to do all relevant calculations in the present value analysis.

Table 6.16 shows the present-value after-tax affects of a project in which the application developed by it is bought outright for \$11,000 with an assumed cost of capital of 8%. According to existing IRS rules (which will be changed by the time this is printed), the software can be depreciated over a period of five years using the MACRS ("Modified Accelerated Cost Recovery System) method of depreciation. This method calls for 15% depreciation in the first year, 22% in the second year, and 21% in the third, fourth, and fifth years. The purchaser is assumed to be in a 27% tax bracket and has decided to purchase the maintenance agreement at \$100 a month. It should be apparent that the annuity formula was applied to determine the present value of the variable costs—the maintenance contract costing \$100 a month. The present worth formula was applied to map the future worth of all tax savings back to the present.

For example, the present value of the \$948 future tax savings in year four is computed as follows.

$$PV = \$948(1+.08)^{-4} = \$697$$

The tax saving column is computed by summing the depreciation and maintenance columns and multiplying this amount by .27 (27% tax bracket).

Suppose the application described above could be leased for \$400 per month with a lease period of three years. At the end of the 36 month lease, the application can be purchased from the lessor for 20% of its original cost. Would it be more advantageous (from a present-value, after-tax point of view) to lease the system or to purchase it outright, assuming a 8% cost of capital and a 27% tax rate? Table 6.17 presents the five-year calculations for this method of financing. The calculations assume the equipment can be depreciated over five years using the ACRS method, just as for new equipment.

Assume the following:					
Cost of capital	8%				
Tax rate	27%				
Product life	5 years				
Depreciation	MACRS (15%,22%,21%,21%,21%)				
Total Outflow					
		<u>Net Present Value</u>			
Fixed costs \$11,000				\$11,000	
Variable costs \$100/month				\$4,932	
					Total flow out
				\$15,932	
Tax Effects					
<u>Year</u>	<u>Depreciation</u>	<u>Maintenance</u>	<u>Tax Saving</u>	<u>PV/NPV</u>	
1	\$1,650	\$1,200	\$770	\$713	
2	\$2,420	\$1,200	\$977	\$838	
3	\$2,310	\$1,200	\$948	\$753	
4	\$2,310	\$1,200	\$948	\$697	
5	\$2,310	\$1,200	\$948	\$645	
		Total tax savings	\$4,591	\$3,646	
Net present value, after-tax cost: \$15,932 - \$3,646 = \$12,286					
Note: All calculations have been rounded to the nearest dollar.					

Table 6.16. Present-value, After-tax Analysis of Small Project

Assume the following:					
Cost of capital	8%				
Tax rate	27%				
Equipment life	5 years				
Depreciation	MACRS (15%,22%,21%,21%,21%)				
Total Outflow					
		<u>Net Present Value</u>			
Fixed costs .2*\$11,000=\$2,200				\$1,746	
Variable costs \$400/month for 36 months				\$12,765	
Variable costs \$100/month				\$4,932	
					Total flow out
				\$19,443	
Tax Effects					
<u>Year</u>	<u>Depreciation</u>	<u>Lease</u>	<u>Maintenance</u>	<u>Tax Saving</u>	<u>PV/NPV</u>
1		\$4,800	\$1,200	\$1,620	\$1,500
2		\$4,800	\$1,200	\$1,620	\$1,389
3		\$4,800	\$1,200	\$1,620	\$1,286
4	\$330		\$1,200	\$413	\$304
5	\$484		\$1,200	\$455	\$310
			Total tax savings	\$5,728	\$4,789
Net present value, after-tax cost: \$19,443 - \$4,789 = \$14,654					
Note: All calculations have been rounded to the nearest dollar.					

Table 6.17. Present-value, After-tax Analysis of Lease-Purchase Project Proposal

Summary and Conclusion

In this chapter, we have endeavored to provide some tools for feasibility and risk analysis relative to the do-ability of the project in anticipation of the actual GO/NO GO decision. These tools should be applied within the first or second stages of the project management lifecycle.

We described the basics of decision theory as a tool for analysis of risky decision projects. We suggested that this type of analysis could be used to facilitate decisions involving risk, such as which among a number of project to bid on, which among a number of projects to actually put into execution, which person to put in charge of a project, which contractor to choose, etc. We endeavored to illustrate how additional information can be brought to bear upon a risky decision and we showed how to calculate a worth of value of such information. This is at the heart of information technology because what information systems professionals do is make additional information available to decision makers within the firm. This kind of analysis can put a dollar value on such information, which can be compared to its cost. Clearly, the economics of information management play a key role in the definition and conceptualization of projects, as ultimately such economics will determine whether the project is allowed to proceed and whether it will ultimately be completed.

In this chapter we developed strategies for comparing projects on the basis of their net present value cash flows. Starting with the negative cash flows associated with the expenditure of funds and proceeding into the cash flows that are anticipated as a result of the expenditure, net present value maps these back to the present so that a valid comparison of cost/revenue effects can be had.

Exercises

1. Define what is meant by:

- Capital budgeting
- EV
- EPPI
- EPSI
- EVPI
- EVSI
- Expected regret
- Linear programming
- PESSIMIST
- OPTIMIST
- Optimization
- REGRETTIST
- IN-BETWEENIST
- INSUFFICIENT REASON
- Multi-attribute tree
- Probability tree
- Payoff table
- Regret table

2. What circumstances would lead a firm experienced in transitioning its customers into client/server architectures move into Internet development instead, which they have no latent experience at?

3. What two major questions must we ask the user to qualify a project? What two major questions must we ask the project team to qualify a project?

4. A particular computer system costs \$12,000 for the hardware and the software is \$4,000. The maintenance contract runs \$100 per month. The purchaser plans to keep the system for five years. Assume the purchaser is in a 40% income tax bracket and the discount rate is 8% per year. No tax credit is allowed on the software, but it is depreciated in the same fashion as the hardware. What is the after-tax present value cost of the equipment? (Use the MACRS method with the following percentages: 15%, 22%, 21%, 21%, 21%)

5. The same purchaser mentioned in problem 4 above could avail himself of a service bureau. The purchaser's output and data-entry requirements are the following.

The data entry requirements are:

Payroll	50,000	characters/month
General ledger	200,000	characters/month
Inventory	200,000	characters/month
Invoicing/order entry	250,000	characters/month

Assume the data entry clerk can type 100 characters/minute when doing data entry.

The output requirements are:

Payroll	3,000	lines/month
General ledger	10,000	lines/month
Inventory	10,000	lines/month
Invoicing/order entry	10,000	lines/month

Assume the printer operates at 100 lines/minute. The average CPU usage/month is estimated at .5 hour. The service bureau's charges are the following:

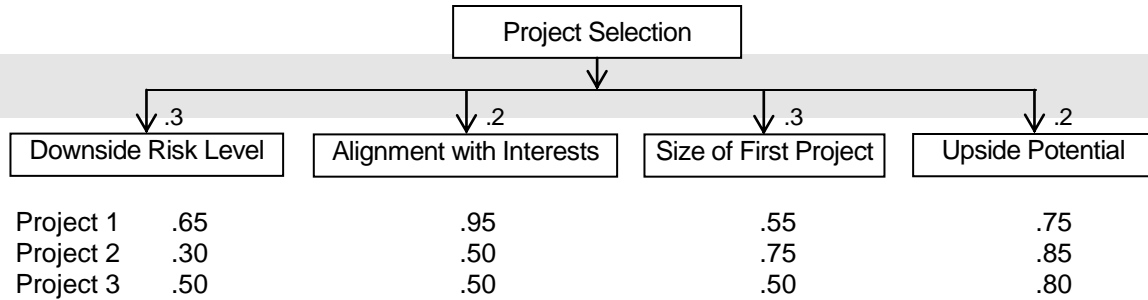
Initial outlay of \$3,000 for printer and terminal
Usage charges per CPU hour run \$300 and connect charges run \$7 for each hour logged on.
The maintenance contract on the hardware runs \$40/month.
The monthly phone bill for this use is \$50/month.

Determine the total monthly variable costs. Calculate the present-value, after-tax cost of the service bureau for a 5 year usage period.

6. Assume in problem 4 above that the \$16,000 system can be leased for \$550/month which includes the maintenance contract. The lease is for a period of 3 years. At the end of the time the system can be purchased for 10% of its initial cost. Calculate the after-tax, present-value cost of this strategy.

7. Assume in problem 4 above that the purchaser has decided to borrow the money to purchase the system outright. Only 80% of the original cost can be loaned. The annual rate of interest on this loan is 16%. The loan is for a period of 5 years (60 months). What is the monthly P&I? Calculate the after-tax, present-value cost of this strategy.

8. Suppose that Sharon, in the [brief](#) case discussed at the end of Chapter 5, has come up with the following attribute tree. Note the weights Sharon has attached to each of her dimensions. She has total control over choice of dimensions and the weights attached to them.



Notice that Sharon has given Project 2 a .3 for downside risk level because the project absolutely has to be completed in three months and because no one really knows how large and time-consuming this project really is. She has given Project 1 the highest grade because she really enjoys WEB-based development. Determine which of the three projects Sharon should select, based on this analysis. Does this approach match with the selection you made earlier for Sharon? What is your assessment of this approach?

9. An undergraduate MIS major has three job offers to consider. The attributes for evaluation taken in relation to the weights are:

ATTRIBUTES	WEIGHT	OFFER 1	OFFER 2	OFFER 3
Location	.1	85	75	50
Opportunity to advance	.2	90	95	60
Alignment with personal goals	.2	75	80	85
Training	.1	85	95	85
Chemistry match with "boss"	.1	80	75	65
Salary	.2	80	90	95
Fringe benefits	.1	90	80	70

Draw the multi-attribute tree. What is the overall grade of each offer? Which offer should be selected, based on the overall grade?

10. A system integration contractor is considering bidding on one of four different project opportunities that it is aware of. The following payoffs are known.

PAYOFF TABLE	WIN	LOSE
Probabilities	.3	.7
Bid Project 1	\$700,000	-\$100,000
Bid Project 2	\$900,000	-\$130,000
Bid Project 3	\$200,000	-\$50,000
Bid Project 4	\$2,000,000	-\$1,500,000

From the above determine what alternative would be chosen if the decision maker is a 1) PESSIMIST, 2) OPTIMIST, 3) IN-BETWEENIST with $\alpha = .5$, 4) a REGRETTIST, or a user of the PRINCIPLE OF INSUFFICIENT REASON. Determine which alternative would be chosen using EXPECTED VALUE. Determine what the EPPI is, the EVPI. What is the maximum the decision maker would be willing to pay for additional information regarding this decision?

11. Consider three projects, all with different possible outcomes, and associated probabilities. For Project 1, three outcomes are possible:

- a) full functionality completed on time, within budget
- b) 80% functionality completed within schedule but over budget

- c) 80% functionality completed over budget and behind schedule

The probabilities and payoffs associated with these outcomes are:

OUTCOME	PROBABILITY	PAYOFF
a)	.30	100
b)	.50	50
c)	.20	-30

The second and third projects have similar outcome spaces. Project 2 has an outcome space that can be characterized as follows:

- a) full functionality completed on time, within budget
- b) exceeded functionality, delayed and over budget
- c) partial functionality, delayed and behind schedule

The probabilities and payoffs associated with these outcomes are:

OUTCOME	PROBABILITY	PAYOFF
a)	.25	100
b)	.45	0
c)	.30	100

Project 3 also has three outcome states as follows:

- a) full functionality completed on time, within budget
- b) partial functionality completed on schedule and within budget
- c) full functionality completed over budget and behind schedule

The probabilities and payoffs associated with these outcomes are:

OUTCOME	PROBABILITY	PAYOFF
a)	.35	100
b)	.30	50
c)	.35	-200

Which project should be chosen based on the considerations of risk and return?

12. A project manager wishes to assess the level of risk associated with a project that is being contemplated. Based on the firm's experience with projects of this sort, there is a 30% chance of success resulting in a 5-year gain of two million dollars. On the other hand there is a 70% chance of failure resulting in a loss of one million dollars. In this latter case, one million gets spent on the project before it is discovered that the requirements are wrong and the project must be scrapped (terminated). What is the expected return for this project? Should the project be undertaken? What is the EVPI?

For \$50,000, the firm can hire an outside consultant who will assess the likelihood for success. Based on past experience with projects of this type, the consultant predicted success when the project was successful 80% of the time. The consultant predicted failure for projects that were duds 90% of the time. Should the consultant be hired? Under what circumstances should the project be undertaken? What is the EVSI?

13. A project manager wishes to assess the level of risk associated with a project that is being contemplated. Based on the firm's experience with projects of this sort, there is a 20% chance of success resulting in a 5-year gain of five million dollars. On the other hand there is a 80% chance

of failure resulting in a loss of two million dollars. In this latter case, two million gets spent on the project before it is discovered that the requirements are wrong and the project must be scrapped (terminated). What is the expected return for this project? Should the project be undertaken? What is the EVPI?

For \$100,000, the firm can hire an outside consultant who will assess the likelihood for success. Based on past experience with projects of this type, the consultant predicted success when the project was successful 80% of the time. The consultant predicted failure for projects that were duds 90% of the time. Should the consultant be hired? Under what circumstances should the project be undertaken? What is the EVSI?

14. In the problems above, how might the payoffs be determined in the real world?

15. A project is being undertaken whose goal is to develop a new software system in a year. Once installed, the system has a five-year life with a monthly net benefit to the firm of \$100,000. Determine, based on the following, the net present value of all outflows. Determine the net present value of all inflows over the six-year period. Should the project be undertaken, considering inflows and outflows only?

MONTH	INFLOW	OUTFLOW
January		-\$100,000
February		-\$200,000
March		-\$200,000
April		-\$200,000
May		-\$300,000
June		-\$300,000
July		-\$200,000
August		-\$200,000
September		-\$100,000
October		-\$100,000
November		-\$100,000
December		-\$100,000
January (next year)	\$100,000	
February (next year)	\$100,000	
...	...	
December (next year)	\$100,000	
(This continues for four more years.)		

How many years does it take to reach a break-even point? What is the ROI after six years?

16. An automated inspection technology firm (a startup) is looking to create a world-wide-web presence on the Internet. The firm is anxious to get this facility going as soon as possible. The firm will need hardware, software as well as application software to support an active server pages technology. An RFP has been transmitted and proposals have been received. Each proposal must be graded on a scale of 0 to 100 where 100 is perfection and 0 is no contribution. The major attributes are **Software, Hardware, Upgrading Potential, Time Considerations, and Vendor**. The relative weights for each of these are .3, .2, .2, .1, and .2 respectively. The software component is further decomposed into **Systems Software** and **Applications Software**, each with relative weights of .5. The Time Considerations component is further decomposed into an **Equipment Delivery Date** and an **Application on-line-by-date**, each with relative weights of .5

Draw the multi-attribute utility tree. Determine the absolute weights of all the lowest-level elements on the tree. Determine the grade of each of the two proposals below. Assume the first

costs \$250,000, the second \$350,000. What is the benefit/cost of each proposal? Which would you choose?

ATTRIBUTES	GRADES		
	WEIGHT	PROPOSAL 1	PROPOSAL 2
Software			
Systems Software		78	78
Applications Software		85	90
Hardware		88	90
Upgrading Potential		90	90
Time Considerations			
Equipment Delivery Date		75	90
Application on-line-by-date		88	90
Vendor		67	80

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Appendix A: Taxonomy of Software Development Risks

- A. Product Engineering** (Class)
1. Requirements (Element)
 - a. Stability (Attribute)
 - b. Completeness
 - c. Clarity
 - d. Validity
 - e. Feasibility
 - f. Precedent
 - g. Scale
 2. Design
 - a. Functionality
 - b. Difficulty
 - c. Interfaces
 - d. Performance
 - e. Testability
 - f. Hardware Constraints
 - g. Non-Developmental Software
 3. Code and Unit Test
 - a. Feasibility
 - b. Testing
 - c. Coding/Implementation
 4. Integration and Test
 - a. Environment
 - b. Product
 - c. System
 5. Engineering Specialties
 - a. Maintainability
 - b. Reliability
 - c. Safety
 - d. Security
 - e. Human Factors
 - f. Specifications

B. Development Environment

1. Development Process
 - a. Formality
 - b. Suitability
 - c. Process Control
 - d. Familiarity
 - e. Product Control
2. Development System
 - a. Capacity
 - b. Suitability
 - c. Usability
 - d. Familiarity
 - e. Reliability
 - f. System Support
 - g. Deliverability
3. Management Process
 - a. Planning
 - b. Project Organization

- c. Management Experience
- d. Program Interfaces
- 4. Management Methods
 - a. Monitoring
 - b. Personnel Management
 - c. Quality Assurance
 - d. Configuration Management
- 5. Work Environment
 - a. Quality Attitude
 - b. Cooperation
 - c. Communication
 - d. Morale

C. Program Constraints

- 1. Resources
 - a. Schedule
 - b. Staff
 - c. Budget
 - d. Facilities
- 2. Contract
 - a. Type of Contract
 - b. Restrictions
 - c. Dependencies
- 3. Program Interfaces
 - a. Customer
 - b. Associate Contractors
 - c. Subcontractors
 - d. Prime Contractor
 - e. Corporate Management
 - f. Vendors
 - g. Politics

Chapter 6: Brief Cases

Suppose your boss comes to you and says “George, I have the chance of a lifetime for you to finally begin your career in project management. We have this project that has just been signed by our salespeople involving work for Douglas Aircraft. It is a good sized one too, \$500,000 and you will be through with it by January 1, xxxx. The project is right up your alley—supply-chain optimization for their parts division.”

“Hmmmmm. That sounds interesting,” you respond. “Why \$500,000,” you ask?

“Because that was the sales force bid which won the contract,” was the response.

“And you say it has to be done by January 1?” “Why??”

“Because that was when the customer requires it to be complete,” was the response.

Would you bet your career on this once in a lifetime opportunity?

TUTORIAL: Introduction to System Dynamics and Vensim—a Tool for Characterizing Project Dynamics

Perhaps no tool in the history of humankind has had so great an impact on the understanding of complex processes and problems. In this section we provide a brief tutorial on how to build system dynamics models. Such models can be a substantial problem-solving aid in coping with the problems of project management. We shall be concentrating on a specific software package called Vensim. While several packages could potentially be chosen for use here, our focus is on Vensim because there is a robust version of it that is free for students to use as a learning tool. More than that, Vensim does what it does as well or better than its competition. For higher education, it has to be the tool of choice.

Vensim Tutorial

Vensim is one of several commercially available programs that facilitate the development of continuous simulation models known as system dynamics models. Compared with competing programs, Vensim is extraordinarily powerful yet inexpensive. Its developer, Bob Eberlein, vends the tool as shareware. This gives students an opportunity to learn the tool and evaluate it before actually buying it.

The Personal Learning Edition (PLE) of Vensim can be downloaded for free from the www.vensim.com web site. Once downloaded, Vensim must be installed. It comes with a substantial array of prefabricated models that can be readily used or re-used.

When creating a new model the user will click on **File** on the main menu and then **New**. The following dialog box pops up.

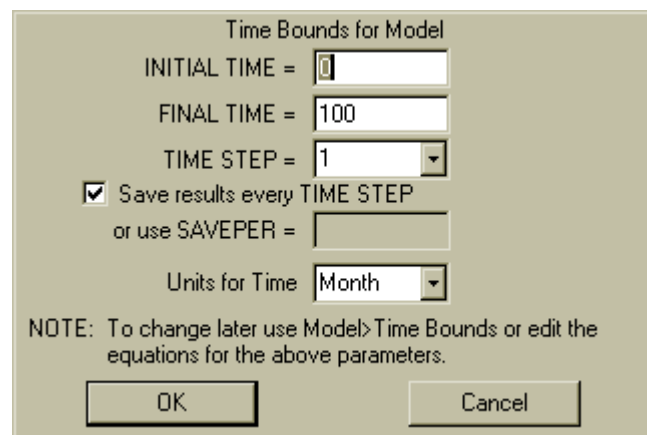


Figure 6A.1. Vensim Time Bounds Box in Upper Right Corner

This is called the time bounds box. In this box, you specify the starting time, the ending time, the time step and the units on time. The time step should create at least 500 steps between the starting time and the ending time. For example, if the starting time is 2010 and the stopping

time is 2060, then you should use a time step that is no larger than .1 year. Units on time can be smaller than a second and larger than a year.

Once you click OK, you exit the time bounds box and are shown the main screen. You can always return to the time bounds box by clicking on Model and then Time bounds.

The main screen presents a drawing canvas and an additional tool palette. You can use this canvas and palette for drawing causal loop diagrams and stock and flow diagrams. However, only stock and flow diagrams can be translated into running simulations.

Vensim adds a fourth row of iconic tools below the tool bar. These icons are used to delineate the diagrams. For causal loop diagrams, only the variable tool and the connector tool are used.

Try creating the following causal loop diagram:

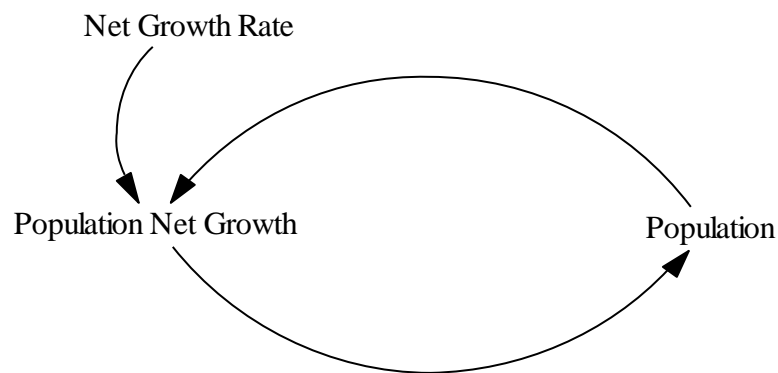


Figure 6A.2. Casual Model for Population

Use the tool just to the right of the arrow on the bottom row of iconic tools to create the variable names net growth rate normal, population net growth rate, and population. You can tell which tool is the variable tool by resting the cursor on the icon. This will cause a prompt to popup. For the variable tool, the popup reads “Variable–Auxiliary/Constant.”

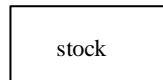
Next, add the connections or edges. Use the fourth tool from the left on the bottom row of icons; the one labeled “Arrow” when the cursor is rested on it. To attach an edge from one variable to another you must first select the Arrow tool. Then click on a variable and then click again at the approximate point where you want the edge to curve. Finally, click on the destination or target variable. You can also click on the origination variable and then directly on the destination variable, but this will produce a straight line connection which is somewhat less aesthetic than the curved connector or edge.

From Causal Loop Diagram to Stock and Flow Diagram

The transition from causal loop diagram to stock and flow diagram has to be performed manually by the user. So far, no such software exists to perform this function for model builders. To accomplish the transition, every variable and edge in the causal loop diagram must be identified as to type. There are three variable types and two edge-types in Vensim. The variable types are Auxiliary/Constant, stock (also called box or level or state), and the rate variable. The edge types are information (which is represented as a connector edge of the type used in the causal loop diagram) and flow. The variable types are exhibited below.

auxiliary

Auxiliary/constant/input/output



stock

stock (state, box, level)

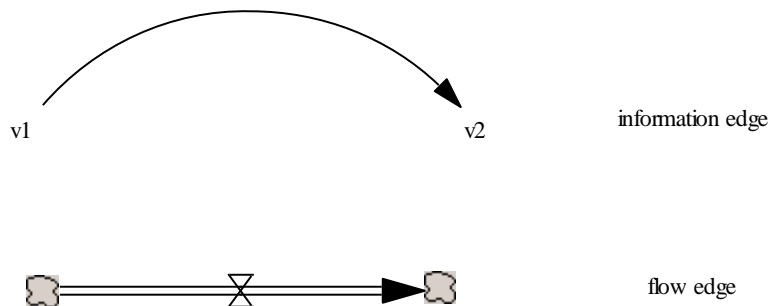


rate

rate variable

The variable delineations above don't tell us anything about the character of the variables themselves. For example, a stock variable represents a point where content can accumulate and deplete, like the holding tank on the back of a toilet or a sink, a bath tub, a gas tank and so forth.

The edge types are exhibited below.



To translate a causal loop diagram to a stock and flow diagram, you must simply identify all of the variables and edges. However, frequently when we do this we discover that things (variables, edges) are missing and that we must add variables/edges to create a relevant stock and flow diagram.

The reason this is the case is because causal loop diagrams are created for a variety of different reasons, not just to be translated into stock and flow diagrams. Often causal loop diagrams are created to efficiently delineate causal relationships without regard to what structure is necessary to expedite transitions to stock and flow diagrams. When this happens rate variables are left out, frequently.

So you must accomplish the transition from causal loop diagrams to stock and flow diagrams manually. Once you've done that you can delineate the stock and flow diagram onto the Vensim canvas. Let's see how this works for the simple population growth model we were discussing earlier. Before we can do that we need a few rules. For example, in any causal loop diagram involving a pair of variables in a loop (technically, a cycle), one of those variables must be a rate and one must be a stock. The loop is created by a pair of edges. One of those edges must be an information edge and the other is a flow edge.

The question is, which is which.

An Example: Population Dynamics

As an example of the synthesis procedure, consider a simple model of a population system, such as an ant hill or bee hive. For simplicity we assume an infinite food supply and a limitless environment conducive to population growth. Thus the growth of population is unhindered and the model need embrace only the population itself.

The quantities to be subsumed by the boundary B are listed in Table 6A.1 together with the units associated with each quantity.

<u>Quantity</u>	<u>Name</u>	<u>Units</u>
P	Population	capita
BR	Birth rate	births/time unit
DR	Death rate	deaths/time unit
BRN	Birth rate normal	births/(capita-time unit)
DRN	Death rate normal	deaths/(capita-time unit)

Table 6A.1. A List of Quantities in the Population Model

This list is sufficient to accomplish steps 1 and 2 of the methodology.

Next, the couplings between the various quantities are specified. The details necessary to accomplish this step will be taken up later. Once the couplings between the quantities are determined, a graph showing the interconnections between the quantities can be drawn. We call this graph a causal diagram. The casual diagram for the simple population model is shown below in Figure 6A.3.

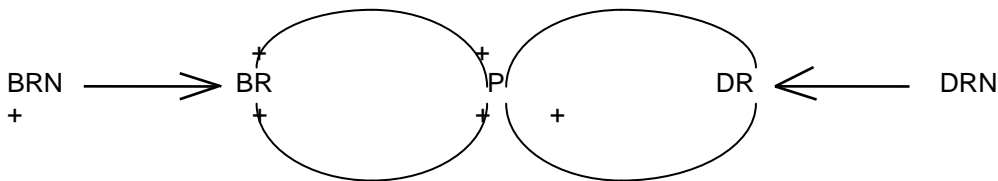
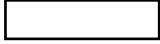




Figure 6A.3. Causal Diagram for a Simple Population Model

An arrow directed from one quantity to another is referred to as a coupling. If the sign associated with the coupling is positive, then the quantity from which the coupling is directed is said to have a positive affect on the quantity toward which the coupling is directed. The reader should convince himself that Figure 6A.3 is correct from an intuitive stand-point.

From the casual diagram model the analyst proceeds to develop the schematic or flow diagram model, involving steps 5 and 6 of the methodology. In order to do this, it is necessary that the analyst have well in mind the distinguishing characteristics of each of the quantity and coupling types.

As previously mentioned, states are represented by rectangles , rates by "valves"



auxiliaries by circles , and parameters by small circles .

There are two types of couplings—flow couplings and information couplings. Flow couplings are represented by solid lines and information couplings by dashed lines. Once all quantities and couplings are classified, the resultant schematic model can be delineated as shown in Figure 6A.4.

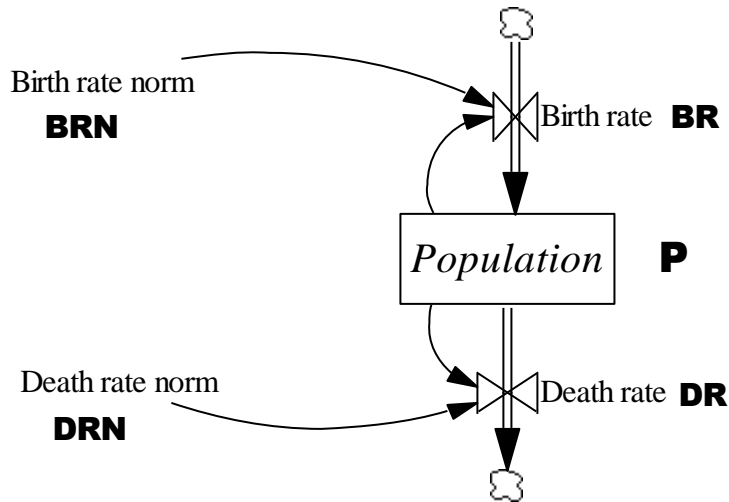


Figure 6A.4. Schematic (Flow) Diagram of a Simple Population Model

From the schematic diagram, the analyst is able to write equations for each of the variables and parameters of the model. The parameter values are established from observations and measurements made on the system directly. For example, assume that 4 births per 100 capita per time unit were observed, as were 2.8 deaths per 100 capita per time unit. Then

$$\begin{aligned} \text{BRN} &= .04 & \text{and} \\ \text{DRN} &= .028 \end{aligned}$$

The other three equations are provided here without justification.

$$P(t+\Delta t) = P(t) + \Delta t*(\text{BR}-\text{DR}) \quad (6A.1)$$

$$P(0) = 1.65\text{E}9$$

$$\text{BR} = P*\text{BRN} \quad (6A.2)$$

$$\text{DR} = P*\text{DRN}$$

Using these equations the analyst is ready to code a simulation computer program or use packaged software that will accomplish the task. An appropriate program is shown in Figure 6A.3 where a time-step of .2 time units is used, a time-domain of 50 time units is specified and an initial population of 1000 capita is assumed. The variables are printed every simulated time unit.

```

BRN = .05
DRN = .03
P = 1000
T = 0
DT = .2
FOR I = 1,1251
BR = P*BRN
DR = P*DRN
PRINT T,P,BR,DR
P = P + DT*(BR - DR)

```

```

T = T+DT
NEXT
STOP
END

```

Figure 6A.5. A BASIC Simulation Computer Program for the Simple Population Problem

However, we can avail ourselves of a different tack, namely use Vensim. To do so, we click on the equation tool on the toolbar—the right-most icon on the lower-most toolbar with the symbol $Y=x^2$ on it.

Vensim will highlight all variables that require equation-related information to be specified. When you click on any of these variables, Vensim brings up its equation editor dialog box. It will then require you to enter information into white, boxed areas of this dialog box. Once you've done what it needs it will allow you to close the box and proceed to another variable. Once all of the equations are specified, you can press the runner icon or go to the menu bar and click on Model and then Simulate under that. Vensim will run the simulation. It is now possible for you to specify a figure like that in Figure 6A.4 that enables you to view the results.

The results are plotted in Figure 6A.6 where it is observed that population, birth rate, and death rate all exhibit exponential growth.

Births/Deaths taken in relation to Pop

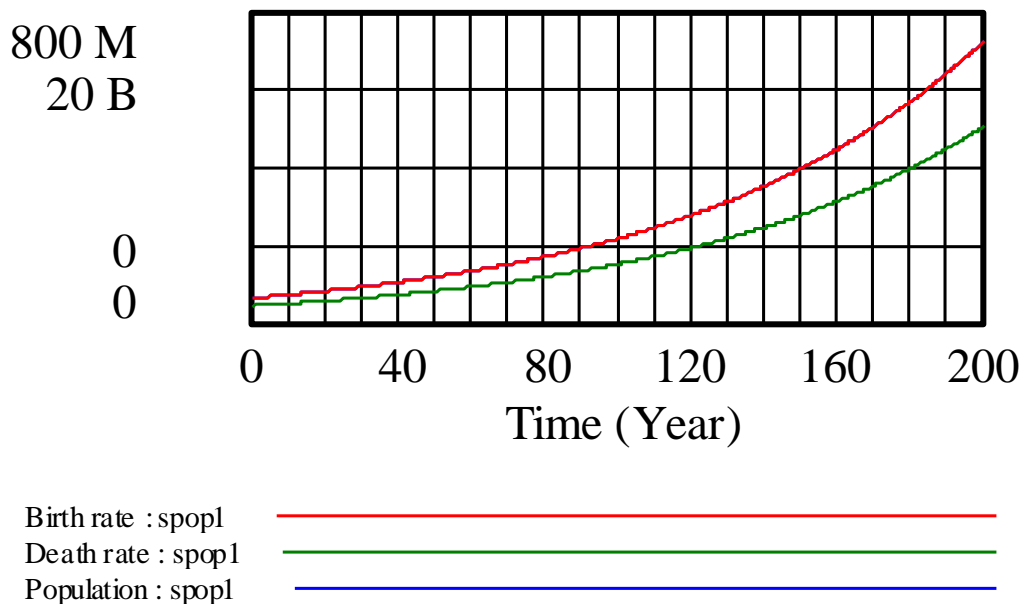


Figure 6A.6. Behavior Exhibited by the Exponentially Growing Population Model

A One-Sector Inventory Model

Consider the following situation. Sonya Magnova is a television retailer who wishes to maintain a desired inventory equal to DI television sets so that she doesn't have too sell her demonstrator and show models. She is currently experiencing moderately constant demand of D units per month. Sonya's ordering policy is quite simple – adjust actual inventory toward desired inventory so as to force these to conform as closely as possible.

Currently, the inventory is low – I_0 units are left. The time required for inventory t be received once it is ordered at AT , the adjustment time. Sonya's order rate in terms of units per month can be approximated by the equation $OR = (DI - I) \cdot AT$.

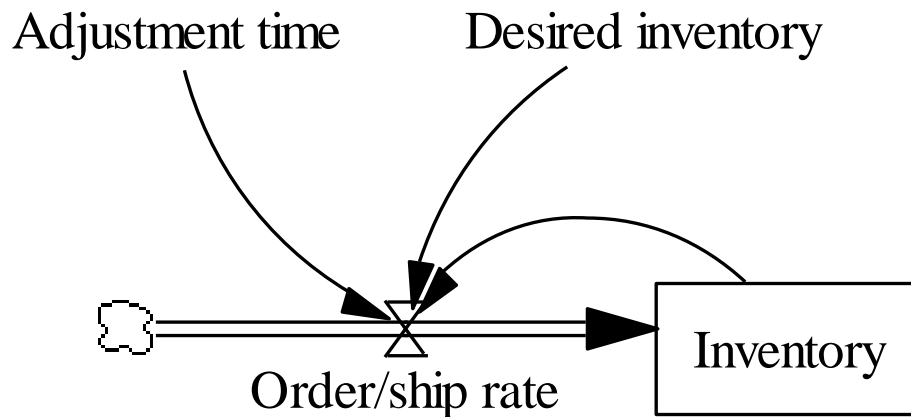


Figure 6A.7. Flow Diagram for a Simple Inventory Adjustment Problem

Sonya's order rate equation contains four essential components:

1. A desired condition, DI
2. An actual condition, I
3. A measure of the discrepancy, $(DI - I)$
4. A way to express action based on the discrepancy, $\frac{1}{AT}(DI - I)$

Most rate equations that express deliberate managerial control of a certain flow contain these four basic components [7]. It should be apparent that the only flow in this case is television sets. This flow is accumulated into and depleted from a state or level called inventory.

The flow diagram for this model appears in Figure 6A.7. The structure appears similar to the population model examined earlier. The behaviors, however, are quite different, due to the differences in the information infrastructures in the two models. These differences cause the actual equations used for the two rates to be quite different. For the inventory model, these are

$$OR = \frac{1}{AT}(DI - I) \quad (6A.3)$$

and $I(t + \Delta t) = I(t) + \Delta t \cdot OR \quad (6A.4)$

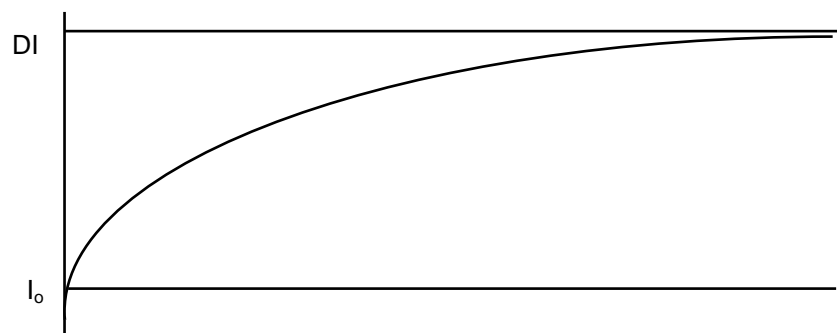


Figure 6A.8. Plotted Behavior of the Simple, One-Sector Inventory Model

By comparing equations (6A.3) and (6A.4) with equations (6A.1) to (6A.2), it becomes increasingly apparent how these two models differ from each other.

The inventory model produces a behavior like that shown in Figure 6A.6. This behavior is called *exponential goal seeking*. Clearly, an actual condition or state is being driven toward some goal or desired condition. The discrepancy between the desired and actual condition decreases, but never quite get to zero, assuming (as in this problem) that the desired condition remains constant. If the desired condition varies, then the actual condition will attempt to follow the desired condition.

Towards a Model of Project Dynamics

Projects begin with a huge block of uncompleted work. Eventually, all of this work gets completed. The rate at which uncompleted work gets finished and thus enters the realm of completed work is called the work rate. Obviously, the work rate would be a function of the number of workers, the efficiency with which they work and so forth.

Based on this short scenario, evidently there are two stock variables, places where work in this case can deplete and accumulate—uncompleted work and completed work. There is one rate variable, the work rate. This rate depletes the stock “uncompleted work” and adds to the stock variable “completed work.” We must decide what units to use for all of this. We pick hours for each of the two stock variables and hours/month for the rate variable.

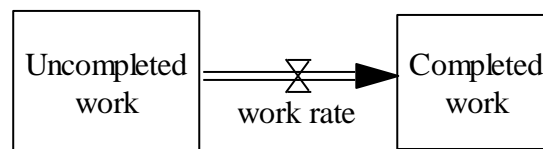


Figure 6A.9. Simple Stock and Flow Model of Uncompleted vs. Completed Work

To create this diagram, we click on the box variable icon and then on the canvas where we want the box variable (stock or state) positioned. Vensim opens up with a text field in which it expects the user to enter a name for this stock. We enter “Uncompleted work” and hit <Enter>. We do this again for “Completed work,” except we do this to the right of the “Uncompleted work” box. Next, we select the rate tool by clicking on it. Then, we click on the stock “Uncompleted work” and again on the other stock “Completed work.” Vensim again responds with a text field in which we enter the text “work rate” followed by <Enter>. Vensim will then delineate a flow from “Uncompleted work” to “Completed work” with a rate symbol representing a rate variable that controls the flow between the two. The diagram is done.

Assume for the moment that 10,000 hours of uncompleted work are determined to comprise a project, whose work rate is 100 hours per month. Initially, there are no hours of completed work. It should be clear that 100 months will be required to complete the project.

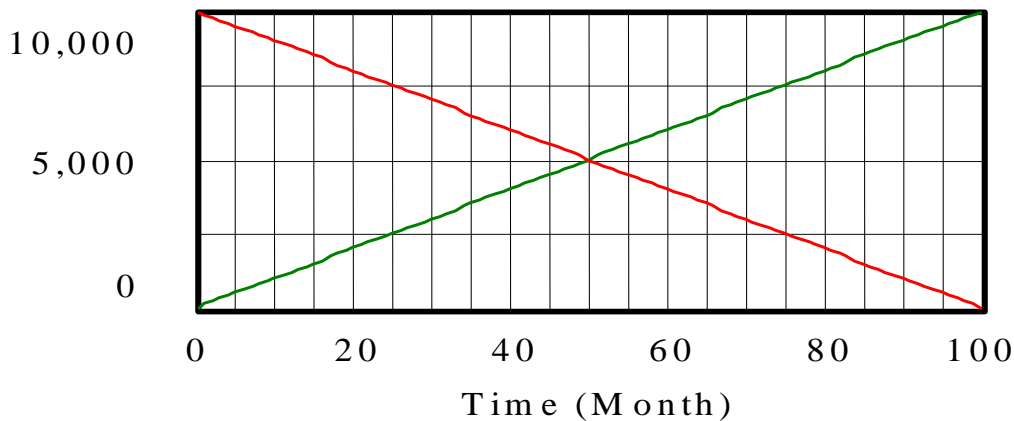
Once the figure above is created on the Vensim canvas, the next step is to specify equations for the model. This is accomplished by clicking on the $Y=x^2$ tool. Vensim then displays all of the variables that require an explicit equation. In general, stocks require, as a minimum, an initial defining condition. For example, click on “Uncompleted work.” The equation editor dialog box pops up with the cursor in the initial value field. We enter the number 10000. This is all we have to do because VENSIM understands that “Uncompleted work” is depleted by the rate “work rate” and has already set up an equation for that in the topmost field of the editor box. We click on OK to close the box. We do the analogous thing for Completed work; namely, we click on it to bring up the equation editor dialog box. Then we enter 0 in the initial value field and click on OK to close the box. Notice now that neither of these two entities (“Uncompleted

work” and “Completed work”) are highlighted. Vensim is satisfied with what it knows about these variables.

Only one variable remains highlighted—“work rate.” As before, we click on it and once again, the equation editor box pops up with the cursor positioned in the equation field. Since we said the work rate was 100 hours per month, we enter 100 and click on OK to close the box. Now, there should be no variables that are not highlighted.

We have one more thing to do before running the simulation. We have to specify a data name for the data file that Vensim will create and store on the hard drive during the time in which the simulation is running. This is done by entering a filename in the white text field at the top of the VENSIM display in the tool bar row immediately below the menu bar. We enter WORK1. Now we can click on the Runner tool next to the white text field, and the simulation runs almost instantaneously.

The behavioral result is exactly what we would expect. The Uncompleted work is depleted to zero in 100 months exactly. At which point in time, all of the work is done. We see this because completed work ekes upward until all 10,000 hours are accumulated within it. The behavior of both variables is entirely linear.



Uncompleted work : work2 —————
 Completed work : —————

Figure 6A.10. Work: From YET TO BE DONE to ALREADY COMPLETED

The above model is unrealistic because we would expect to hire several people to work on the project, where as the above model seems to assume only one person at 5/8 time. Typically, there are 160 hours in a month, assuming a 40-hour work-week. Let's assume that one person gets hired a month for each of the first five months. Now, how long will it take to complete the project? Certainly, it will take less than 100 months. If all five persons were available at the very beginning, then 160*5 or 800 hours would be available each month. The project would be complete in 12.5 months. However, each person is brought on gradually because the project manager, the one who is hired first, can only train one at a time. His training time is built into the 10000 hour estimate. Assume also that the first month of each person's time on the job is productive at half of the normal rate; that is, 80 hours of productive time is all that is derived from each team-members' first month on the job.

These considerations give rise to the following work rate function:

Work rate = 160 * time if time<=5 and 800 if time is greater than 5. We use an IF THEN ELSE() function to model this in VENSIM, as follows:

```
IF THEN ELSE(time<=5,160*time, 800)
```

Here, the first argument of the IF THEN ELSE function is the conditional expression “time<=5.” The second argument is the result the function will return if the expression is true, while the third argument is the result the function will return if the expression is false.

We will build this expression into our model by clicking on the equation editor icon or tool $Y=x^2$ on the second toolbar at the top. In place of 100, we type or paste in the above expression exactly as it appears above. When we click on OK, Vensim comes back with the following remark; “The following inputs were not expected (but are used): Time Do you want to update the input list?” Your response to the query should be Yes. So, click on Yes.

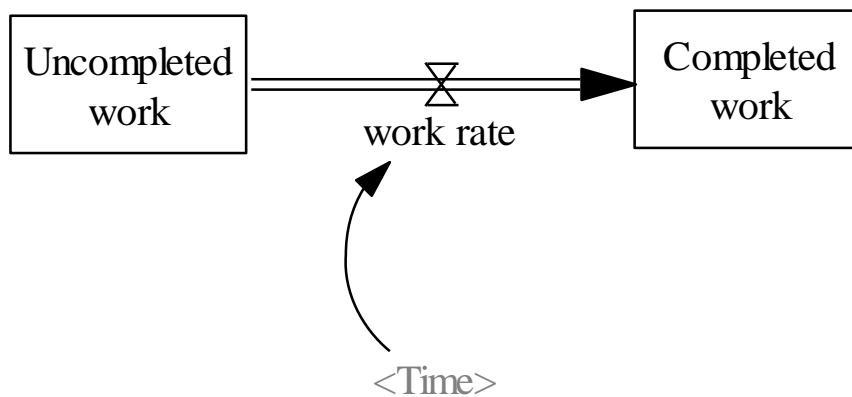
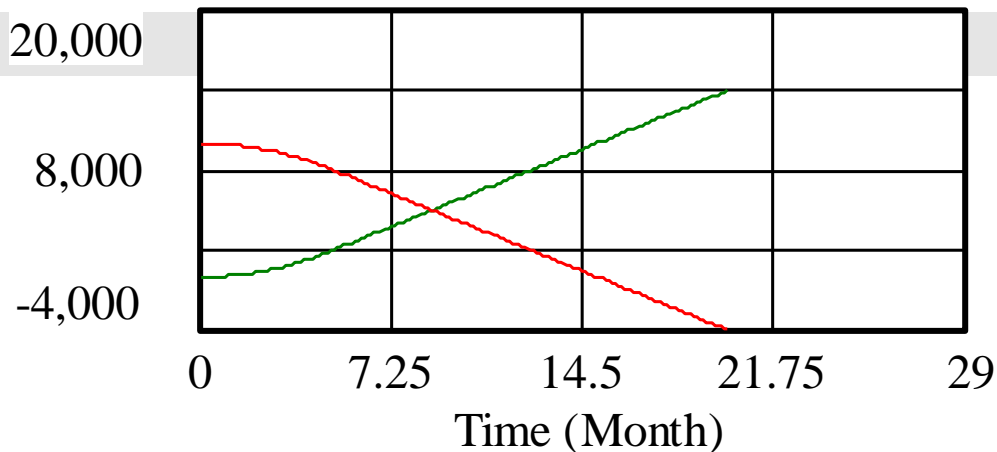


Figure 6A.11. Vensim Delineation of the Uncompleted to Completed Work Model

Vensim closes the equation editor dialog box and returns you to the model formulation canvas, which should look like this, after you have used the pointer to move the time up above the variable “work rate.”

Since we expect this project to now be done in twenty months, we reset the duration to twenty months as follows. On the menu bar, we click on **Model** and then on the menu item **Time Bounds...** The time bounds dialog box comes up and we reset the final time to 20 months and the time step to .125 months. Next, we change the data name to Work3 because a new data name is needed for storage on the hard drive of the data that will be generated during the simulation run. Now we press the runner icon. The plotted results appear below.



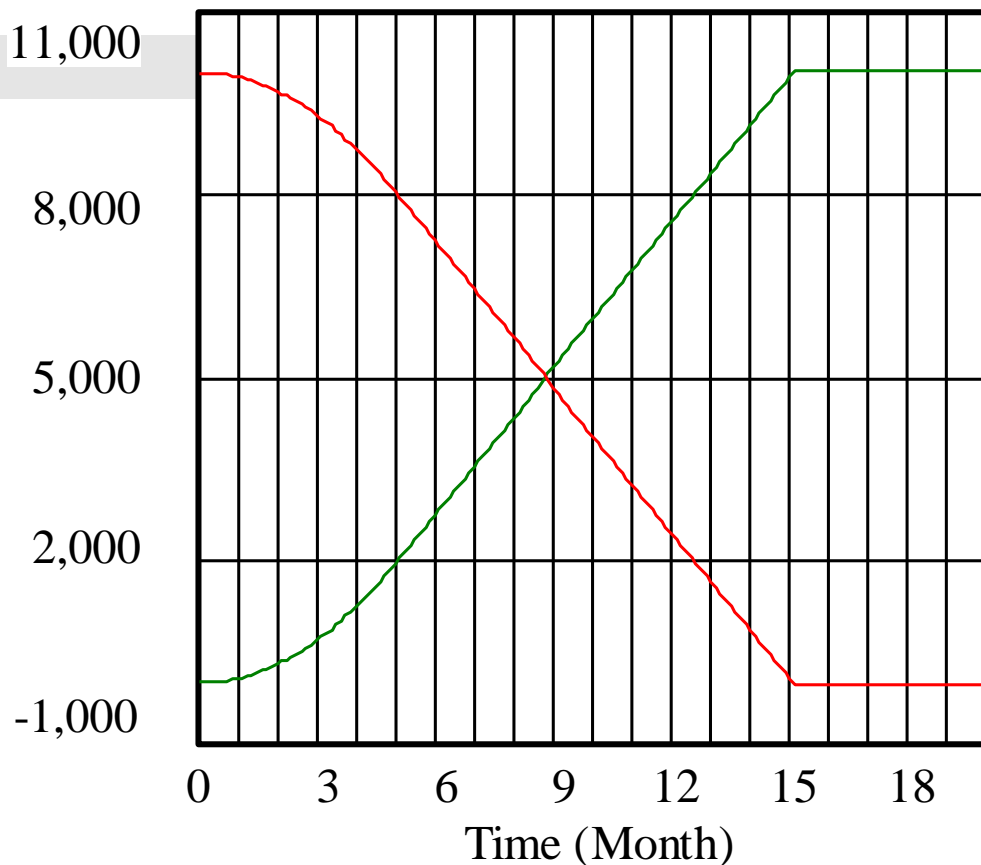
Uncompleted work : work3 —————
 Completed work : work3 —————

Figure 6A.12. Plot of Uncompleted Work vs. Completed Work for a 29 Month Period

Something isn't quite right in this picture because "Uncompleted work" gets drained to a negative 3,950 man-months in the twenty-month period. In other words, the project ran much longer than it needed to because it was unable to detect when all of the work was completed. Rather than using cut and try techniques of trying to estimate when the project will be through—obviously, somewhere between 12.5 months and 20 months, we choose instead to pass information about "Uncompleted work" to the rate "work rate." To do this we use the connector tool. We click on the connector tool to select it. Then we click on "Uncompleted work" and again on work rate, to indicate that we want information about "Uncompleted work" passed to "work rate." Finally, we must once again change the equation for work rate as follows:

```
IF THEN ELSE(Uncompleted work>0, IF THEN ELSE(time<=5,160*time, 800), 0)
```

This will force the work rate to zero when the amount of uncompleted work is zero. We change the data name to Work4 and click on the runner. The result appears in the figure below.



Uncompleted work : work4 —

Completed work : work4 —

Figure 6A.13. Revised Plot of Uncompleted Work vs. Completed Work for a 20 Month Period

Clearly, it took longer than 12.5 months to complete the project. In fact, the project is complete in roughly 15 months time. Now, by passing information about “Uncompleted work” to “work rate” we have been able to construct an equation that will set work rate to zero when “Uncompleted work” is zero, as indeed it should be. It should also be clear that we can nest the IF THEN ELSE function within itself.

Suppose that the 10,000 hours of uncompleted work is just the first of three major phases that make up a project and that the second and third phases, themselves also each 10,000 hours long, cannot start until the first phase is complete. Furthermore, assume these phases must use a startup policy identical to that of the first phase; namely, a new person is brought on-board each month. To accomplish this we can establish focus on the entire structure so far by “rubberbanding it with our cursor, copying it and then pasting it back twice. First, we make sure the cursor is selected. Then, we mark a position to the left and above the structure, hold down the left mouse button and drag the cursor down to a point below and to the right of the structure. Make certain all of the structure is within the rectangular area with a dashed line for a border. When we release the left mouse button, the whole structure is highlighted, indicating all of it has been selected. We then select (click on) **Edit** and then **Copy** (or hit <Ctrl>-C) to copy the entire structure onto the clipboard. Next we select **Edit** and then **Paste** (or hit <Ctrl>-V) to paste the entire structure back onto the canvas. VENSIM has a question about what we are doing. It

wants to know if this is to be *replicated* structure. We answer Yes. The pasted structure is highlighted and needs to be moved off of the structure it was cloned from. Vensim has changed the names by adding a 0 after each name. Since we need two of these structures, one for each of phases two and three, we need to paste the structure onto the canvas again. We do this the shortcut way by hitting <Ctrl>-V and once again, we get the question about replication from Vensim. As before, we answer with Yes and a replicated structure is pasted over the structure that was cloned. We pull it over to a portion of the canvas that is unused.

Next, we use the connector to pass information about “Completed work” to “work rate 0” and “work rate 1.” The end result should appear as shown below.

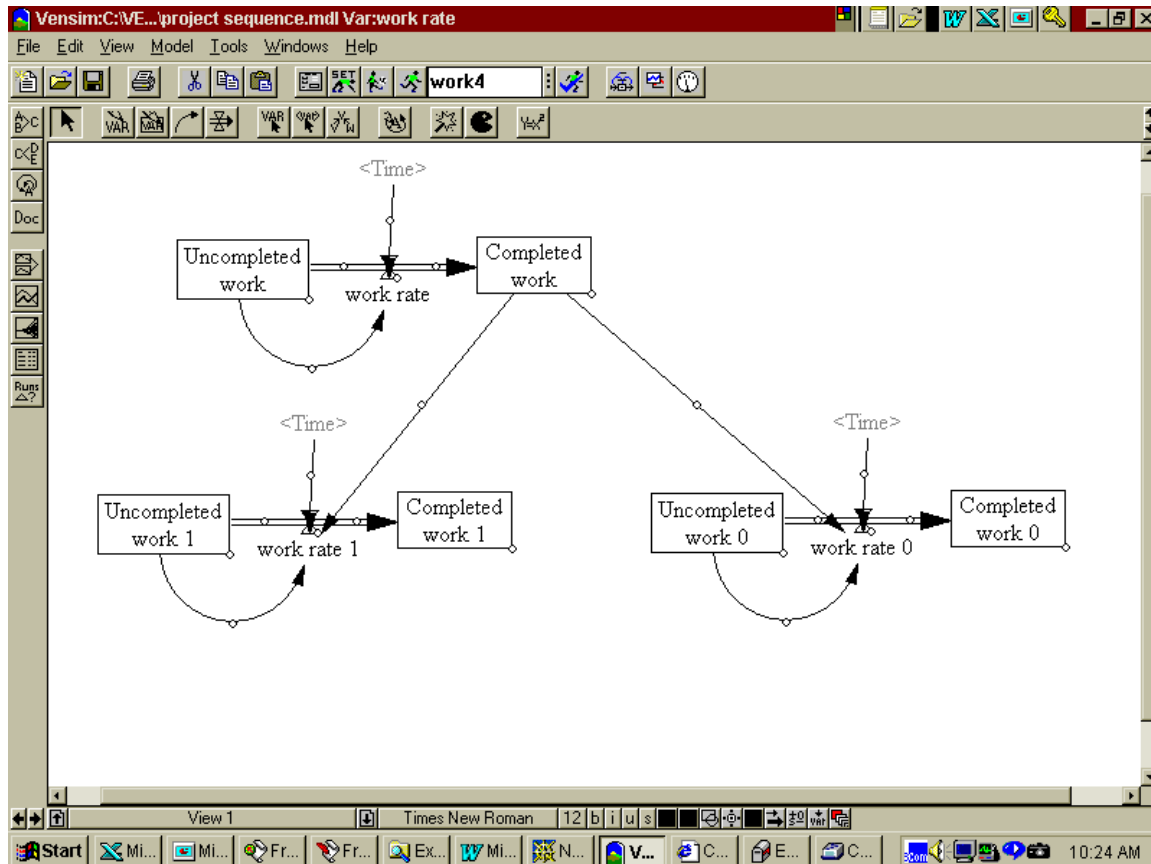
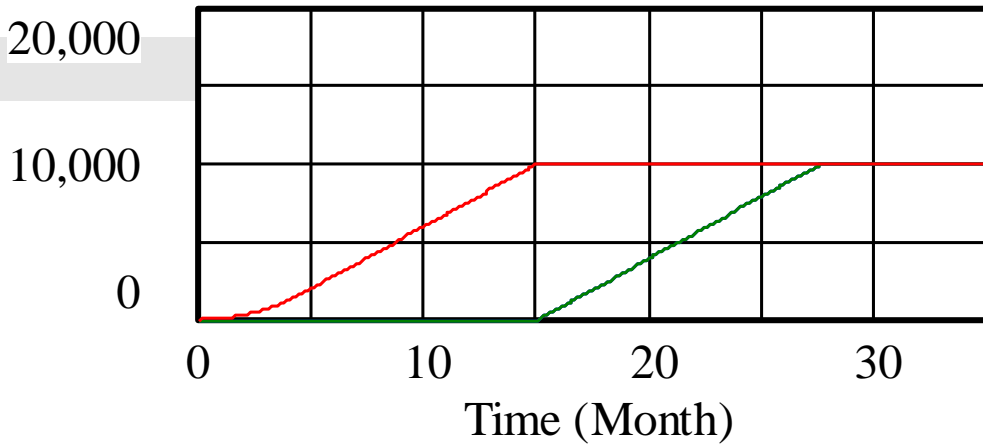


Figure 6A.14. Plot of Several Tasks Linked Together

We must now adjust the equations for “work rate 0” and “work rate 1.” We click on the equation editor and just these two variables are highlighted, indicating Vensim thinks these two variables are the only ones whose equations require any modification. We agree. We click on “work rate 0” and establish the following relationship:

IF THEN ELSE(Completed work>9999,IF THEN ELSE(Uncompleted work 0>0, IF THEN ELSE(Time<=5,160*Time, 800), 0), 0)

This is just the earlier relationship for work rate with the another IF THEN ELSE added. That prevents “work rate 0” from being anything other than 0 until the previous phase involving “Completed work” is 99.99% finished. We do the same for “work rate 1.” Then we adjust the time bound on the model (click on **Model** and then **Time Bounds...**) to set a Final Time of 35. (We think it will take approximately 30 months, but we want to leave some extra time to see what happens after all of the work is completed.) We get the following result:



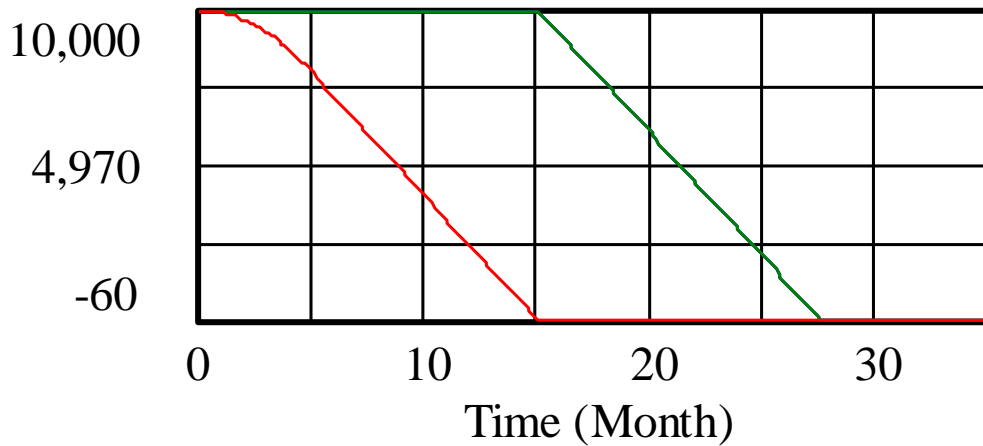
Completed work 5 : work5 —————

Completed work 0 : work5 —————

Completed work 1 : work5 —————

Figure 6A.15. Plot of Completed Work for a Succession of Two Tasks in which the Second Task cannot Start until the First Task is Finished

There are no surprises in the figure above. The follow-on phases start immediately after the first phase is complete and run until they are themselves complete.



Uncompleted work 5 : work5 —————

Uncompleted work 0 : work5 —————

Uncompleted work 1 : work5 —————

Figure 6A.16. Plot of Uncompleted Work Depletion for a Succession of Two (Three) tasks

Exercises

1. A certain project requires 100 experienced professionals to complete it. An estimated 8000 man-months of work is to be done. Currently, there are five rookies and five experienced people on the project. New hires are brought-on to the project as rookies at the rate of 8 a month. It takes six months for a rookie to become “experienced.” (Every month, 1/6 of the rookie group flows into the experienced group.) The rate at which experienced people quit and take on other jobs is 2% of the existing cadre of experienced professionals each month. The rate at which work is being completed each month is measured in man-months/month and is simply the number of experienced people on the project at any given time. “Work” flows from “work undone” to “work completed.” The purpose of the model is to determine how long in actuality it will take to complete the project assuming everything goes according to plan. What units will you use on time? Hint: There are at least four states (stocks) in your model.
2. Suppose, in Exercise 1 above, that “work completed” is found to be 10% defective, resulting in a flow back into “work undone.” Suppose also, that rookies leave the company at a rate of 3% a month. Add these constructs to the model you developed above.
3. Suppose in Exercise 1 above, you are interested in determining total project cost. Rookies are paid \$45 per month, while professionals are paid \$65 per month. What is the total project cost?
4. A project initially has 2,000 months of work entailed in it. Assume there are 50 people working on the package, i.e., the work rate is 50. After 40 months the project is expected to be completed. Determine a structure that will characterize work remaining and work accomplished for a 40 month period. Delineate variables, a causal loop diagram and a stock-and-flow diagram.
5. *THE END-OF-SEMESTER CRUNCH.* A student is having trouble coping with the end of semester crunch as assignments, test preparations, and term projects compete for less and less time. For convenience, we shall refer to all of these time consuming activities as “school work.” As more and more school work gets assigned or becomes due, the backlog of uncompleted school work begins to build up. The only way to reduce the backlog is to get the work done. This we shall refer to as the “work completion rate.”

The real problem is the work pressure that builds up. Certainly, a larger assignment backlog contributes to more work pressure, but there are other contributors as well such as time remaining to complete the work (or just “time remaining”). Time remaining is the difference between the current calendar date and the due date of the assignments and projects, and the test dates.

The grad student copes with this work pressure in two ways. By working longer hours (more hours per week), the student can increase the work completion rate. Doing a skimpier job by taking short cuts on the assignments, test preparations, and projects also speeds up the work completion rate as effort devoted to each assignment is reduced. Both of these strategies have their down sides, as we shall see. Can you think of any other strategies for coping with this problem?

Consider the strategy of working long hours. This deprives the student of sleep, resulting in burnout, ultimately. After a week or two of long hours, the student begins to suffer from burnout and productivity begins to drop. A drop in productivity reduces the work completion rate.

Consider the strategy of reduced effort in which the student takes short cuts. Reduced effort strategies result in reduced grades which are also undesirable (in some students minds at least). Actually, what happens is that reduced effort reduces the quality of the work which results in reduced grades. But reduced grades taken in relation to a grades standard will result in increased effort devoted to work.

- a. What are the major variables?
- b. Are there tautologies that need to be eliminated?
- c. How do these variables change over time?
- d. What does your work backlog look like over the course of a semester?

6. A work package initially has 1,000 months of work entailed in it. Assume there are 100 people working on the package, i.e., the work rate is 100. After 10 months the package is expected to be completed. Determine a structure that will characterize work remaining and work accomplished for a 24 month period. Delineate variables, a causal loop diagram and a stock-and-flow diagram.

7. A certain project requires up to 100 experienced information technology professionals to complete it. The project consists of two major tasks in a finish start relationship; that is, task two cannot commence until task one is complete. For both tasks, there is a flow from work undone to work completed. An estimated 10,000 man-hours of work is to be done for each task. All of the available professionals will be applied to the first task and then to the second. Currently, there are ten professionals on the project. New hires are brought-on to the project at the rate of 5% of the professionals on the project a month. The rate at which people quit and take on other jobs is 2% of the existing cadre of professionals each month. The rate at which work is being completed each month is measured in man-months/month and is simply the number of professionals on the project at any given time. "Work" flows from "work undone" to "work completed" for the first task. Once the first task is complete, an identical second structure involving work undone and work completed is needed for the second task. The purpose of the model is to determine how long in actuality it will take to complete the project assuming everything goes according to plan. What units will you use on time?

8. A certain project requires experienced information technology professionals to complete it. The project consists of two major tasks. The second task begins in month four and bears no relationship to task one, except that the two tasks will share resources 50-50. Task one gets all of the human resources (professionals) until the start of month four, after which each task gets half. For both tasks, there is a flow from work undone to work completed. An estimated 1,000 man-months of work is to be done for each task.

Currently, there are ten professionals and five new hires on the project. The hiring rate for new hires is 6% of the professionals on the project. The maturation time for new hires is six months, so every month one sixth of the new hires flow into the professional category. After the total number of professionals reaches 50, hiring is stopped. The rate at which professionals quit and take on other jobs is 2% of the existing cadre of professionals each month. The rate at which work is being completed each month is measured in man-months/month and is simply the number of professionals on the project at any given time. "Work" flows from "work undone" to "work completed" for both tasks. The purpose of the model is to determine how long in actuality it will take to complete the project assuming everything goes according to plan. What units will you use on time? Hint: There are six stocks and three flows in your model.