

**Lean Project Management Framework for the Entrepreneur:  
Traditional Project Management, Critical Chain, and System Dynamics**

by

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SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM  
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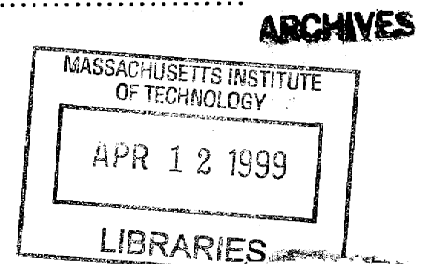
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## **ABSTRACT**

The thesis presents a lean and efficient project management framework that addresses many of the project management challenges found in an entrepreneurial environment. The framework contains an optimal and practical combination of the most critical and successful elements of traditional project management and concepts from critical chain management and system dynamics. The project management approach focuses on improving management efficiency within an entrepreneurial setting. The proposed project management framework does this by accomplishing the following: 1) establishes the over-arching objective of project management, 2) identifies the fundamentally, critical elements and value-added elements of project management, and 3) proposes an appropriate set of approaches, methods and tools. An important value-added element in the proposed project management framework is the ability to quantify the cost and quality implications that occur when new requirements or significant changes are forced on the product and project.

The framework is developed from an entrepreneurial perspective and therefore emphasizes a project management approach that is effective (intuitive framework that captures essential, value added elements), efficient (requires low maintenance and does not become a project in itself), and flexible (approaches and methods proposed are responsive to change). The framework also emphasizes the importance of viewing and managing the project from a systems perspective so that better decisions about the tradeoffs can be accomplished. The combination of traditional project management, critical chain management and system dynamics helps to produce a robust and holistic representation of the project that provides idealistic, realistic and pessimistic views of the project. The proposed framework offers a consolidated project management method to help managers in an entrepreneurial environment in the following three key areas: 1) effectively plan and manage the development effort, 2) understand and communicate the effects of changes to the project, and 3) develop better contingency plans.

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# 1. Introduction

The objective of this thesis is to present a lean and efficient project management framework that addresses many of the project management challenges found in an entrepreneurial environment. The framework contains an optimal and practical combination of the most critical and successful elements of traditional project management and concepts from critical chain management and system dynamics. The project management approach focuses on improving management efficiency within an entrepreneurial setting. Here an entrepreneurial setting is defined as a management process “that involves pursuing opportunities without regard to the resources currently controlled.” Entrepreneurs “identify an opportunity, assemble the required resources, implement a practical action plan, and harvest the rewards in a timely, flexible way.” [33]

It is important to recognize the potentially unique project management dynamics that exist in an entrepreneurial environment. On one dimension, a successful project management framework must plan for the fact that the project itself is of high risk, highly dependent on timeliness and highly dependent on value creation. On a second dimension, the project management must also consider and accommodate the fact that each stage of the entrepreneurial process has a concentrated focus on specific aspects of the overall entrepreneurial opportunity. Initially, the entrepreneur is primarily driven by the perception that an opportunity that exists within an area of interest without regard to the resources controlled. In this stage of the process, the primary focus is to evaluate and qualify the opportunity and then develop a business concept to satisfy the opportunity. In the next stage, the focus shifts to act on the opportunity by developing a prototype of the product or service to demonstrate the feasibility of the business concept and then acquiring the minimum set of resources required to fulfill the opportunity. The final stage focuses on value creation and continuous risk management during the execution and delivery phases of the entrepreneurial venture. The proposed project management framework can be used in all of the three critical phases of the entrepreneurial process. Traditional project management, critical chain management and system dynamics can be used to help evaluate the viability of an opportunity, efficiently manage the project, and reduce the risk of the project.

The advent of deregulation, a global economy and the explosion of connectivity have produced a business environment that is filled with both new opportunities and tremendous challenges. The increased competitive climate has placed an enormous amount of pressure on companies (whether small, large, new or established) to accelerate product development. In an entrepreneurial environment where business is driven by opportunity, success or even survival primarily depends upon the ability to develop and deliver these products within a cost structure and during a specific window of opportunity. The successful companies, whether established or entrepreneurial, are able to accomplish this feat primarily due to the good overall management of the project and its critical and value-added elements.

The thesis presents a lean and efficient project management framework that outlines these good project management practices so that the process can be successfully repeated. The proposed project management framework accomplishes the following: 1) establishes the overarching objective of project management, 2) identifies the fundamentally, critical elements and value-added elements of project management, and 3) proposes an appropriate set of approaches, methods and tools. The Systems Architecture Framework provides an approach to decompose the system and its complexity into smaller, more manageable subsystems. The Work Breakdown Structure (WBS) provides a good, simple planning method that helps to identify all of the tasks required and then estimate the effort required to complete the project. Critical chain management is a low-overhead approach to organize and schedule the work required and then efficiently manage the critical path of the project. The system dynamics method is used to better understand and communicate the cause and effect relationships that occur in a project. System dynamics captures the human dynamic influences and feedback paths of a project in a software model. An important value-added element in the proposed project management framework is the ability to quantify the cost and quality implications that occur when new requirements or significant changes are forced on the product and project. The system dynamics model helps to capture and quantify the effects of these changes and the underlying factors that play a significant role in causing projects to slip schedules, incur cost overruns and/or develop quality issues.

The proposed project management framework presents an efficient and practical approach to project management. The framework is developed from an entrepreneurial perspective and therefore emphasizes a project management approach that is effective (intuitive framework that captures essential, value added elements), efficient (requires low maintenance and does not become a project in itself), and flexible (approaches and methods proposed are responsive to change). The framework also emphasizes the importance of viewing and managing the project from a systems perspective so that better decisions about the tradeoffs can be accomplished. The combination of traditional project management, critical chain management and system dynamics helps to produce a robust and holistic representation of the project that provides idealistic, realistic and pessimistic views of the project. The proposed framework offers a consolidated project management method to help managers in an entrepreneurial environment in the following three key areas: 1) effectively plan and manage the development effort, 2) understand and communicate the effects of changes to the project, and 3) develop better contingency plans.

## Overview of Project Management Framework

Entrepreneurial Process	Entrepreneurial Needs	Project Management Activities	Project Management Tools
Opportunity Evaluation Business Plan (Business Concept)	<ul style="list-style-type: none"> <li>• Emphasize Value Creation</li> </ul>	<ul style="list-style-type: none"> <li>• Planning</li> </ul>	<ul style="list-style-type: none"> <li>• Traditional Project Management</li> <li>• System Architecture</li> <li>• Systems Approach</li> <li>• Work Breakdown Structure</li> <li>• Risk Management</li> </ul>
Business Plan Resource Acquisition (Prototype and Product Development)	<ul style="list-style-type: none"> <li>• Manage Value Creation</li> <li>• Manage Timeliness</li> </ul>	<ul style="list-style-type: none"> <li>• Monitoring and Controlling (Manage Project)</li> </ul>	<ul style="list-style-type: none"> <li>• Systems Approach</li> <li>• Critical Chain</li> <li>• Risk Management</li> </ul>
Venture Launch	<ul style="list-style-type: none"> <li>• Manage Risk</li> <li>• Manage Timeliness</li> <li>• Manage Value Creation</li> </ul>	<ul style="list-style-type: none"> <li>• Reporting (Understand and Communicate Project Changes)</li> <li>• Risk Management and Contingency Planning</li> </ul>	<ul style="list-style-type: none"> <li>• Systems Approach</li> <li>• Critical Chain</li> <li>• Systems Dynamics</li> <li>• Risk Management</li> </ul>

## **2. Entrepreneurship**

### **2.1. Definition**

The most widely accepted definition of entrepreneurship is “the process of creating or seizing an opportunity and pursuing it regardless of the currently controlled resources. It involves the definition, creation, and distribution of value and benefits to individuals, groups, organizations and society.” [39] The key proposition is not necessarily to develop a get rich-quick scheme but to develop long-term value and durable cash flow streams. Historically there have been great successes because entrepreneurs have created a number of multi-billion dollar industries such as: semiconductors, mini- and microcomputers, telecommunications, cellular phones, and biotechnology.

An important element to entrepreneurship is the existence and recognition of opportunities that can be exploited to create value. These opportunities arise when in a free enterprise system there are “changing circumstances, chaos, confusion, inconsistencies, lags or leads, knowledge and information gaps, and a variety of other vacuums in an industry or market.” [37] Opportunities commonly exist in fragmented markets that lack a dominant standard or product. Markets with dominant large, multibillion players can also provide opportunities because it can take several years (range of six to ten years) for a large company to change and implement a new strategy efficiently. The slow responsiveness of these large companies provides an opportunity for small businesses that view the period of six to ten years as a lifetime.

Technological changes and innovations provide a great number of opportunities. The advent of mobile connectivity via computers (and other connection terminals), cable, wireless and satellite communications, and the Internet have radically altered the economics of information, sales, and distribution. The Internet and cable television have expanded the distribution channels for sales and advertisement. In cable television, a number of companies have begun to rely on 30-minute infomercials in lieu of expensive full-page magazine advertisements. This connectivity has not only increased the number of distribution channels but also provided channels of distribution that are more efficient and cost effective. Several important elements in this era of mobile connectivity is the availability of information and this aspect of “network externalities” which actually causes the value of the information to increase as the number of connections increase. In the travel industry, the Computer Reservation Systems (CRS) industry provides travel information like fare prices, flight schedules and availability status to travel agents worldwide. The emergence of the Internet has provided an opportunity for the CRS companies to capture additional volume by providing access to this information for a fee. This opportunity has also allowed new entrants (entrepreneurs) to use this information and compete directly with the airlines and the travel agencies for airline-ticket bookings.



Government policy is a major contributor to the creation of opportunities. Policy decisions to lower capital gains taxes and de-regulate certain industries have been instrumental in encouraging entrepreneurial businesses. The de-regulation of the airline industry in 1978 provided opportunities for new industries like CRS industry to evolve. After the de-regulation, the airlines competed on multiple strategies including the price and availability of flights. The CRSs were soon developed and expanded to assist the travel agents with airline-ticket bookings and to improve airline productivity by controlling inventory and automating internal operations. In 1984, the Justice Department required the CRS companies to provide unbiased listings of the travel information and forced the CRSs to become independent of an individual airline. This allowed the CRSs to build comprehensive travel information databases, which later was leveraged in the on-line booking industry. The de-regulation of telecommunications industry in 1984 also provided opportunities for new industries like the long distance carriers, operator service providers, and public access terminal industries to evolve. [8]

Educational institutions also help to encourage the creation of opportunities by offering courses and programs that prepare managers to be attuned to the effective ways of pursuing opportunities and managing resources. [33] Many of the top business schools have courses and programs that focus on the entrepreneurial process and teach students how to discover and access opportunities, obtain the human and financial resources, launch the venture, manage the enterprise, and harvest the value. The Sloan Business School at the Massachusetts Institute of Technology (MIT) offers courses like New Enterprises, Entrepreneurial Marketing, and the Entrepreneurship Lab, and activities like the 1K and 50K Competitions (business concept and business plan competitions) which teach and encourage entrepreneurship. Other top business schools like the Harvard Business School, Wharton Business School and Stanford Business School offer a set of similar courses and activities.

A difficulty with identifying and recognizing opportunities is that they exist and disappear in real time. Timmons describes the process of creating and seizing an opportunity in real time as being similar to the process of selecting objects (opportunities) from a conveyor belt moving through an open window (window of opportunity). The moving conveyor belt causes the window containing the opportunity to constantly open and close. Changes in the speed of the conveyor belt represent the volatile nature of the market. [39]

Entrepreneurship is not limited to individuals and should be encouraged within organizations. For America to successfully meet the challenges of global competition, it must turn to collective entrepreneurship, which relies on the talent and creativity of all of their employees to provide continuous, incremental innovation that creates value. One possible representation of organizational entrepreneurship is collective entrepreneurship which entails a closer working relationship among the workers at all levels that spans across job descriptions, disciplines, the different business cycle phases and processes. For example, the designers and engineers need to understand the functions and information provided by the sales and marketing and technical support groups. On the other hand, the sales and marketing and

technical support groups need to have a complete understanding of the product and organization's capacity to design and deliver product modifications and custom products. Improved coordination and communication between these groups allow the collective group and organization to better understand the customer's needs (opportunities), evaluate them and respond in a manner that creates value and is compatible with corporate strategy. Within this context, organizations, which are composed of many workers that continuously discover opportunities to improve or modify a product or process to meet specific customer or market needs, can be viewed as entrepreneurs. A more traditional representation of organizational entrepreneurship is when companies seek to start new businesses without having to start new companies. In this scenario, the companies act as venture capitalists and either invest or establish joint ventures with start-up companies. A good example of this type of organizational entrepreneurship can be seen in the company, Teradyne, which manufactures automated test equipment for the semi-conductor industry. The company adopted a strategy of seeking new opportunities and creating new businesses with the philosophy of attracting top-notch start-up teams by offering them the opportunity to both run their own business and make good money. The process of investing in entrepreneurial opportunities consisted of "evaluating the entrepreneur's five-year business plan, getting agreement with the entrepreneur on a fixed evaluation amount and then paying the entrepreneur some money up front with the bulk of the money coming later based on achievement of the plan." From the entrepreneur's perspective, the partnership with Teradyne was particularly attractive because it gave them access to Teradyne employees with the specific skills that were valuable to the new venture. [19]

## **2.2. Entrepreneurial Process**

The entrepreneurial process contains six critical phases that capture an entrepreneurial event from conception to implementation. The six critical phases of the entrepreneurial process include the following:

1. Identification and recognition of an opportunity
2. Evaluation of the opportunity
3. Development of a business concept and strategy
4. Development of a business plan
5. Assessment and acquisition of human and financial resources
6. Launch of the venture

The identification and recognition of a feasible and profitable entrepreneurial opportunity is arguably the most difficult step. It is important to note the distinction between an idea and an opportunity. An *opportunity* is an *extension of an idea that is feasible, profitable, durable and business attractive*. Most entrepreneurial ideas are a natural outgrowth of an individual's education, work experience, and hobbies. [32] There is a high correlation between prior work and new-venture ideas. In fact a large majority of successful start-ups, between sixty and ninety percent depending upon the type of industry, were related to prior work. [33] Although

there is not a proven formula to correctly identify successful entrepreneurial opportunities, the common elements include at least one or more of the following items:

- Entrepreneurs recognized market or technology shifts
- Entrepreneurs satisfied a specific customer or market need
- Entrepreneurs leveraged own expertise in terms of knowledge and experience
- Entrepreneurs leveraged relationships in terms of personal or industry contacts

The entrepreneurial opportunity is evaluated on the terms of business attractiveness and business fit. The business attractiveness evaluation is primarily based on the potential financial returns and growth of the opportunity and its degree of risk. An opportunity that has good business attractiveness must be attractive, durable, and timely and must create value for its buyer or end user. Elements of attractive opportunity include positive assessment of the following: return on investment (ROI), investment cost, growth potential, market size in terms of absolute dollars and potential returns, and applicable market segments. Durability is associated with the product or service's proprietary protection and projected rate of obsolescence. It is important to maintain a proper balance between the time spent evaluating the opportunity and the value of the information collected. Too much time spent in this task can lead to "analysis paralysis" where the product or service is not launched within the window of opportunity or, in some cases, never even launched. There are also cases where too much information can actually become harmful. Since some of the information collected is speculative in nature, the abundance of information can actually steer the business concept and strategy down a narrow perspective that may later be very difficult to change. This can lead to an unsuccessful self-fulfilling outcome because subsequent information can be accepted or discarded too quickly based upon whether it supports the narrow business concept and strategy adopted. The evaluation of the market can be done in two different ways: top-down approach based on the thorough research of existing information, bottom-up approach based on information directly about and/or from the customer. In either case, it is recommended to get a "reality check" early by obtaining some customer feedback about the product.

The business fit evaluation is associated with the fit between the individual(s) entrepreneurs and the new opportunity relative to personal interests, experience, commitment and the opportunity costs. The experience relative to business fit is associated with the current need of the entrepreneurial team and opportunity. The needs are typically evaluated in terms of the functional business disciplines and a set of intangibles. The functional disciplines include financing (ability to raise funding), engineering and development, marketing and distribution, manufacturing, and technical support. The intangibles primarily include previous experience with other start-up ventures and the ability to handle the stress of working in a dynamic environment with many uncertainties.

The business plan for the entrepreneurial opportunity provides the entrepreneur to sell the business concept, for the opportunity, to investors. It must clearly summarize the business concept and strategy (containing a product or service) and the opportunity (which satisfies a

market or end user need) and then describe the high profit potential and the corresponding activities and resources required to achieve those profits. The fundamental core section of the business plan is the business concept and strategy because it describes the business opportunity, why it exists and why the management has what it takes to execute the plan. [38] From a systems engineering perspective, the business concept and strategy describes the system requirements to capitalize on the opportunity and the other business plan sections describe the architecture of the process to capitalize the opportunity. The business concept and strategy selected must be somewhat flexible because the value and competitive advantage can change throughout the process of evaluation as new information is collected about the customer, market and product. The flexibility within the business plan should be similar to a cross-country flight plan where it simply defines the most desired, most likely, and least-hazardous route to a given destination. The actual course of the flight will vary based on a number of factors like the weather and traffic. [39] An important secondary goal during the creation of the business plan is the development of a prototype of the product or service. The prototype serves two important goals; it can be used to obtain customer feedback and will also help to sell the business concept. A working prototype demonstrates the feasibility of the product or service and removes some of the ambiguity associated with the translation of a good concept to a profitable venture.

A successful business plan contains the following key components: executive summary, business concept, market, management and operations, financials, and appendices. The following section describes several of the important fundamentals in a winning business plan. The presentation of the business plan must clear, concise and convincing and the information about the concept, market and financials must be accurate relative to the product or service and its target market segment. The investment amount must be explicitly stated and the investment structure should not be complex in nature. The current status of the business must be stated so that the investors can determine the risk based on the stage of the business. The typical five stages in the life of an entrepreneurial business are: seed stage (founding team has developed a business concept but does not have a prototype), start-up stage (the prototype has been developed but funding is needed to develop/manufacture the product or service and launch the business), first stage (company has been launched and is in business but is not yet profitable) or second stage (company is profitable but is not of the proper size and scale). The exit strategy for the investor(s), allowing investor(s) to liquidate the investments so that they can be re-invested, must also be explicitly stated. Finally, the description of the management team should emphasize the knowledge and experience within that particular industry, and its ability and commitment to launch and sustain the venture.

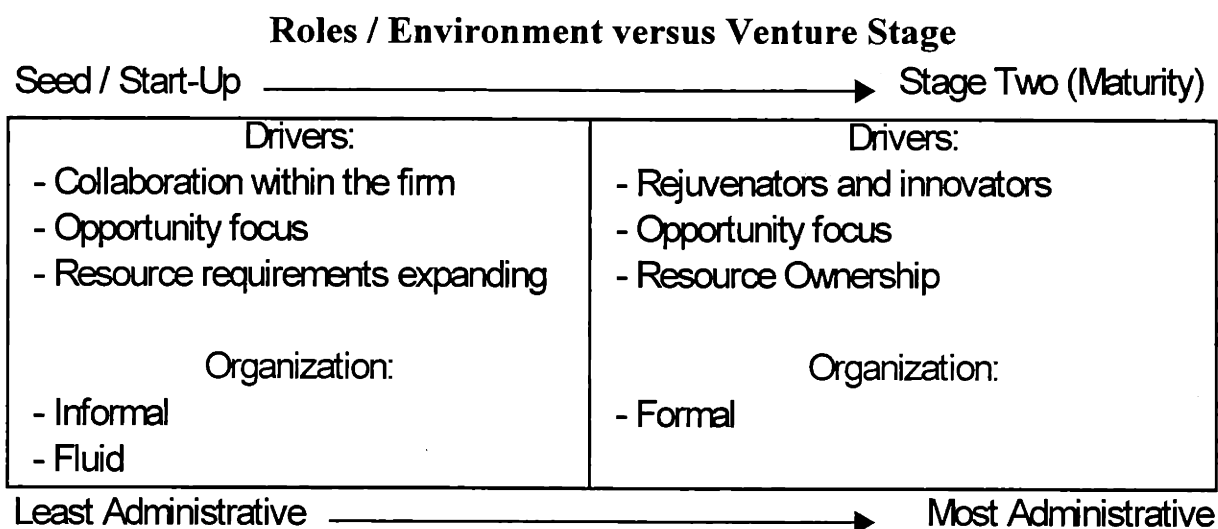
The resource assessment and acquisition activity focuses on the selection and acquisition of the senior and founding management team, supporting set of human and equipment resources, and financial resources. The support resources could include a mixture of permanent resources and non-permanent resources like contract/temporary employees and equipment rentals/leases. The important issues in the selection and effective utilization of outside professionals include the organizational form of the firm (public or private, corporation, etc.), specific needs of the firm (franchising, licensing, contracts, litigation, etc.), and their cost

structure and level of service provided. A common reason to use consultants includes the compensation for a lower level of professional experience, targeting a wide market segment, and undertaking projects that require large start-up investments in equipment. In an entrepreneurial environment, the ownership of the support resources is not essential but the control and influence over other people's resources is extremely vital. [38] The use of control instead of ownership allows the entrepreneur to maintain flexibility and low fixed costs. Minimizing the use of resources and managing to accomplish a little more with a little less is an important trait of a successful entrepreneurial venture.

The launch of the venture is accomplished after the entrepreneurial firm completes an important set of milestones. These milestones include the following: 1) concept and product testing, 2) prototype demonstration, 3) acquisition of the first level of financing, 4) initial plant tests or first article testing, 5) market testing, 6) production start-up, and finally 7) the "bellwether sale" which is the first substantial sale to an expected major account. The concept and product testing determines whether or not to proceed with any further development. The test serves as safeguard against self-delusion and is also a source of alternative-opportunity identification. It challenges the assumptions about desired product characteristics, target markets, pricing range, and perception of need. The completion of the prototype serves several purposes. It helps to identify if there are any additional patentable items and provides insight to the final product-development times and costs. The initial plant tests constitute pilot production run of the product or a pilot operational run of the service to better quantify the material suitability and costs, processing costs and skills, investment prerequisites, training needs, supplier quality issues, and processing specifications, run time and maintenance. The market testing uses several hundred pre-production units to challenge the basic market assumptions and determine how the unit performs in a variety of field applications, how well the unit would actually sell, and the achievable market size. The first successful production run provides the true costs of mass producing the product or service. [33]

### 2.3. Roles and Responsibilities

The perspective taken by the entrepreneur is influenced by the many different roles and responsibilities assumed. One of the roles more closely resembles a manager that is a promoter; one who has the confidence to seize an opportunity regardless of the resources under control. Another role is that of a creator and innovator. This role is not necessarily concerned with breaking new ground but also seeks the creative application of traditional approaches to satisfy the opportunity at hand. A more common and consistent role of entrepreneur is that of a leader; one who sets the vision and example and then promotes it by motivating and encouraging the other team members. The management style is typically requires creativity and an ability to effectively cope with high levels of change and uncertainty. A common management approach used is Management By Wandering Around (MBWA). An important note is that these roles and responsibilities of the entrepreneur will tend to change based upon the stage and maturity of the venture. [39]



The entrepreneur is essentially responsible for the launch of the entire venture and may receive relief from some of these responsibilities as the core management team is expanded. One aspect that is particularly important to an entrepreneur is the area of risk management. The difference between a successful and unsuccessful launch depends upon the ability to constantly manage the trade-offs between the amount of resources committed and the potential return. The entrepreneur always attempts to maximize value creation by minimizing the resource set and accepting more risk. [37] Successful entrepreneurs take very careful, calculated risks. The entrepreneur tries to influence the odds, often by getting others to share the risk, or by avoiding or minimizing risks if the option is available. [39]

As stated earlier, in an entrepreneurial environment, the primary focus is to increase value and minimize the amount of committed resources. The reward system or employee compensation system must also reflect this approach. An important note is that reward system should not only consider the amount of value created but also consider the total amount of expenses and risk exposure since all three factors are closely related. In these value-driven environments, the compensation tends to be based on team and/or individual performance, where performance is closely related to value-creation. [37]

### **3. Project Management Overview**

#### **3.1. Definition**

The definition of a project is a set of tasks or activities related to the achievement of a planned objective, which is typically unique or non-repetitive. Management is the process concerned with the achievement of goals and objectives. The combination of project and management entails the coordination of group activity where management plans, organizes, staffs, directs, and controls to achieve an objective with constraints on time, cost, and performance of the end product. Project management is essentially a blend of art and science. The art of getting things done through and with people in formally organized groups and the science of handling large amounts of data to plan and control so that the project duration and costs are balanced, and excessive and disruptive demands on scarce resources are avoided. [23]

In an entrepreneurial environment, the project management activity must be practical and efficient so that the execution of the task in itself (project management) does not become a full-time project. The project management activity is viewed as a support task in the overall effort of pursuing an opportunity and creating value. The fundamental objectives of the activity is to ensure that the product and/or service development meets the operational requirements of the opportunity and its customers, does not exceed the cost budget and is available for delivery and use during the window of opportunity. In simple terms, the project management activity ensures that the project results are accomplished within the time and cost constraints of the entrepreneurial opportunity.

An important element in this activity is the definition of the project requirements. The project requirements build upon the business concept in the business plan and specify the high-level functional and performance requirements, development costs, production costs based on volume, and the target delivery schedule of the product and/or service. An important note here is that the project objectives be clearly defined, clearly seen, well understood and accepted by all concerned or involved in the project. In an entrepreneurial environment, these project requirements may tend to be fairly dynamic, therefore success is fundamentally based on establishing and finalizing the requirements so that they at least become more difficult to change, similar to the analogous flexibility of “wet cement”.

One of the most important elements in successful teams is to establish a common understanding among all of the team members of why the team is needed and of the objectives it has to accomplish. The project must not only do something useful but also meet some customer need regardless of whether the customer is internal or external. A sufficient amount of time must be spent on understanding the full concept of the project so that the team can determine and establish a set of objectives that they are clearly defined, focused and achievable. The project objectives must also be compatible with the overall business strategy of the company. A set of high-level project objectives describe the vision of the product and



how it will be produced. These high-level objectives are then continuously decomposed throughout the project development to provide concrete milestones. An overarching goal for any team should be the belief and continuous search for dramatic improvements because if they exist, then one has a better chance of finding them. The environment should also be one that encourages innovation and some level of reasonable risk; this is accomplished by advocating that the reward for finishing early is much greater than the penalty for finishing late.

In general, project success or failure depends not only on the project's accomplishments or outcomes, but also on how these accomplishments are measured. This measure is usually based upon the client's or manager's expectations of the project. The best way to maximize the possibility of achieving project success is to identify and understand these expectations and then produce a project outcome that exceeds these expectations. An important point here is that if the project can not accomplish those expectations, it is best to work out a compromise thus lowering the expectations as soon as possible. If a project's expectations are set inadequately or if some of these expectations are ignored, the project outcome will most likely be judged unfavorably. Another way to increase the chance of achieving project success is by allowing or encouraging people who are instrumental in judging the project's outcomes (including the client) to actively participate in the project and take credit for ideas and concepts that have improved the project. This unselfish act will help to make the project decision-maker feel like an integral part of the project team. This encourages the decision-maker to be an active participant and thus create an environment that maximizes the probability of achieving project success. [27]

### **3.2. Stakeholders**

In any successful venture it is important to identify the stakeholders and then understand their particular needs and expectations. The key stakeholders for most organizations can be categorized into the following groups: customers, entrepreneurial (founding) team, investors, suppliers, and employees (both permanent and temporary). For projects in an entrepreneurial environment or particularly in a new enterprise, the more daunting task is not necessarily understanding the stakeholders but also attracting the type of stakeholders who are willing to take some risk and invest their time and money in an entrepreneurial opportunity. The process of attracting these stakeholders is much more difficult because of the risk and uncertainty associated with an entrepreneurial environment. Unlike a well-established organization, the new entrepreneurial has a higher level of uncertainty because it does not have a long-standing reputation in dealings with employees, suppliers, and customers. The higher level of risk is associated with the negative effects to the stakeholder if the product or the enterprise fails.

## Table of Stakeholder Needs

Potential Stakeholders	Needs, Interests and Expectations (from the perspective of a potential stakeholder)
Entrepreneurial (management) team members	<ul style="list-style-type: none"> <li>• Expectations of substantial long-term reward</li> <li>• Good team chemistry – total commitment and high-level of trust</li> </ul>
Investors	<ul style="list-style-type: none"> <li>• Expectations of substantial long-term reward</li> <li>• Unused quota for certain types of investments (technology loans)</li> </ul>
Employees	<ul style="list-style-type: none"> <li>• Expectations of substantial long-term reward</li> <li>• Satisfaction from working for Mission Impossible-type of enterprises</li> </ul>
Customers	<ul style="list-style-type: none"> <li>• “Real” need for product and/or service</li> <li>• Publicity and thrill of being first user of technology outweighs economic downside</li> </ul>
Suppliers	<ul style="list-style-type: none"> <li>• Currently have excess capacity or an abundance of the materials needed</li> </ul>

Once the key stakeholders have been identified, courted and they make a commitment to participate with the entrepreneurial enterprise, the common interest and expectation becomes the creation of a successful enterprise. From the perspective of the project manager, there still exist some individual stakeholder needs that are related to their specific tasks for the opportunity. Although these needs typically are for the benefit of the both the enterprise and stakeholder, they may produce undesirable effect to the project cost and/or delivery schedule. For example, the customer may have determined that a new requirement or a significant modification to an existing requirement is needed for the new product and/or service to operate properly. In another case, the development team may have identified a superior technique or tool that can significantly improve the performance of the product and/or service but will require a certain amount of re-work. Finally in yet another example, the entrepreneur (which may also function as the project manager) requests new requirements or modifications to existing requirement to expand the use of the product and/or service for a different market segment or industry. It is important to recognize that these needs exist and then utilize a project management approach that has the flexibility to incorporate this feedback, evaluate it and respond to it within a reasonably short amount of time.

The performance of the team is greatly affected by the work environment and leadership in terms of the composition, communications, decision-making, and conflict-handling capabilities of the team and its members. Studies done by Thamhain in 1990, DiBella in 1995, Thamhain and Wilemon in 1996, have shown that the management style and work

environment significantly influence the innovative performance of the team. These studies identified that there was a high correlation between high-performing technical teams and project success when certain work environment elements exist. The following chart shows the characteristics of the work environment and their correlation to team performance. The work environment characteristics were evaluated from the perspective of the team members and the performance was evaluated from the perspective of senior management. [38]

**Chart of Work Environment Characteristic versus Team Performance**

Work Environment Characteristics	Ability to Change	Team Performance			Overall Performance
		Time-to-Mkt Performance	Resource Effectiveness	Innovation Performance	
Recognition and Accomplishment	0.39	0.42	0.41	0.39	0.4025
Stimulating work environment	0.32	0.38	0.36	0.41	0.3675
Clear Understanding of Market and Requirements	0.46	0.37	0.24	0.36	0.3575
Direction and Leadership	0.4	0.37	0.32	0.33	0.355
Involvement in Project Planning	0.33	0.41	0.38	0.25	0.3425
Project Management Tools	0.31	0.42	0.37	0.22	0.33
Conflict and Problem Resolution	0.3	0.27	0.33	0.37	0.3175
Good Communications and Trust	0.33	0.33	0.28	0.3	0.31
Clear Understanding of Organizational Interfaces	0.42	0.22	0.22	0.35	0.3025
Low Interpersonal Conflict	0.28	0.25	0.26	0.27	0.265
Job Skills and Expertise	0.21	0.28	0.24	0.28	0.2525

The work environment characteristics were measured by asking the project team members to indicate their agreement with specific statements on a five-point Likert-type scale where 1=strong disagreement, 2=disagreement, 3=neutral, 4=agreement, and 5=strong agreement. The statements to measure the perception of Stimulating Work Environment included the following: “My job is interesting and professionally stimulating”, and “I always enjoy my work”. The statement to measure the perception of Recognition and Accomplishment included “My work leads to significant accomplishments which are being appreciated and properly recognized by the organization”. The team performance results were measured by asking senior management to indicate their judgements based on a four-point scale where 1=poor, 2=marginal, 3=good, and 4=excellent. The data collected produced a rank-order correlation between the team work environment and the team performance. The statistical

significance of the rank-order correlation is: probability of 0.10 for  $\tau \geq 0.20$ , probability of 0.50 for  $\tau \geq 0.31$ , and probability of 0.01 for  $\tau \geq 0.36$ . [38]

### **3.3. Planning**

Project management is fundamentally composed of three major activities: planning, monitoring and controlling, and risk management. All three activities are considered to be ongoing tasks that are continuously updated and optimized throughout the entire project, particularly as the project progresses through the different phases of development (requirements analysis, development, integration, validation and field testing). In an entrepreneurial environment it is critically important that the planning process is not viewed as an end in itself because the project management will quickly become a crisis management activity. It should be acknowledged and used as a continuous ongoing activity. Effective planning, particularly in an entrepreneurial environment, is needed for the following obvious reasons: 1) sets specific, time-phased, measurable goals, subgoals, and action steps, 2) helps anticipate obstacles, 3) encourages and promotes involvement and commitment, and 4) helps one to learn from previous experiences. The ability to apply leanings from previous experience and stay flexible and responsive is particularly helpful in an entrepreneurial setting given that there is usually a higher number of surprises. [39]

According to the Project Management Institute (PMI), the planning process is divided into two different processes, which are a core planning process and a set of facilitating processes. [12] The core planning process contains a number of fundamental steps that is useful in all project management activities and environments, whether in an established or entrepreneurial setting.

The core planning process, as defined by PMI, includes the following steps:

• Scope Definition	Subdividing the project deliverables into smaller, more manageable components
• Activity Definition	Identifying the specific activities that must be performed to produce the various project deliverables
• Activity Sequencing	Identifying and documenting the interactivity sequencing dependencies
• Activity Duration Estimation	Estimating the number of work periods that will be needed to complete the individual activities
• Schedule Development	Analyzing the activity sequences, activity durations, and resource requirements to create a project schedule
• Resource Planning	Determining what resources (people, equipment, materials) and what quantities of each should be used to perform the project activities
• Cost Estimating	Developing an approximation (estimate) of the costs for the resources needed to complete the project activities
• Cost Budgeting	Allocating the overall cost estimate to the individual work items
• Project Plan Development	Taking the results of the other planning processes and putting them into a consistent, coherent document

The facilitating processes are more dependent upon the complexity of the project and the type of organizational environment. These processes are performed intermittently based upon need. The core facilitating process, as defined by PMI, includes the following steps:

• Quality Planning	Identifying which quality standards are relevant to the project and determining how to satisfy them
• Organizational Planning	Identifying, documenting, and assigning the project roles, responsibilities, and reporting
• Staff Acquisition	Getting the human resources needed assigned to and working on the project

• Communications Planning	Determining the information and communication needs of the stakeholders: who needs what information, when will they need it, and how will it be given to them
• Risk Identification	Determining which risks are likely to effect the project and documenting the characteristics of each
• Risk Quantification	Evaluating risks and risk interactions to assess the range of possible project outcomes
• Risk Response Development	Defining the enhancement steps for opportunities and responses to threats
• Procurement Planning	Determining what to procure and when
• Solicitation Planning	Documenting product requirements and identifying potential sources

The following is a proposed combination between the core planning and facilitating processes that is useful and practical in an entrepreneurial environment. The hybrid process is meant to be an iterative process that allows one to initially sweep across all of the project management activities for breadth (verify system flow) and then gather more depth (refining the details) in every subsequent iteration. The hybrid process includes the following steps:

<b>Project Management Process Steps</b>	<b>Entrepreneurial Needs</b>
1. Define the deliverables and key milestones	Planning to achieve value creation
2. Define the tasks required for each of the deliverables	Planning to achieve value creation
3. Define the sequence of tasks	Planning to ensure Timeliness
4. Identify the critical path(s)	Planning to ensure Timeliness
5. Define and evaluate the risks	Planning to reduce Risks
6. Develop risk management	Planning to reduce Risks
7. Develop schedules and contingencies	Planning to reduce Risks
8. Re-evaluate the critical path(s)	Planning to reduce Risks
9. Plan for the physical resources (building, equipment, etc.)	Planning to achieve value creation (minimizing committed resources)

10. Plan for the personnel resources (permanent, temporary, contract, etc.)	Planning to achieve value creation (minimizing committed resources)
11. Calculate the budget with reserves	Planning to achieve value creation (minimizing committed resources)
12. Repeat steps above as required	Planning for value creation, Timeliness & Risk Management
13. Obtain agreement and commitment from all parties	Planning for value creation, Timeliness & Risk Management
14. Launch the project	Planning for value creation, Timeliness & Risk Management

### **3.4. Monitor and Control**

The monitor and control activity is a combination of the two PMI processes called the executing and controlling processes. The activity focuses on monitoring and reporting the performance of the project and the implementation of preventive and corrective actions based upon the performance of the project. The observance of significant performance variances requires adjustment to the appropriate planning processes. The collective activity, as defined by PMI, includes the following steps:

• Scope Verification	Formalizing the acceptance of the project scope
• Quality Assurance	Evaluating the overall project performance on a regular basis to provide confidence that the project will satisfy the relevant quality standards
• Team Development	Developing individual and group skills to enhance project performance
• Information Distribution	Making needed information available to project stakeholders in a timely manner
• Solicitation	Obtaining quotations, bids, offers, or proposals as appropriate
• Source Selection	Choosing from potential sellers
• Contract Administration	Managing the relationship with the seller
• Overall Change Control	Coordinating changes across the entire project
• Scope Change Control	Controlling changes to the project scope
• Schedule Control	Controlling changes to the project schedule

• Cost Control	Controlling changes to the project budget
• Quality Control	Monitoring specific project results to determine if they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance
• Performance Reporting	Collecting and disseminating performance information including status reporting, progress measurement, and forecasting
• Risk Response Control	Responding to changes in risk over the course of the project

The following is a list of key factors used to determine and set the project priorities:

- Completion or delivery date
- Non-Performance penalty risks
- Customer
- Competitive risks
- Technical risks
- Management sponsor
- Return on Investment
- Magnitude of Costs or Investment
- Impact to other projects
- Impact to other affiliated organizations
- Impact to other product lines
- Political and visibility risks

A brief and concise Project Management Plan (PMP) documents the way the program will be managed and controlled by containing the following information:

- functional requirements, design documentation and product specifications
- list of the critical resources (equipment and personnel)
- list of the manufacturing and special test equipment
- description of new or high risk technology
- list of the development tools
- high level project schedule with assigned resources
- identify key technical events and milestones
- detailed list of tasks with the assigned resources
- detailed project schedule
- system test plan



There are good practices for the project manager in an entrepreneurial environment, typically the entrepreneur, parallels the set responsibilities for other project managers. These responsibilities typically include the following:

- Plan to plan
- Set a clear overall strategy and set of objectives
- Motivate the team
- Involve knowledgeable and interested resources
- Get a commitment from the resources and then empower them
- Closely manage the cost and schedule
- Challenge the schedule and look for ways to improve it
- Quickly resolve any cost and schedule conflicts
- Closely manage the risks and look for ways to minimize them
- Maintain a current plan

### **3.5. Risk Management**

The definition of risk is a measure of the probability and consequence of not achieving a well-defined project goal. Risk Management is an organized means of identifying and measuring the different options to resolve these risks. In the context of a project, risk management is the art and science of identifying, analyzing, and responding to the risk factors throughout the life of a project and in the best interest of the objectives. The most important issue with risk management is the identification of the different risks themselves. After the risks have been identified, the focus becomes the identification and selection of alternative action plans that are consistent with the project objectives and minimize or avoid the risks. Unfortunately there are many sources of risks, they are typically a result of poor planning, poor risk analysis, poor management and/or unanticipated technology changes. The following will identify some of the sources of risk. [11]

#### **General Risks**

- Inappropriate technical people because they lack training or experience with the technical tools (hardware and/or software tools) used in the project. Independent individuals that don't function well in a team environment, which relies on cooperation, and good interpersonal skills and team communication.
- Improper working environment that does not provide all of the appropriate development tools needed to efficiently complete the project. The environment should also minimize the number of overall interruptions.
- Third party supplied resources that are not under direct control. The relationship with this party must be explicitly defined and should include intermediate performance reviews and penalty clauses for non-performance.
- Unspecified payment/budget because of the complications related to payment collection. The project payment process needs to be structured and synchronized with the project development and management strategy. Projects that rely on funds every quarter run the risk of being cancelled every quarter while projects relying on payment after completing certain milestones depend on clear definition of the milestone acceptance requirements.

#### **Financial Risks**

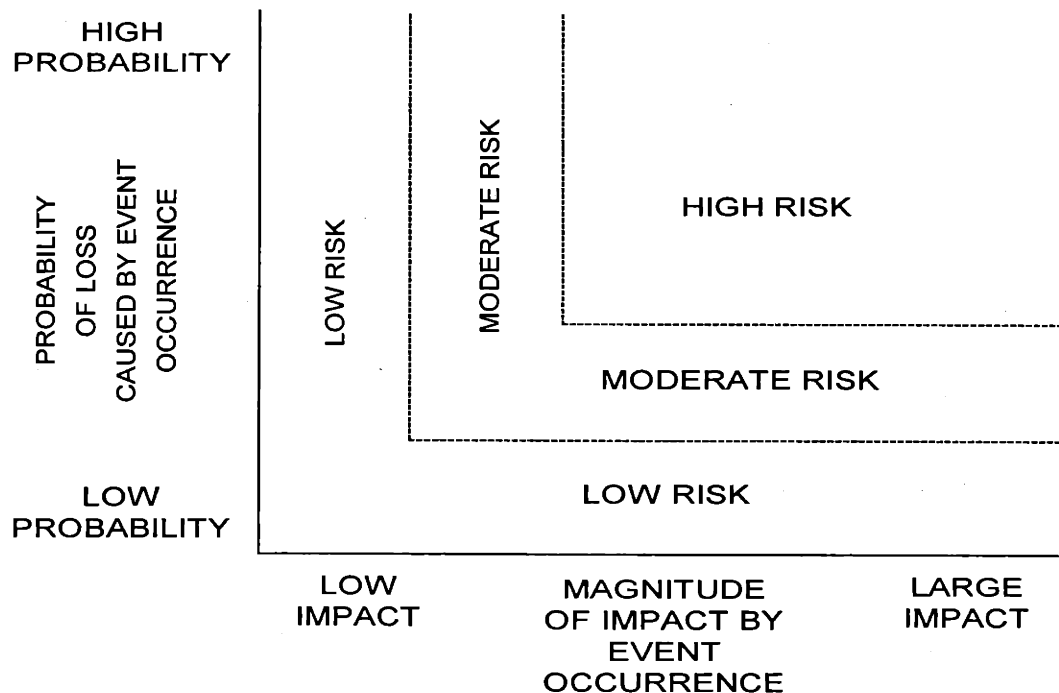
- Distributed project management with dispersed development teams can lead to excessive travel expenses.
- Over-management of the project that requires documentation for every significant and non-significant project activity and that relies on committee decisions.

### Technical Risks

- Wrong technical solution where the underlying architecture, tools or configuration does not properly match the cost, performance or capacity requirements of the product. For example, the BASIC programming language should not be used to develop an Internet-based software system.
- Bad requirements/specifications that are unclear and ambiguous are likely to require project/product changes that may be expensive and difficult to implement. The combination of these events could all also greatly complicate the payment collection process.
- Lack of User knowledge and how the product will be used may lead to product emphasis on the wrong issues or the oversight of a critical issue. Product attributes with respect to user friendliness and responsiveness can be difficult to quantify without actual end user involvement. [28]

Risk has three primary components: an event (unwanted change), its probability of occurring, and the overall impact of the if the event occurs (typically in terms of dollars). Proper risk management particularly within an entrepreneurial is proactive and not reactive. The project manager develops contingency plans in advance to reduce the likelihood of a potential high risk event occurring and the overall magnitude of its impact. The following chart helps to categorized the risk associated with an event based upon its primary components.

### Risk Classification based upon RiskComponents



## **4. Traditional Project Management**

### **4.1. Overview**

Traditional project management focuses on the definition of the project work structure and the production of detailed schedules and budgets for monitoring and controlling performance throughout the entire project life cycle. [25, 32]. The traditional techniques and methods provide extremely useful means of organizing and capturing vital project information and then communicating it via graphical representations and reports. Most of the traditional project techniques support one of the following functions: work definition, network techniques for work schedules, and cost and performance analysis.

### **4.2. Planning Considerations**

The planning process has different paradigms that reflect the many different perspectives of planning. The project planning activity can be viewed from three different perspectives, the task, resource or assignment perspective. Task planning can be done via outlining, work breakdown structure, interactive programming and bar charting. Outlining is the easiest and the most intuitive method because it closely resembles the way a person thinks. The process is iterative in nature where the project tasks are defined in broad terms, typically by the type of activity, and then refined as more details are available. The type of activity can be also be sub-classified by the lifecycle phase (requirements, design, implementation, integration, testing, production, etc.) of the project. Resource planning is used to define realistic project schedules based upon the availability of the different resources needed. Assignment planning identifies the specific resource that will perform each task based upon the skill set, level of effort required and the availability of the resource. [11]

The planning process should give ample consideration to the issues related to the team environment and team performance. Informal communication between the group members can be encouraged by the physical layout of the offices. The number of regular meetings with the entire team should be reduced and complemented with a combination of regular meetings with the core team members, informal meetings between team members, and the process of seeking out specific information by individual core members. This will help to eliminate the wasted time and increased level of frustration that occurs when the meeting has too many elaborate discussions on things that only involve a small portion of the team. Periodic team meetings with the entire team should only be used as a coordination activity to keep everyone informed and updated on the progress and status of the project.

The team members should be empowered and thus given sufficient latitude so that they can manage their work on a day-to-day basis, handle their job responsibilities, internally plan and schedule their work, make production-related decisions, take action to solve problems, and share leadership responsibilities. The use of empowerment creates an environment where employees function with greater efficiency and productivity. This empowerment though does not come without a price and that is typically increased risk and/or project costs. Sometimes the empowered decisions by individuals or by a team focused on specific project attributes lead to results that do not add value to the overall system. In these types of circumstances the risk is that the overall project costs are significantly increased. The project manager and the team must therefore evaluate these types of decisions from a holistic, system level perspective to ensure that the overall affect to the system is a positive one. Project management must also be more tolerate of mistakes. The management style best suited for this type of environment is one of accommodation where management looks for stakeholders and finds compromise between the parties. [41]

The implementation planning of the product should take into consideration the five different modes of implementation: in-house development, farmed-out development, licensing, joint venture, and acquisition. An important point is that the different modes are not mutually exclusive. Each of the different modes have their strengths and weaknesses. In most cases, but particularly for an entrepreneurial firm, the best implementation mode or combination of implementation modes is highly dependent upon the maturity stage of the company and the amount of funding that is available. Exclusive use of a mode like farming-out is unadvisable and seldomly used. One example being, if the entrepreneurial company has identified an opportunity that requires a technology or process that they own the patent on, then it would make sense to keep the development and core competency in-house. On the other hand, if the opportunity and value proposition is based on the marketing and/or distribution of the product, then ample consideration should be given the options beyond in-house development. [33]

<b>Implementation Mode</b>	<b>Strengths</b>	<b>Weaknesses</b>
In-house	<ul style="list-style-type: none"> <li>• Better control, coordination and decision making</li> </ul>	<ul style="list-style-type: none"> <li>• Need to have the critical skills or resources</li> <li>• Requires detailed management</li> </ul>
Farmed-out	<ul style="list-style-type: none"> <li>• Use of external expertise to complement organization</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of direct control on operations</li> </ul>
Licensing	<ul style="list-style-type: none"> <li>• Use of external expertise to complement organization</li> </ul>	<ul style="list-style-type: none"> <li>• Limitations of license</li> </ul>
Joint Venture	<ul style="list-style-type: none"> <li>• Use of external expertise to complement organization</li> </ul>	<ul style="list-style-type: none"> <li>• Limitations of agreement</li> </ul>
Acquisition	<ul style="list-style-type: none"> <li>• Quickest availability of product and/or service</li> </ul>	<ul style="list-style-type: none"> <li>• Typically requires largest amount of funding</li> </ul>

### **4.3. Systems Definition**

The word “system” can mean many things to different people. A commonly accepted definition of a system is a “an organized or complex whole; an assemblage of things or parts interacting in a coordinated way.” These parts within a system do not need to be physical entities; they can in fact be abstract or conceptual entities like words in a language or steps in a specific process. A list of the commonly referred to systems includes river systems, planetary systems, transportation and communication systems, nervous and circulatory system, production and inventory systems, ecosystems, urban systems, stereo systems, philosophical systems, and computer systems. Several other features of a system are that the parts of the system are affected by being in the system and are changed if they leave it. The collection of parts must accomplish something. An important attribute to a system is that this collection of connected elements provides functionality greater than the sum of its individual elements. A simple example of this attribute is water because it is more than just the characteristics of hydrogen and oxygen combined. A project can also be viewed as a system – a system composed of people, equipment, materials, and facilities organized that is managed to achieve the project goal. At the same time, the objective of the project is to probably develop a product or service that itself is also a system. [10, 25]

### **4.4. Systems Architecture Framework**

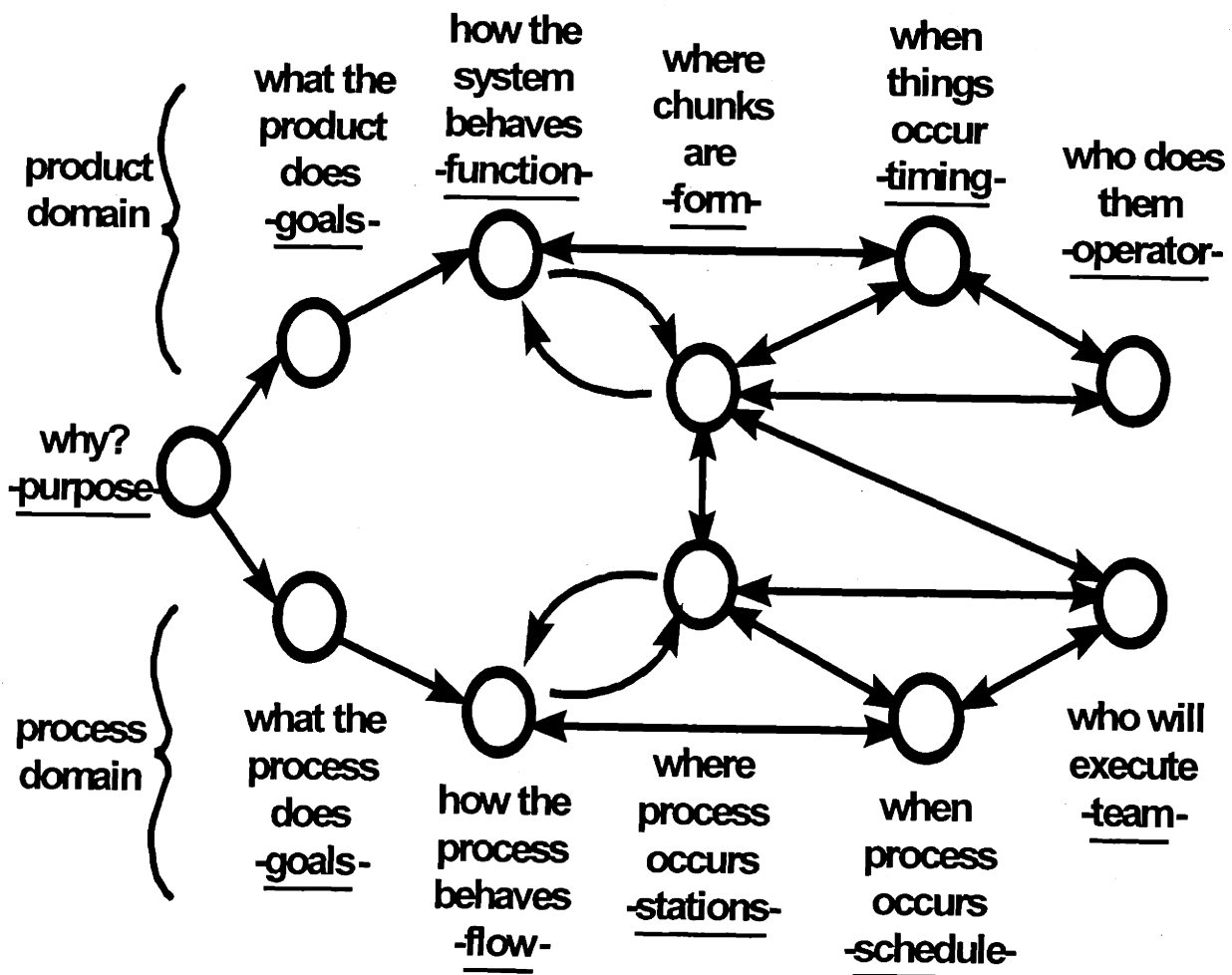
Systems architecture provides a process of partitioning and decomposing the system (or product) into smaller subsystems so that it can be developed and managed more effectively. There are also several accepted definitions of system architecture: 1) structure, arrangements or configuration of system elements and their internal relationships necessary to satisfy constraints and requirements [10], and 2) arrangement of the functional elements into physical blocks [13]. System architecture is particularly important because modern systems are becoming increasingly complex. Systems that are generally considered to be complex contain multiple levels of functionality and/or require a large level of decomposition to be understood. Complex systems will also typically contain a large number of subsystems and interfaces and/or sophisticated subsystems and interfaces.

An overarching aspect of system architecture is to clearly define the relationships among the elements in a way that minimizes complexity. This is an important contribution to project management because less complexity typically equates to better project management and execution regardless of whether or not it is in an entrepreneurial environment. There still are several important elements to any successful system architecture. The first element is the problem statement itself, which must be continuously challenged to ensure that the final problem definition is generic, accurate and complete. Setting specific system boundaries will help to simplify the problem statement. The second element is the functional description of the system. The functional description should in a solution neutral format and describe how the system behaves and what the architect wants to achieve while the form describes the

physical/logical partitioning of the system elements. The other important element is the translation from function to form, which includes several iterations of the following four steps: function definition, concept definition, form definition and function to form mapping. These steps enforce the principle that form follows function. The form refers to the process of partitioning and answers the question of how does the system/product achieve its result. The function refers to the process of decomposition and answers the question of what does the system/product have to achieve.

The critical initial step is to consider the system from a holistic perspective. There are several holistic frameworks but a good general holistic framework is a total holistic view of the product and process architecture. This will help one to understand the needs of the entire system and its stakeholders so that one can identify and focus on the critical part(s). [10]

## Total Holistic View of Product/Process Architecture



#### **4.5. Systems Approach**

It is important to view and manage the project, the development of its product(s) and service(s), as a holistic system so that one can make the appropriate planning and execution trade-offs. A systems approach acknowledges the fact that behavior of any one systems element may affect other elements, and no other single element can perform effectively without the help of others. The systems approach is fundamentally built on this recognition of interdependency and cause-effect among elements. In this scenario, the system is managed from the perspective of the entire overall system. This approach is extremely valuable regardless of whether or not it is in an entrepreneurial environment because project decisions are made to optimize the system as a whole. As stated by Joseph Moder, the systems concept instills the desire to achieve overall effectiveness of the organization, in an environment, which may invariably involve conflicting objectives, motivations, etc. [23]

Management from a systems perspective considers all of the following key elements:

- Objectives and performance measures of the whole system.  
The mission or objective of the system must be precise and measurable in terms of specific performance criteria. The system performance metrics should be realistic and reflect many of the consequences of the system.
- Environment and constraints of the system.  
The environment of the system must be explicitly identified so that their inter-relationships can be understood and better managed. This process will disclose the inputs, outputs and constraints for all of the different subsystems and external resources required by the system.
- Resources of the system.  
These resources which are internal to the system should also be explicitly identified so that they are utilized effectively while they are still available.
- Elements of the system - along with their functions, goals, attributes, and performance measures.  
The elements of the system are viewed in terms of the “work packages” they are designed to provide.
- Management of the system.  
The management of the system is the function responsible for planning, monitoring, controlling, and risk management of the system while taking into account all of the previously mentioned aspects of the system.

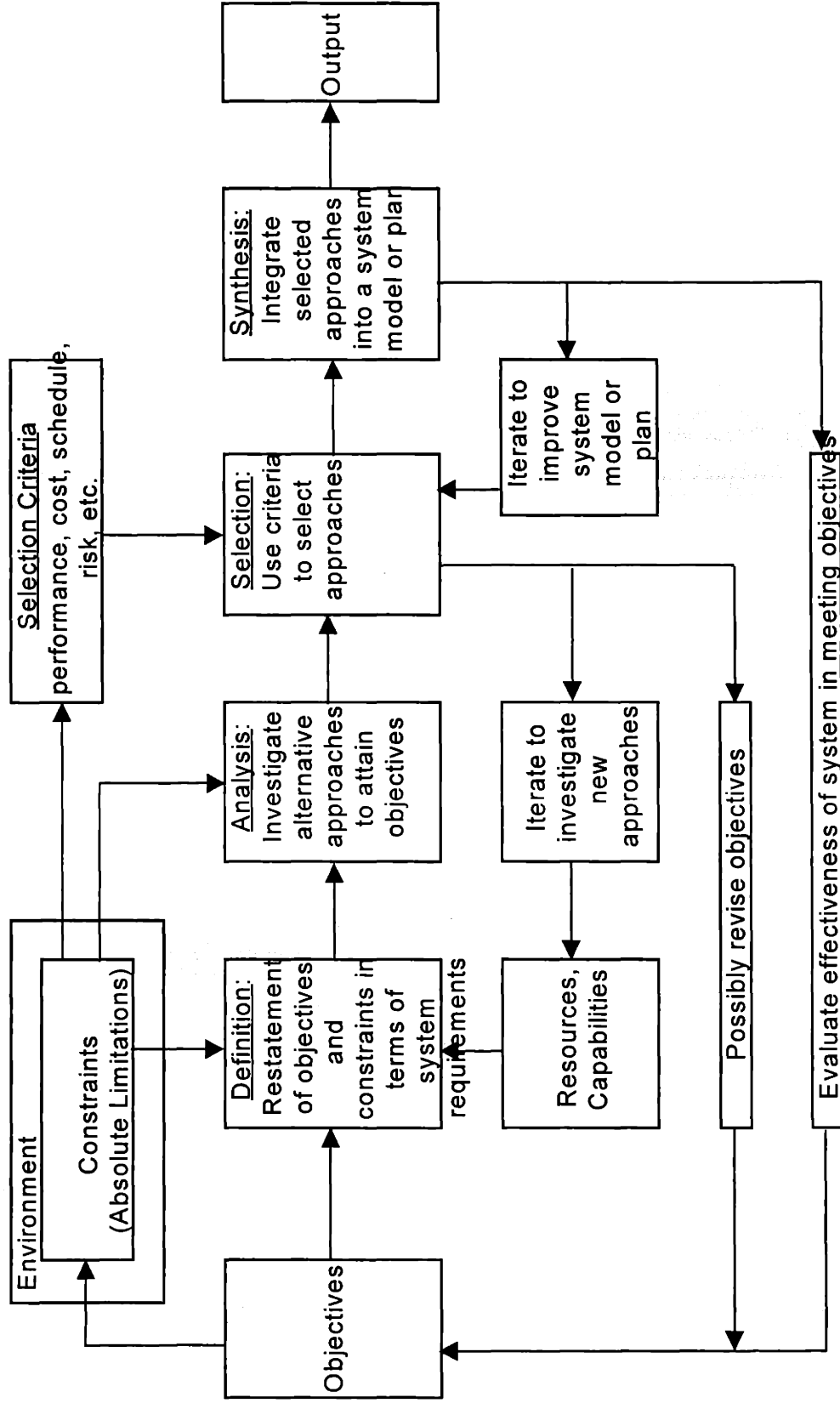
Systems engineering practices are well suited to tackle this problem. Systems engineering is the process required for the analysis, development (design) and integration of a system and takes an active role during all of the product development phases. In this scenario, the role of system engineering is to transform an operational (user) need into a system configuration that best satisfies the operational need within an environment and according to appropriate measures of effectiveness. It will also integrate related technical parameters and ensure compatibility of all physical, functional, and technical program interfaces in a manner that



optimizes the total system definition and design, while minimizing technical and problematic risk. (Boppe - SEI, Systems Engineering Capability Maturity Model). [7] A sample list of the major activities during system analysis includes: identify customer needs, develop requirements, identify functionality, derive architecture, identify interface, and develop measures of effectiveness. Some of the major activities during system design include: design synthesis and analysis and component definition. Finally, several of the major activities during system integration are component and system test and validation. [7]

# Systems Approach Chart

(J.M. Nicholas, *Managing Business & Engineering Projects*)



#### 4.6. Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) is a method to define the overall work scope by identifying all work of the components necessary to produce a complete system. The WBS is a deliverable-oriented grouping of the project elements that organizes and defines the total scope of the project. Work not mentioned in the WBS must be outside the scope of the project. [11] A complementary systems approach of performing a WBS is by further decomposing the project tasks based upon the outputs from the system architecture and systems engineering activities. An important objective of the WBS is to reduce the complexity of the tasks by breaking them down into several other tasks. This breakdown process continues until all of the following criteria have been satisfied; the resulting tasks or subtasks must be:

• Assignable	One can assign an individual the responsibility for accomplishing the task(s).
• Measurable	One can develop a rough estimate for the amount of effort (typically in person-days) that is required to accomplish the task(s). The progress of the task(s) must also be measurable.
• Independent	The individual tasks can be developed and completed independently.
• Integrateable	The individual tasks can be combined with other activities and add value and/or functionality.
• Manageable	The individual tasks can be scheduled based upon their duration and dependencies.

The person or group that is responsible for accomplishing that specific task should develop the estimate of the effort involved for each task. This process of estimating is critically important in project management because any error or oversight will mostly likely require significant changes to the project schedule, and the project and risk management strategies. Three common techniques used in estimating the effort for a task are professional judgement, historical data, and formulas. The use of all three techniques will typically provide the best estimate. The professional judgement technique is primarily based upon the experience of the person generating the estimate, so the more experienced the person – the better the estimate. The historical data technique is based upon recorded data from past projects. The philosophy here is that one can estimate a re-use of similar a project much more accurately than a rewrite. The formula technique is probably the most comprehensive method but unfortunately is also the most time consuming method. The formula technique relies upon a mathematical equation that incorporates heuristics and historical knowledge on the three basic factors that affect the duration of a task: the complexity of the task, the general work experience of the person/group performing the task, and the type of job knowledge required by the task in relation to the general work experience of the person/group performing the task.

The WBS is usually structured by product and then by the elements of the product and is often used to confirm a common understanding of the project scope. The WBS has many levels depending upon the micro or macro-level perspective. A project will typically contain at least three different levels that describe the project, task, and subtasks. The project level provides the system level perspective that describes all of the subsystems and their major tasks. The subtasks, which must meet the criteria mentioned above, provide low level, measurable details. The tasks/subtasks identified by the WBS are the fundamental elements necessary for the development of a project network and schedule.

A simple version of a WBS includes the following essential elements:

- WBS level
- Task name / ID
- Brief task description
- Task duration (in terms of person-days)
- List of constraints
- Required inputs / dependencies
- Expected output
- Special equipment requirements
- References to all of the critical specifications or support documents

#### 4.7. Risk Management Applications

There are several project management techniques and strategies to reduce risk management. The techniques typically focus on improving the identification and quantification of the risks. The simple risk management technique presented emphasizes the importance of constantly anticipating risks and then preparing for them. The technique requires the project manager to maintain an active list of the top potential risks and assign them a probability of occurrence, impact and priority (numbers assigned range from 1-10 where a 10 could stop the project). The risk management strategies presented are primarily based upon the amount and type of known information about the unwanted event and can therefore be categorized into three realms: certainty, risk, and uncertainty. The progression from certainty to risk to uncertainty means that the overall negative impact to the project increases. The emphasis in risk management is to understand and gather information about unwanted events so that the amount of uncertainty and risk for the event is reduced - therefore shifting it into the realm of certainty. [18, 28]

**Risk Identification Table**

Item No.	Risk Description	Probability (1-10)	Impact (1-10)	Priority (P I)
1	Don't get user clarification on requirement xx	2	7	14
2	Don't identify second source for xx	6	7	42
...	...	...	...	...
N	Don't complete supplier agreement for xx	5	9	45

Ideally, the best risk management strategy is to make project decisions under certainty because by definition all of the important information about the unwanted event is known. These types of decisions simply require an evaluation to determine which option is best suited for the project. For example, using the table below, the project manager should select Strategy #2 because under all of the circumstances the project is profitable.

**Pay-Off Matrix (Decisions under Certainty)**

Strategy	Event Outcome #1	Event Outcome #2	...	Event Outcome #N
S <sub>1</sub>	\$6M	\$4M	...	-\$1M
S <sub>2</sub>	\$1.75M	\$0.25M	...	\$1M
S <sub>3</sub>	\$1M	\$1M	...	-\$1.5M
...	...	...	...	...
S <sub>N</sub>	\$8M	\$6M	...	-\$4M

In reality, it is more likely that one will have some (not all) of the important known information about the unwanted event and there is enough information to predict the probability of the event occurrence. The Project decisions in this case are based under risk where each outcome per strategy contains the result of outcome and the probability of occurrence. In this environment, the best choice is the strategy with the highest expected value, which is the summation of the payoff multiplied by the probability of occurrence for each of the possible strategies. The general mathematical formula is  $E$  (per strategy) =  $\Sigma$  (Outcome Result \* Probability of Occurrence). The project manager should select strategy with the largest expected value that does not exceed the maximum amount of money the company is willing to invest. For example, according to expected value calculations based on the table below, if the company can afford to invest \$4M, then the project manager should select Strategy #N. The next best strategy is Strategy #1 then followed by Strategy #2. Notice that Strategy #3 actually produces a negative number; given the outcomes and probabilities in the table, it should never be selected.

Expected value calculations:

$$\begin{aligned}
 E_1 &= (\$6M * 0.25) + (\$4M * 0.25) + (-\$1M * 0.50) = \$2.00M \\
 E_2 &= (\$1.75M * 0.25) + (\$0.25M * 0.25) + (\$1M * 0.50) = \$1.00M \\
 E_3 &= (\$1M * 0.25) + (\$1M * 0.25) + (-\$1.5M * 0.50) = -\$0.25M \\
 E_N &= (\$8M * 0.25) + (\$6M * 0.25) + (-\$4M * 0.50) = \$2.50M
 \end{aligned}$$

### Pay-Off Matrix (Decisions under Risk)

Strategy	Event Outcome #1 Probability of 25%	Event Outcome #2 Probability of 25%	...	Event Outcome #3 Probability of 50%
S <sub>1</sub>	\$6M	\$4M	...	-\$1M
S <sub>2</sub>	\$1.75M	\$0.25M	...	\$1M
S <sub>3</sub>	\$1M	\$1M	...	-\$1.5M
...	...	...	...	...
S <sub>N</sub>	\$8M	\$6M	...	-\$4M

The final case is where there is some (not all) of the important known information about the unwanted event and there is not enough information to predict a meaningful probability for each event occurrence. The project decision in this case must account for uncertainty. The strategy chosen will be based on two primary issues: the type of risk preference of the company and project manager, and the maximum amount of money the company is willing to invest (or willing to possibly lose). The complexity when making project decisions under uncertainty comes from process of comparing all of the possible options available. The risk management decisions can be made from the perspective of minimizing the potential risk or maximizing the potential profit or some complex combination between the two. For example, using the table below, a project manager who wants to minimize the risk would select Strategy #2. On other hand, a project manager wanting to maximize the return would select Strategy #N.

### Pay-Off Matrix (Decisions under Risk)

Strategy	Event Outcome #1 Probability Unknown	Event Outcome #2 Probability Unknown	...	Event Outcome #3 Probability Unknown
S <sub>1</sub>	\$6M	\$4M	...	-\$1M
S <sub>2</sub>	\$1.75M	\$0.25M	...	\$1M
S <sub>3</sub>	\$1M	\$1M	...	-\$1.5M
...	...	...	...	...
S <sub>N</sub>	\$8M	\$6M	...	-\$4M

In most environments, whether in an entrepreneurial or established firm, many of the daily project decisions about risk management are done based upon personal or corporate heuristics. An important point is to separate the daily tactical decisions from the strategic project decisions. These strategic project decisions should explicitly rely on one or several of the decision strategies. The process of the decision should also be recorded so that the document can serve as an informational reference for others on the project or as knowledge repository for future projects.

## **5. Critical Chain Management**

### **5.1. Overview**

The Critical Chain method is an application of the Theory of Constraints Principles in project management. [16] For any successful project there must be a well defined problem statement, a project objective that resolves the problem statement, a project scope and design that achieves the project objective, and finally good project execution where the project is completed within the budget and on time. The Critical Chain methodology focuses on improving the project scheduling and management. It relies on three fundamental concepts: eliminate or minimize the use of multi-tasking, remove safety buffers from individual tasks and add large safety buffer at strategic places, and continuously account for proper resource contention.

One of the most important contributions of the Critical Chain method is that it minimizes or eliminates some of the larger inefficiencies of traditional project management. Critical Chain encourages minimum use of resource multi-tasking because multi-tasking in itself is a very inefficient way to use valuable resources. The use multi-tasking will inherently extend the completion date for all of the tasks being multiplexed. There are also other negative effects associated with the loss of time and efficiency incurred while switching between the tasks.

Another inefficiency with traditional project management techniques is that an early finish of a task is not necessarily encouraged. When estimating the effort to complete each task, a safety buffer is added to the tasks. Unfortunately, the safety time for an individual task becomes "lost time" because the person responsible to complete the task tends to pace themselves or procrastinate. The fundamental flaw is that the potential gain (schedule gain) by completing tasks early is rarely appreciated. On the other hand, the delays caused by uncertainty when completing the more complex tasks produces an overall schedule delay.

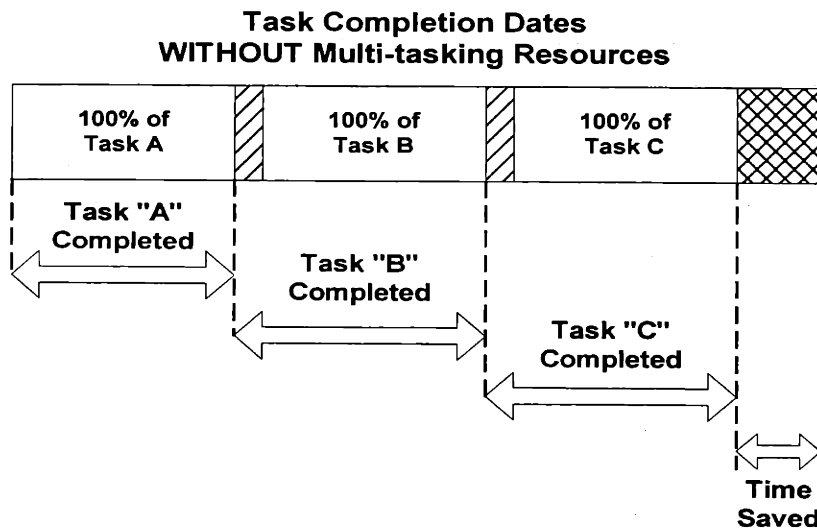
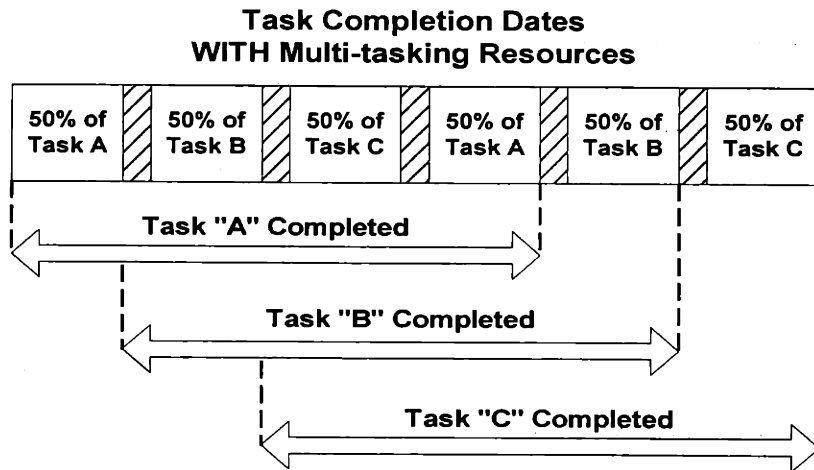
#### **5.1.1. Multi-tasking Deficiencies**

The following illustration will show a comparison between two identical projects. Each project contains three different tasks all having the same duration. In the first example, 50 percent of Task A is first completed, then 50 percent of Task B is completed and then 50 percent of Task C is completed. The remaining 50 percent of the tasks are then completed in the same order. There is a fixed amount of time lost while switching between the tasks. This switching time can represent a number of things like the re-initialization of equipment and individual ramp up time. In the second example, all of Task A is first completed, then all of Task B is completed and then finally all of Task C is completed. The same amount of lost time (due to switching between tasks) exists between the tasks. The simple illustration depicts several negative affects of multi-tasking resources. One negative is that the completion date for each the tasks are extended. The other noticeable negative affect is the



total time lost (when compared to not using multi-tasking resources) at the end of the project.  
[9, 24]

### Negative Effects of Multi-tasking Resources



**Note:** The pattern areas between the tasks represent lost time due to switching between tasks

Critical Chain method discourages the use of multi-tasking resources. It also encourages the early finish of individual tasks by removing the safety buffer from the individual tasks. The individual task duration times tend to be more aggressive. It is best to assign the task duration times and resources as a team. Team peer pressure will help to keep the task estimates honest. The team-based activity will help to ensure buy-in and commitment over the long haul. The overall project is still protected against uncertainty by adding a single large safety buffer at the end of the project. It is important to note that the single safety buffer is typically much smaller than the sum of the individual safety buffers.

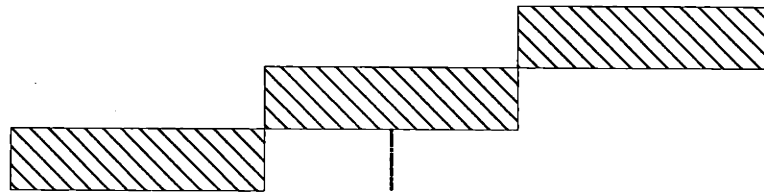
Traditional project management approaches do not consider the hidden costs associated with work-in-process (WIP) and lost productivity. The development WIP costs are similar to the increased costs of WIP in a manufacturing environment. Several examples of development WIP costs are:

- External investments with vendors or subcontractors
- Internal costs associated with resource and equipment usage
- Costs can represent investments in raw material

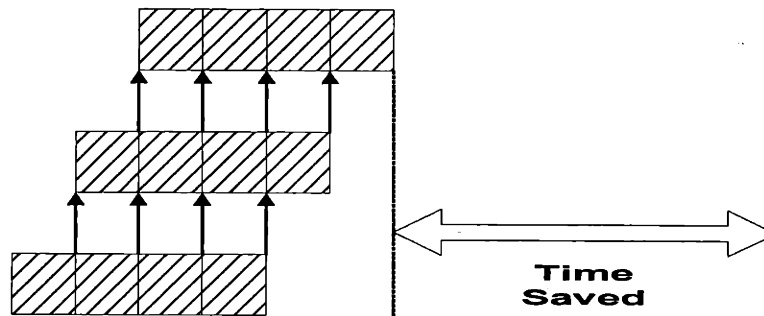
### **5.1.2. Work Transfer Deficiencies**

WIP can also be artificially inflated by simply working on and transferring large batches of work between resources. It is artificially inflated because the increases in WIP are not related to actual durations of the tasks. Over-commitments from resource multi-tasking also lead to increases in WIP. In this case, the resource will typically focus on the high priority tasks because they can not afford to get too far behind on any single project. The resource soon falls into the vicious cycle of constantly switching between these tasks on different projects, which makes both tasks take longer than required. [24]

### Large Batch Work Transfers



### Small Batch Work Transfers



The most notable advantage to reducing WIP is the improvement in product delivery time because the pipeline is no longer clogged with older materials. This improvement also reduces the lead times and allows quality problems to potentially be discovered much earlier in elapsed time thus effecting a fewer number of overall products. These improvements in delivery time also provide subtle reinforcing improvements related to the fact that the shorter the project cycle, the less likely the requirements will change.

The hidden costs associated with lost productivity are related to human nature. One is described in Parkinson's Law, which states that work expands to fill the available capacity. Potential symptoms of Parkinson's Law could be found if people are almost never idle, people become more productive during sudden periods of critical need, and/or people waste time at the beginning of the project. Productivity losses can also be found in any of the following:

- Set-up time incurred while switching between multiple projects
- Too many people on a task actually increases the time to complete it because of the high overhead associated with the intercommunications between the people
- Too much work becomes demoralizing because the person responsible for completing the work knows that the high amount of work will always be there and can therefore never get ahead
- Penalty for being late is much greater than the reward for being early

In summary, the hidden costs associated with increased WIP and lost productivity that may lead to late, over-budget, and under-performing projects fundamentally stem from the fact that:

- Workers are measured on how busy they stay
- Workers are measured on whether they meet their commitment dates
- Workers are encouraged to finish too early because they would then appear like someone who over inflates estimates

In order to properly address many of these core problems, project managers (in particular) should make the following recommended adjustments:

- Workers should not be *strictly* measured on how busy they are or whether they consistently meet their commitment dates
- Use average task duration estimates rather than the inflated estimates that are padded for uncertainty
- Stop or minimize the use of resource multi-tasking so that tasks can be completed in the average time estimate
- Accept the concept that late tasks don't imply late projects and that busy workers don't imply better bottom-line results
  - For example, a person may work extra hard and put in extra hours to complete a task on time only to find out that the next person in line is not even ready for it.
- Reduce overall uncertainty in the project by focusing on global (system-wide) improvements rather than local ones. Identifying the weakest link (critical chain) as being the longest path through the network (in terms of time) and then making improvements on this link to actually complete the project earlier
- Believe and look for dramatic improvements because if they exist than one has a better chance of finding them

## **5.2. Advantages**

The ideal project schedule combines the attributes of being extremely accurate without the requirement of continuous updates. Unfortunately, the practical existence of this project schedule and environment is non-existent. A good compromise, though, would be a schedule that is realistic and requires low maintenance. A project schedule of this type is extremely compatible with the demands of an entrepreneurial environment. This realistic, low overhead project schedule would have the following characteristics.

- Realistic and primarily based on known information
- Does not require frequent changes
- Reliable and deals with short-term uncertainty
- Illustrate key tasks
- Emphasizes system level perspective (rather local optima)

The Critical Chain allows the project manager to develop a realistic schedule that does not require major changes every time a late task is encountered. By knowing the status of the safety buffers, the project manager will have a better sense of the impact that a late task has to the overall project. Without this type of information, one is likely to under react or over react to the situation.

The benefits of the Critical Chain approach to project scheduling include:

- Realistic schedule since it is based on resource usage
- Provides better results (value creation) since based on average task durations and not padded durations
- Reliable because it uses strategically placed buffers
- Reduces need for frequent changes because project manager simply manages the status of the strategically placed buffers
- Emphasizes system level perspective by using globally oriented measurements

In summary, the important contribution of the critical chain process is to develop a realistic schedule that significantly improves chances of success by focusing on the important requirements of the project and strategically placing safety buffers in the project for protection against uncertainty. The uncertainty is managed by monitoring the buffer status to determine project status and then developing the proper actions of response. Uncertainty can also be reduced by simply scheduling the high-risk tasks as early as possible. The project manager will then have more time to respond to any potential problems. An example of reducing high-risks tasks that appear late in the project is by separating the formal acceptance testing task and performing the rigorous testing portion earlier in the project. This allows the potential problems to be discovered and corrected much earlier in the project and thus minimizing its effects to the project buffer. When all is said and done, the two key measurements of a good project schedule will be: how quickly the project finished and the amount of WIP it required (similar to the amount of committed resources).

### **5.3. Scheduling**

The Critical Chain approach to scheduling is built on the principle of identifying all of the key tasks and then exploit their performance. These key tasks are all on the critical chain, which ultimately dictates the duration of the project. The tasks are exploited to make sure that everything possible is done to ensure that these tasks are completed ahead or at minimum according to the schedule. The high visibility of key tasks promotes a general awareness by others for the need to work together to protect the critical chain.

### **5.3.1. Critical Chain Identification**

The process of identifying the critical chain is based on organizing tasks on the basis of work-flow rather than the type of resources available. Initially, the resources are not viewed as a constraint to the development of the schedule. This approach is very compatible with the needs of an entrepreneurial environment because the work is organized independent of the resources, particularly when the entrepreneurial firm controls only a small number of resources. The organization of the tasks by work-flow will show the precedence dependencies, particular order or time sequence of the tasks. In summary, the critical chain is the set of tasks, which determines the overall duration of the project. It must also take into account the following: precedence and resource dependencies, use of additional resources on critical tasks (assuming there is a cost benefit for using them rather than extending the schedule), and the placement of high-risk tasks as early as possible. Scheduling the tasks as late as possible, without effecting the critical chain, also minimizes the amount WIP in the system. This inevitably improves project flexibility and performance by minimizing the amount of rework required and reducing the overall investment (particularly cash outlays in an entrepreneurial setting) committed in the project at any given time.

In general, the tasks should be scheduled to finish as close as possible to their “late completion” times while still taking into account the precedence dependencies. This will help to reduce the overall amount of re-work when changes occur. In an entrepreneurial environment, it re-enforces the issue of delaying the use of committed resources to the latest moment possible. The individual task estimates should be based on average durations (excluding padding). The schedule should also encourage and promote the concept of not multi-tasking resources because it is a more efficient use of resources. Proper load leveling of the resources should be done so the resource dependencies are not violated. This process ensures that resources are not overloaded by pushing up the start dates (moving them to an earlier date) of the tasks in question with focus of still maintaining the system WIP as low as possible.

### **5.3.2. Application of Buffers**

The project schedule contains three different type of buffers: a single project buffer at the end of the critical chain, feeding buffers on tasks that feed into the critical chain, and resource buffers to ensure resources are available to complete the tasks. An important note is that the project buffer is not slack, it is a key element of the schedule. The use of these buffers is not optional (unlike float, slack & lag times or time reserve). These buffers are needed to protect customers and the critical chain and are not needed with non-critical tasks. The feeding and resource buffers are used to ensure that resources (material, equipment, personnel, etc) are available to supply the critical chain.

The project buffer is strategically placed at the end of the critical chain. It provides protection against fluctuations in the critical chain tasks. The size of the project buffer is based upon the cumulative risk on the critical chain. It should generally be long enough to give 90 percent chance of finishing the project on time, the rule of thumb is to allot 50 percent of the critical chain duration.

The feeding buffers are placed wherever a non-critical chain task joins the critical chain. They provide protection from disruptions on the tasks feeding into the critical chain. The buffers also allows one to get an early start in support of the critical chain in cases where the project completion is ahead of schedule (proactive approach that plans for success). The size of the feeding buffers is based on the overall duration of the feeding chain; the rule of thumb is to allot 50 percent of the feeding chain duration.

The resource buffers are placed wherever the resource working on the critical chain is different from resource used in the previous critical chain task. The buffer provides assurances that the resources will be available to work on the critical chain task. The size of the resource buffer is typically about two weeks. The buffer intention is to simply be a wake-up call to both management and the resource(s) in question.

#### 5.4. Estimating

A modified version of the previously mentioned formula technique (see Work Breakdown section) can be used to calculate the size of the project buffer. The simplified formula technique is based on heuristics and incorporates the three important factors that affect the duration of the buffer size: duration of the critical chain (CC), the complexity of the task(s) in the critical chain (C), and the work experience of the person/group performing the task(s) (WE). The following will briefly describe an example of the simplified formula technique.

**Formula:**  $\text{Project Buffer} = \text{CC} (C + \text{WE}) / 2$

#### Table Template for Complexity Factor

Scale Based Percentage of Critical Chain Size:

Low=0.25, Moderate=0.50, and High=0.75

Critical Chain Attributes	Complexity Rating (Percentage of Critical Chain)
Type and Number of Inputs	x
Internal and External Interfaces	x
Internal Algorithm / Functionality	x
Type and Number of Outputs	x
<b>Average Complexity</b>	x

**Table Template of Relative Efficiency  
Based on Years of General Work Experience**

Classification of Person/Team	Average Years of Experience	Percentage of Critical Chain
Senior Staff	<i>10+</i>	<i>0.30</i>
Senior	<i>5 - 10</i>	<i>0.40</i>
Average	<i>3 - 5</i>	<i>0.50</i>
Junior	<i>1 - 3</i>	<i>0.75</i>
Trainee	<i>0 - 1</i>	<i>1.00</i>

Note: The table entries and numbers (numbers in Italics) should be adjusted based upon heuristics and the firm's work environment.

**Sample Calculation:**

Description of Assumptions	Factors
• Critical Chain estimate is 100 person-days	<b>CC = 100</b>
• Resource classification is Senior (team average work experience is 5 years)	<b>WE = 0.40</b>
• Complexity classification (see table below)	<b>C = 0.4375</b>

**Sample Complexity Factor Table**

Scale Based Percentage of Critical Chain Size:

Low=0.25, Moderate=0.50, and High=0.75

Critical Chain Attributes	Complexity Rating	
	Assignment	Value
Type and Number of Inputs	<i>Moderate</i>	<i>0.50</i>
Internal and External Interfaces	<i>Low</i>	<i>0.25</i>
Internal Algorithm / Functionality	<i>Moderate</i>	<i>0.50</i>
Type and Number of Outputs	<i>Moderate</i>	<i>0.50</i>
<b>Average Task Complexity</b>	<i>N/A</i>	<b><i>0.4375</i></b>

- **Project Buffer =  $100 * (0.40 + 0.4375) / 2 = 42$  person-days**



## **5.5. Monitor and Control**

The monitor and control activities rely on two categories of measurements, global measurements and local measurements. The global perspective encompasses the entire system, macro perspective where results are evaluated over a broad period of time. This is typically not a day-to-day analysis. The different types of global measurements are described below.

- Throughput or Throughput Dollar Days (value creation & productivity) where project throughput and task lateness is in terms of dollars. The dollar value for each day late is equivalent to the selling price of the entire project because it puts the entire project in jeopardy. Both negative and positive numbers can be used, where negative numbers indicate late completions and the positive numbers indicate early completions. The dollar days are assigned to the person responsible for completing the project early or late. The measurement is based on the net contribution of that individual.  
An example of the throughput dollar days: Assume the project cost is \$1M, and the previous person causes the overall project to be two days late. The person is then assigned (-\$2M) but if the subsequent person is able to reduce the number of days late by one day so that the overall project is now one day late then the subsequent person is assigned (+\$1M). [24]
- WIP (amount of investments / committed resources) is measured as the amount of WIP generated in terms of time. The time is the actual time delay of getting the customer the new product.
- Operating Expenses (costs)
- Project Completion Date
- Performance

The local measurements are typically done from a worker's perspective. They focus on a local part of the system (subsystem) and attempt to measure how quickly each resource completes task and the amount of buffer used by the resource. Resources can use a lot of the buffer if the average task estimates are too low, if there is a high variability with the average task estimates, or if multi-tasking is being used.

In general, the project milestones should be expressed in terms of buffer status where the optimal target is when no buffer is used and the critical target date is when the entire buffer is consumed. The measurements adopted should promote win-win situations where the compensation and reward system is synchronized with the objectives of the organization. For example, a win-win situation between the company and its employees has a compensation package that provides monetary rewards based on the performance of the company via bonuses, profit sharing or stock options.

The general focus should be on the strategic resources because the savings incurred by that resource, directly effects the critical chain and thus the throughput of the entire organization. The resources performing the tasks need clear definition of the start times for tasks with no predecessors (these tasks are gateways that control the flow of work, thus the WIP in the

system), task priority level in cases where multiple tasks exist. The multi-tasking of resources should be avoided in most cases. If this can not be avoided, a priority level should be assigned to the tasks. The critical chain tasks will always have the highest priority and then the remaining tasks that are needed to avoid buffer problems will have the next level of priority. The resource manager (or project manager) needs to maintain a list of all of the early and late tasks, their durations, the current expected start and finish times for all upcoming tasks, and the resource buffer status. The project manager needs to be aware of the project buffer status, feeding buffer status, resource buffer status, and the critical chain tasks.

Approaches to overcome resistance due to the “Not Invented Here” (NIH) Syndrome. The amount of resistance is proportional to  $T / (E * C)$  where T is amount of time person has dealt with problem, R is amount esteem for the presenter and C is the complexity of the proposed solution to the problem.

## 6. System Dynamics Method

### 6.1. Overview

Systems dynamics is the application of feedback control system principles and techniques to managerial, organizational, and socio-economic problems. The new concept was introduced by Jay Forrester, at MIT, as a method for modelling and analyzing the behavior of complex social systems, particularly within the context of industrial systems. It has been used to examine various social, economic and environmental systems, where a holistic view is important and feedback loops are critical to understanding interrelationships. [30] Management is defined as the task of designing and controlling an industrial system. When this management is extended to include project management, it is then natural for the management of the system to also include the principal interactions among all of the important components in that system. These interactions can typically be characterized as feedback systems that contain many feedback loops. The feedback loops capture a closed sequence of cause and effect behavior that reinforces the behavior (positive feedback loop) or counter-acts the behavior (negative feedback loop).

There are many examples of feedback systems, the following describes several examples.

- Automatic thermostat system in a home. When temperature rises above a preset temperature in the thermostat, the air conditioner is started to cool down the home. Once the temperature in the home reaches the preset temperature in the thermostat, the air conditioner is then stopped. The cycle can be re-initiated over and over again based upon temperature fluctuations inside the home.
- Typical business cycle in industry. A new profitable industry has few competitors making large profit margins on their products. The industry begins to look attractive and as more competitors enter the industry, the profit margins begin to decrease to the point where only small profits are made. This makes the industry look unattractive and unprofitable forcing the number of competitors to decrease and eventually drive profit margins back up. The cycle can continue over and over again as new products with high profit margins are introduced or new industries are created.

System dynamics is particularly useful with information feedback systems. These systems exist whenever the environment leads to a decision and action that effects the environment and thereby influences future decisions. [14] One common application of system dynamics in information feedback systems is the use of system dynamics in project management. According to Andres Rodrigues and J. Bowers, the application of system dynamics to project management has been motivated by various factors. [31]

- Considers the whole project rather than a sum of individual elements (the holistic approach)

- Need to examine major non-linear aspects typically described by balancing or reinforcing feedback loops
- Need for a flexible project model which offers a laboratory for experiments with manager's options
- Failure of traditional analytic tools to solve all project management problems and the desire to experiment with something new.

### 6.1.1. Applications of System Dynamics

There has been a broad acceptance to the application of system dynamics to project management. The following table summarizes the applications to project management. [30]

**Applications of System Dynamics to Project Management**

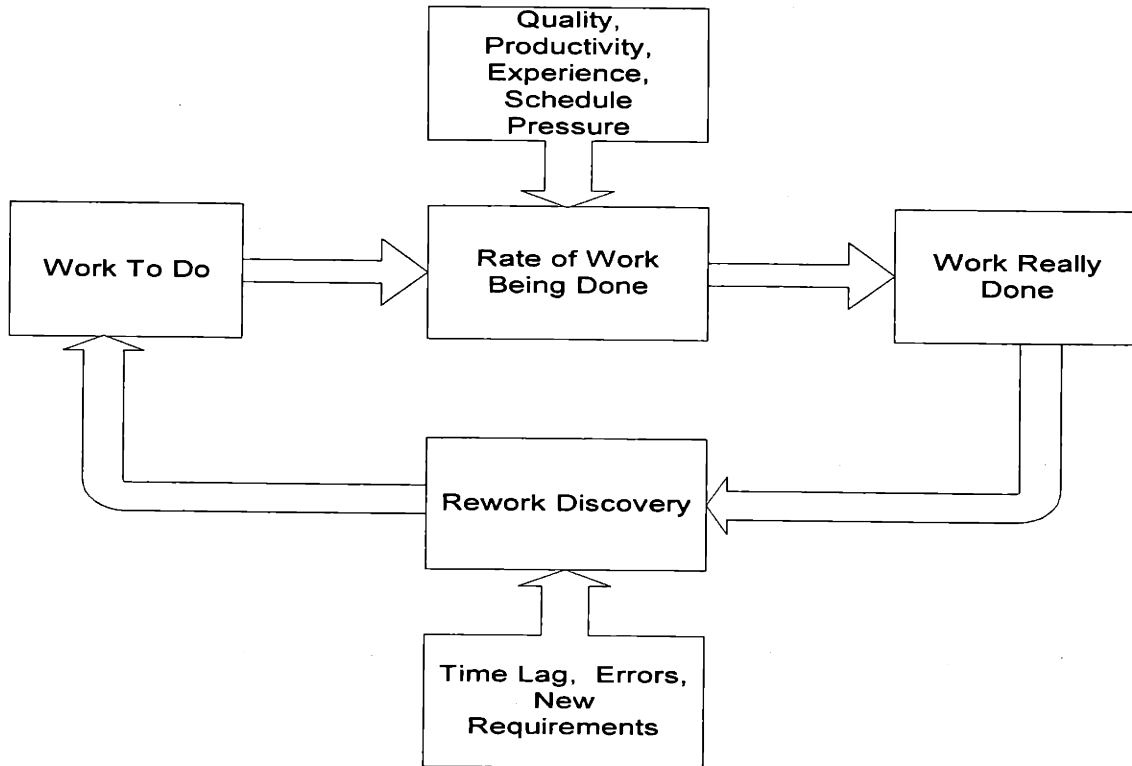
Author	Project Type	Summary
Roberts	Research and Development	Perceived versus Real progress
Kelly	Research and Development	Development of Research and Development dynamics, multi-project management
Richardson, Pugh	Research and Development	Productivity, rework generation, and staff hiring policy
Jessen	Research and Development, Construction	Project team motivation and productivity, client and project team relationship
Keloharju, Wolstenholme	Research and Development	Time-cost trade-off
Abdel-Hamid	Software Development	NASA Goddard Space Flight Center: project staffing policies, cost and schedule estimates as targets, managerial turnover
Barlas, Bayraktutar	Software Development	Simulation based game, staffing policies
Pugh-Roberts Associates	Various large projects	PMMS: a specialist system dynamics project management tool, design and workscope changes, dispute resolution
Smith <i>et al.</i>	Software Development	Charles Stark Drapper Laboratory
Chichakly	Software Development	High Performance Systems, Inc.: technology transition

Lin	Software Development	NASA Jet Propulsion Laboratory: integrating engineering and management
Aranda	Software Development	Aragon Associates Inc.: TQM and product life cycle
Cooper, Mullen	Software Development	The rework cycle, project monitoring progress ramps
Williams <i>et al.</i>	Product Development	Dispute resolution, impact of parallelism

### 6.1.2. Rework Cycle

A system dynamics model of a project management will try to capture all of the major feedback factors that influence the overall system behavior. These factors include the “hard” measurable factors like project costs, actual work completed and quality, and the “soft”, human factors like productivity. A typical system dynamics model of a project is fundamentally built on the concept of the rework cycle. The rework cycle captures the general set of imperfections that exist during the execution and completion of any project. This rework cycle is the fundamental core of the model because it includes undiscovered rework, time to discover rework, work quality and staff productivity. [22]

## Rework Cycle



The system dynamics model captures the dynamic aspects that occur during a project. The dynamic aspects of a project are usually driven by the political/social environment, legal agreements, and human factors. These factors unfortunately have a tremendous influence on the outcome of the project. It is important to be able to capture and quantify these dynamic effects, make corrections to accommodate them and record the results as historical data (corporate memory) for use in future planning. During the planning phase of a project, the estimating processing should explicitly consider dynamic factors like workforce motivation, schedule pressure and work force experience. During the project-reporting phase, the status should be based on the actual amount work remaining instead of the perceived amount of work remaining. Finally, throughout the entire project the information captured as historical data should be used strategically for risk management and contingency planning.

The most important contribution of the system dynamic model is that it helps to identify and quantify the dynamic aspects of a project. The foundation to the system dynamics methodology is the feedback loop that shows that for every behavioral pattern there is a correlating dynamic factor in the system structure. For example, corporate downsizing occurs to improve profits, yet the layoffs effect the overall morale, productivity and quality of service which in turn reduce the profits. Another example is when additional resources are added because the project is behind schedule, yet the additional resources help to dilute experience and introduce quality problems, which in turn could delay the project even more.

The most common dynamic factors are the human factors (so called soft factors) like morale, productivity, work experience, quality and schedule pressure. It is not only important to identify these factors and plan for them in the model but also to understand the scope of their impacts in the short and long term. As an example, the use of schedule pressure to ensure high productivity in the short term will have a negative effect in the long term due to staff exhaustion and low quality work.

## **6.2. Advantages**

There are significant advantages when using system dynamics in project management. The over-arching advantage is that the model provides a real-life, iterative representation of the dynamics (that are typically not easily quantified) that influence the project outcome. This alternative view of the project concentrates on the whole project from a systems perspective. The approach provides a means to achieve an overall understanding of the whole system where the product development and management process is viewed as a tightly integrated, continuous, dynamic system. The system dynamics model captures and contains the internal interactions and interdependencies, which helps with problem solving and solution evaluation and traces the chain of events to determine immediate consequences like newly created problems and second and third-order consequences.

The importance of viewing the product development process and project management from a systems perspective can not be understated. This allows the project manager to better understand the system behavior and avoid the common pitfall of strictly focusing on the low-level details to optimize a subsystem. The major pitfall here is that the optimization of subsystem does not guarantee or equate to optimization of the overall system. A better understanding of the system behavior will also allow the manager to prepare and quantify the impact of new requirements or modifications of the requirements to the overall system. The ability to capture and quantify the “soft”, human aspects of the project is also extremely important contribution since there is growing evidence that shows that these elements (particularly within a team environment) play a significant role in determining the project outcome. In summary, system dynamics provides valuable strategic lessons for project management and should be seen as a complementary tool (and not a substitute) to the detail-rich techniques offered by traditional project management.

### **6.3. Model Description**

The systems dynamics model described in this section will illustrate how system dynamics is able to treat the project as a system and still capture the major dynamic elements. The system dynamics model is separated into the following four major subsystems: requirements/product development subsystem, resource subsystem, schedule subsystem, and the cost/profit subsystem.

#### **6.3.1. Requirements/Product Development Subsystem Model**

The Requirements / Product Development Subsystem captures and quantifies the factors required to actual complete the tasks based upon an established set of product/project requirements. The model takes into consideration the possibility that new requirements or modifications to the existing requirements will be introduced before the product has been completely developed and the rate of work obsolesce created. These requirement changes are classified into three categories based upon when they are introduced into the project: the first third of the project (“Changes Introduced Early in Project”), middle third of the project (“Changes Introduced at Mid Project”), and last third of the project (“Changes Introduced Late in Project”). Each of these categories of requirement changes are based an input called “Amount of Requirement Changes” which is provided by project manager. The input should take into consideration the amount of effort required based upon the tasks and its complexity.

The model also takes into consideration the effects that productivity, work experience, and quality will have to rate at which work is being completed. The productivity parameter (“Productivity”) is based on two key elements, the quality of the work produced and the average experience of the work force. The productivity will continue to increase as the work experience is added or gained (“Effect of Experience on Productivity”), and as the quality



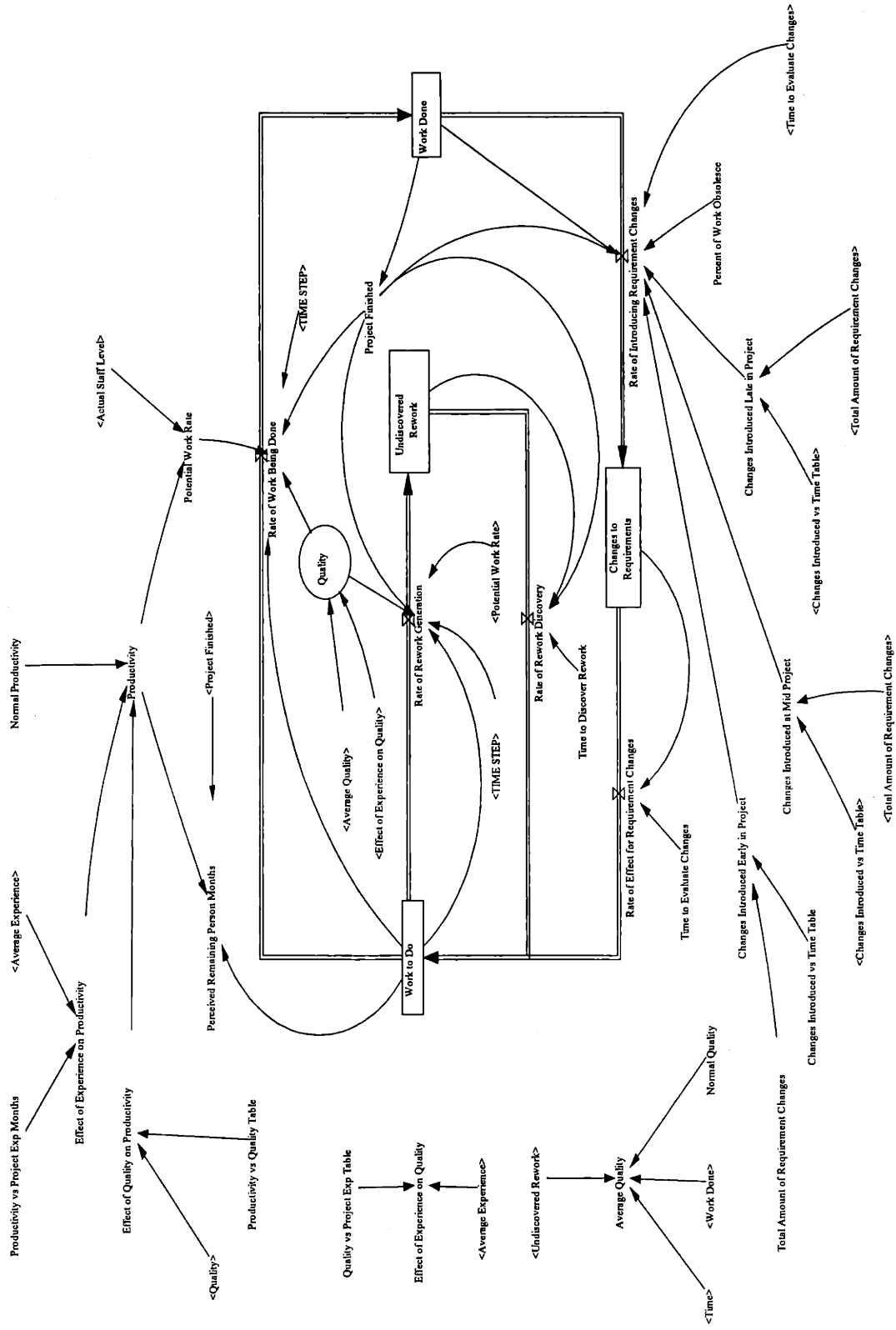
improves (“Effect of Quality on Productivity”). The maximum level of achievable productivity is also based on a parameter, called “Normal Productivity”. The quality parameter (“Quality”) is based on three key elements, the amount of work done, the amount of undiscovered rework, and the average experience of the work force. The quality will continue to increase as the work experience is added or gained (“Effect of Experience on Quality”), and as the amount of undiscovered rework decreases relative to the amount of done (“Average Quality”). The maximum level of achievable quality is based on a parameter, called “Normal Quality”.

The following describes the internal and external factors captured by the system dynamics model.

### **Requirements/Product Development Subsystem**

<b>Inputs</b>	<b>Internal</b>	<b>Outputs</b>
<p style="text-align: center;">Actual Staff Level Amount of Requirement Changes Average Experience</p>	<p style="text-align: center;">Work to Do Work Done</p> <p style="text-align: center;">Undiscovered Work Changes to Requirements Rate of Work Being Done Rate of Rework Generation Rate of Rework Discovery Rate of Introducing Requirement Changes Rate of Effect for Requirement Changes Potential Work Rate Productivity Quality</p>	<p style="text-align: center;">Project Finished Perceived Remaining Person Months</p>

# Example Model of Requirements / Product Development Subsystem (Using Vensim Software)

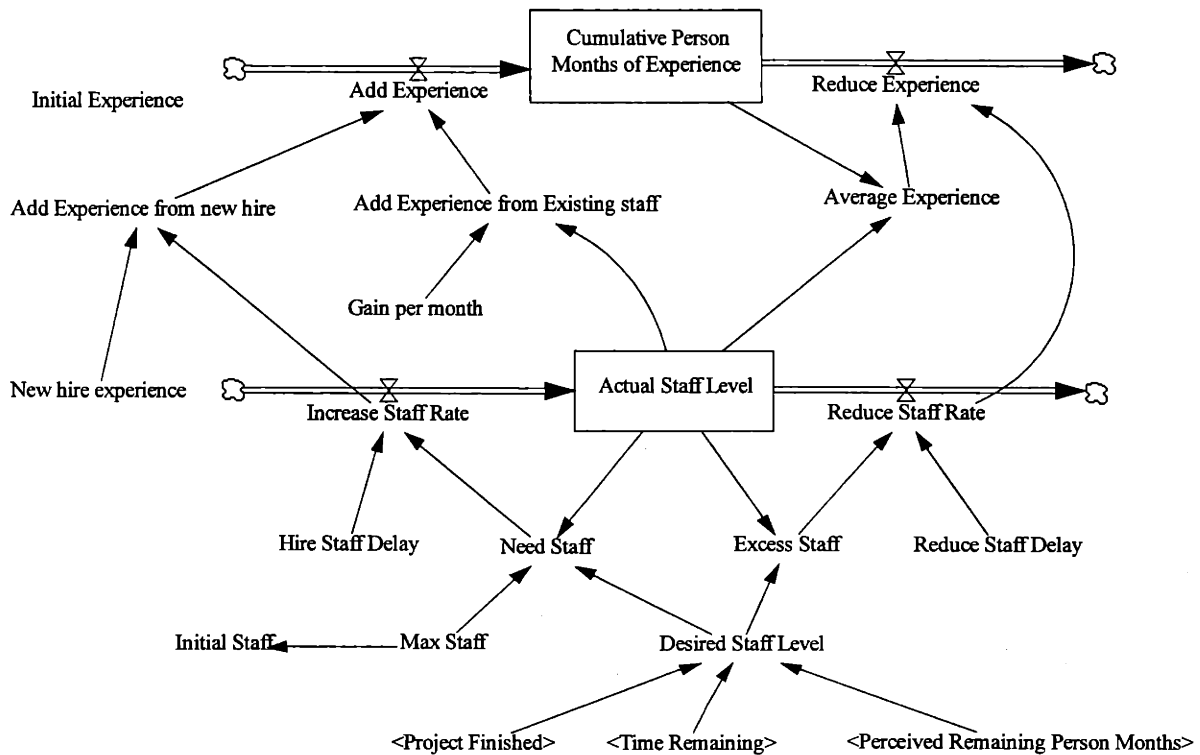


**6.3.2. Resource Subsystem Model**

The Resource Subsystem captures the dynamic factors human work force levels that are required to complete the product/project requirement. These work force levels are represented in terms of number of resources needed and currently used, the overall experience level of the work force, and the time delays to increase or decrease the size of the workforce. The following describes the factors captured by the model.

<b>Resource Subsystem</b>		
<b>Inputs</b>	<b>Internal</b>	<b>Outputs</b>
Projected Completion Date Time Remaining	Desired Staff Level Work Force Experience Growth Rate Work Force Experience Reduction Rate Work Force Increase Rate Work Force Reduction Rate Reduce Staff Delay	Actual Staff Level Average Experience  Hiring Staff Delay

**Example Model of Resource Subsystem  
(Using Vensim Software)**



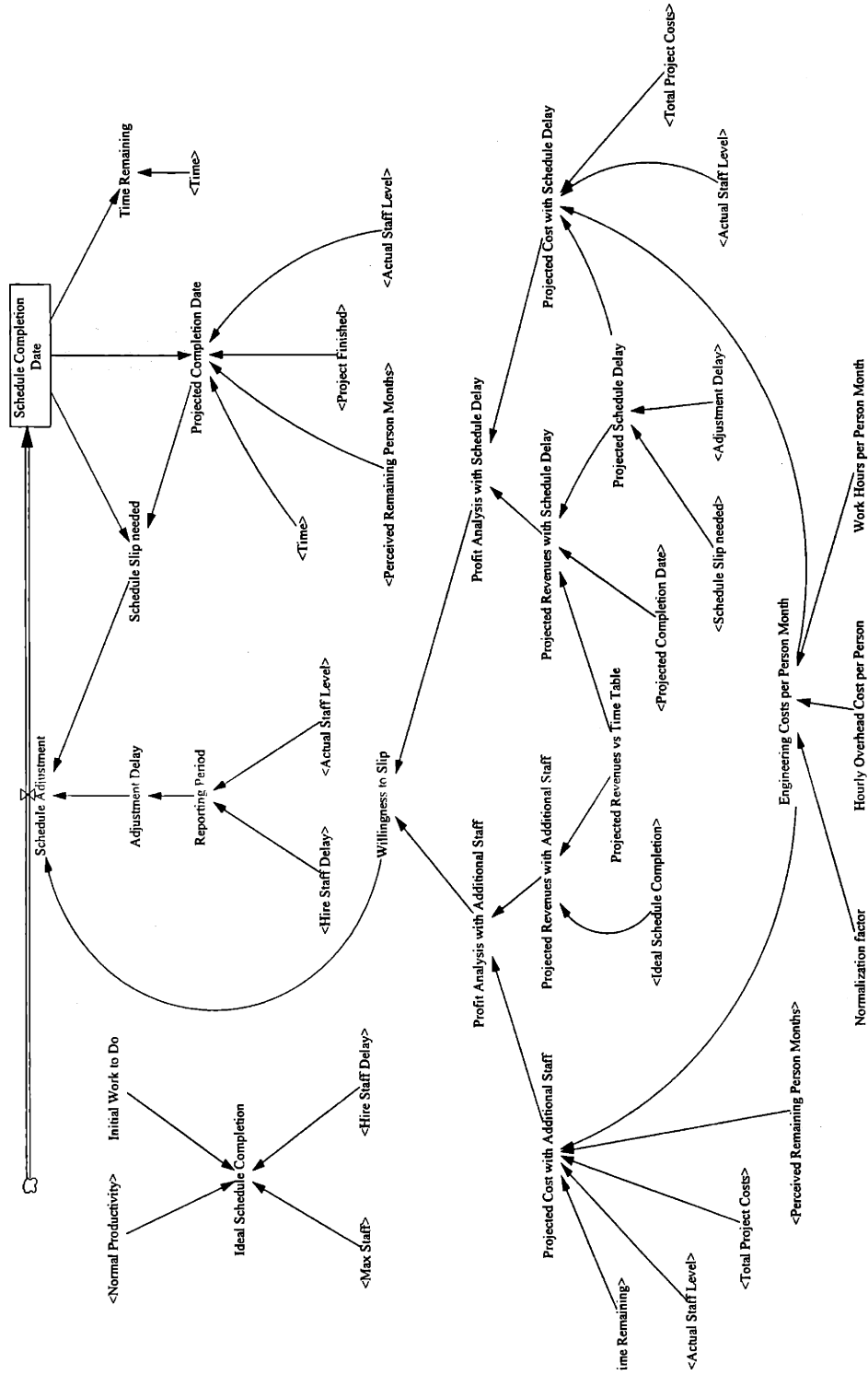
### 6.3.3. Schedule Subsystem Model

The Schedule Subsystem captures the factors required to calculating the time left to complete the project and forecasts a completion date for the product/project. The model uses this information and also performs an internal analysis to determine if it is better to delay the schedule or incur additional costs by utilizing incremental resources. The model determines whether to adjust the schedule (“Scheduled Adjustment”) based on upon two key factors, whether a schedule slip is actually needed (“Schedule Slip Needed”) and whether it makes sense to slip the schedule (“Willingness to Slip”). The analysis to determine if it makes sense to slip is based upon comparisons between the profit calculations for the scenario using additional staff (“Profit Analysis with Additional Staff”) and the scenario using a schedule slip (“Profit Analysis with Schedule Delay”). The actual profit calculations are derived from project revenue and cost tables and parameters (like “Projected Revenues vs Time Table” and the “Engineering Costs Per Person Month” parameters) that are maintained by the project manager. The completion date parameter (“Projected Completion Date”) is primarily based upon two key elements, the remaining amount of effort (“Perceived Remaining Persons Months”) and the work force level (“Actual Staff Level”). The following describes the factors captured by the model.

## Schedule Subsystem

<b>Inputs</b>	<b>Internal</b>	<b>Outputs</b>
Actual Staff Level Hire Staff Delay Perceived Remaining Person Months Project Finished  Total Project Costs	Target Completion Date Willingness to Slip Profit Analysis with Schedule Delay Profit Analysis with Additional Staff Projected Cost with Additional Staff Projected Revenues with Additional Staff Projected Cost with Schedule Delay Projected Revenues with Schedule Delay Engineering Costs Per Person Month	Projected Completion Date Time Remaining

# Example Model of Schedule Subsystem (Using Vensim Software)



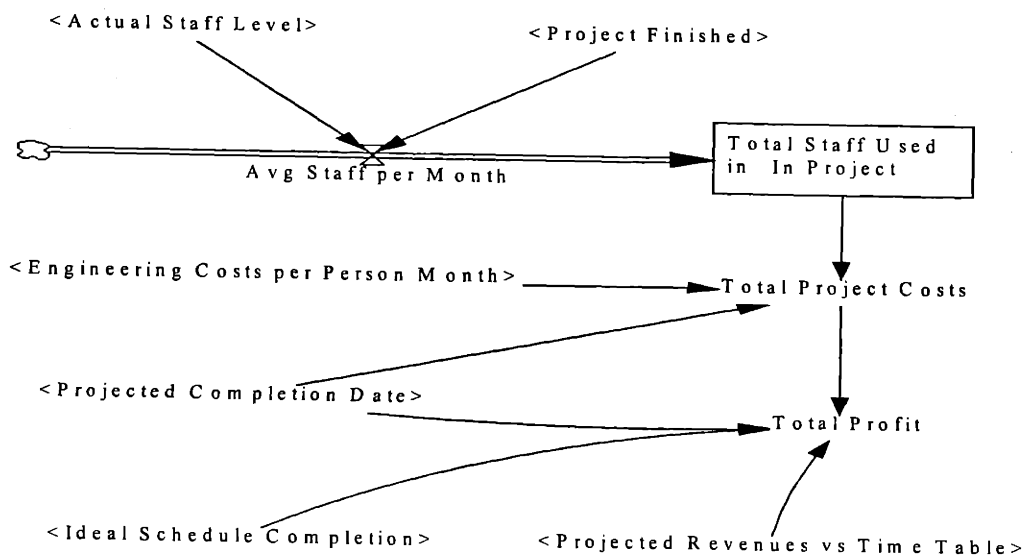
### 6.3.4. Cost/Profit Subsystem Model

The Cost/Profit Subsystem captures the factors required to calculate the running totals for a summary of the project costs and project profits. The model calculates the current project costs ("Total Project Costs") and profits ("Total Profits") based upon three key parameters: the projected completion date ("Projected Completion Date"), the average monthly engineering costs per person month ("Engineering Costs Per Person Month"), and the projected revenue stream ("Projected Revenues vs Time Table). The project manager maintains the last two parameters. The following describes the factors captured by the model.

#### Cost/Profit Subsystem

Inputs	Internal	Outputs
Actual Staff Level Projected Completion Date Projected Finish Engineering Costs Per Person Month Projected Revenues vs Time Table Ideal Schedule Completion	Total Staff Used in Project Total Project Profits	Total Project Costs

#### Example Model of Project Cost/Profit Subsystem (Using Vensim Software)



#### **6.4. Contingency Planning**

The systems dynamics model is a powerful tool to perform risk analysis and assessment on the project. The risk analysis and assessment process simply requires one to modify the parameters of interest and then re-run the model. The outputs of the model can then be further evaluated to determine patterns and alternatives. The graphical representation of the project also serves a good communication tool to discuss the cause and effects.

Risk analysis and assessment is particularly useful in determining and understanding the effects of introducing requirement changes throughout the project. The cost of a requirements change can be quantified in terms of its impact to the project completion date, quality and overall cost. Once the risk analysis and assessment has been completed, contingency planning can occur by further modifying the model to simulate the possible alternatives.

#### **6.5. Other Considerations**

The system dynamics model should be tested, calibrated and validated. This will help to ensure that the model does not contain human mechanical errors, responds with a predictable behavior. The extreme conditions should be verified. The calibration of the model is accomplished by comparing simulated data with actual historical data and then reconciling the differences. There is no absolute method to validate the model. The validation will have to be replaced by establishing a level of confidence in the model. This level of confidence will increase as the model passes more tests, which reflect reality. The model should be stored as a baseline after calibration and after any significant modification or simulation run.

There are several software packages available for System Dynamics modeling. The most common software packages are DYNAMO, IThink and Vensim. The Vensim software package provides an user friendly graphical interface to develop the model and run simulations.



## 7. Conclusion

The entrepreneurial environment requires a project management framework that must consider and accommodate for the following: the project itself is of high risk, highly dependent on timeliness and highly dependent on value creation, and each stage of the entrepreneurial process has a concentrated focus on specific aspects of the overall entrepreneurial opportunity. Initially, the entrepreneur is primarily driven by the perception that an opportunity that exists within an area of interest without regard to the resources controlled. In this stage of the process, the primary focus is to evaluate and qualify the opportunity and then develop a business concept to satisfy the opportunity. In the next stage, the focus shifts to act on the opportunity by developing a prototype of the product or service to demonstrate the feasibility of the business concept and then acquiring the minimum set of resources required to fulfill the opportunity. The final stage focuses on value creation and continuous risk management during the execution and delivery phases of the entrepreneurial venture. The project management framework is well suited to the entrepreneurial environment because it emphasizes a project management approach that is effective (intuitive framework that captures essential, value added elements), efficient (requires low maintenance and does not become a project in itself), and flexible (approaches and methods proposed are responsive to change).

In any environment, whether in an entrepreneurial or established firm, there are proven project management processes, principles and activities that significantly contribute to a successful project. A brief summary of the key processes and principles includes establishing a clear definition of the mission, project objective and requirements, common understanding of the expectations, and the identification of the stakeholders and their needs. The project management process also includes three fundamental ongoing activities: project planning, project monitoring and control, and risk management. Effective planning, particularly within an entrepreneurial environment, allows one to 1) set specific, time-phased, measurable goals, subgoals, and action steps, 2) better anticipate obstacles, 3) encourage and promote involvement and commitment, and 4) apply learnings from previous experiences. Project monitoring and control allows one to closely manage and communicate the progress of the project and then implement preventive or corrective action based upon the performance of the project. Risk management allows one to methodically identify and reduce project risks and thereby increase the probability of achieving the project objectives. All of these processes, principles and activities are extremely critical to successful project management in an entrepreneurial environment because the project itself is of high risk, highly dependent on timeliness and highly dependent on value creation.

Traditional project management techniques and methods like the systems architecture framework, the systems approach, the Work Breakdown Structure (WBS), and the use of simple risk management techniques provide a foundation of the most critical and successful elements of project management. The system architecture framework, particularly the Total Holistic View of Product/Process Architecture, provides a valuable approach to partition and

decompose the system (or product) into smaller subsystems so that it can be developed and managed more effectively. The framework considers the system from a holistic perspective and allows one to better understand and define the relationships among the elements so that one can reduce the overall complexity and efficiently focus on the critical part(s) of the system. The systems approach provides an iterative guideline on how to manage and measure the project from a systems perspective so that future decisions will always improve the system as whole and not just improve one part of the system at the expense of another. The WBS provides an effective method of defining the overall work scope of the project by breaking down the project effort into a number individual tasks/activities that are independent, assignable, measurable, manageable and integratable.

Critical Chain management provides a low-overhead approach on how to organize and schedule the work required and then efficiently manage the critical path of the project. The low-overhead approach allows the project manager to develop a realistic schedule that does not require major changes every time a late task is encountered. The approach provides several other important contributions. It puts a strong emphasis on actually finishing the project early by re-enforcing the importance of focusing on the important elements of the project, the tasks on the critical chain. The approach promotes the concept that one of the primary objectives of project management is to find and make improvements on the critical chain because they will help the project finish early.

The systems dynamics approach provides a method to capture all of the major feedback factors that influence the overall behavior of the system. System dynamics uses a model to capture these dynamic factors, which includes: 1) the “hard” measurable factors like the project costs, actual work completed, amount of work remaining and quality of work, 2) the “soft” human factors like the effects of productivity and work experience, and 3) other important underlying influences like undiscovered rework and the effects of requirement changes. The system dynamics model helps to capture and quantify the effects of these changes and the underlying factors that play a significant role in causing projects to slip schedules, incur cost overruns and/or develop quality issues.

In conclusion, the thesis presents a lean and efficient project management framework that addresses many of the project management challenges found in an entrepreneurial environment. The project management framework is based upon proven, successful project management processes, principles and activities that include the approaches and techniques found in traditional project management, critical chain management and system dynamics. The framework contains an optimal and practical combination of the most critical and successful elements of traditional project management and concepts from critical chain management and system dynamics, which will ultimately help entrepreneurs and/or managers in an entrepreneurial environment in the following three key areas: 1) effectively plan and manage the development effort, 2) understand and communicate the effects of changes to the project, and 3) develop better contingency plans.

## 8. Systems Dynamics Model Listing

- (01) Actual Staff Level = INTEG (Increase Staff Rate-Reduce Staff Rate, Initial Staff)  
Units: person
- (02) Add Experience = Add Experience from Existing staff + Add Experience from new hire  
Units: person\*Months/Month
- (03) Add Experience from Existing staff = Actual Staff Level \* Gain per month  
Units: person\*Months/Month
- (04) Add Experience from new hire = Increase Staff Rate \* New hire experience  
Units: person\*Months/Month
- (05) Adjustment Delay = IF THEN ELSE (Reporting Period = 0, 1, Reporting Period)  
Units: Month
- (06) Average Experience = Cumulative Person Months of Experience/Actual Staff Level  
Units: Months
- (07) Average Quality = IF THEN ELSE (Time < 10, Normal Quality, Work Done / (Undiscovered Rework+Work Done) )  
Units: 1  
Dimensionless 10 weeks into the program, previous program's quality (Normal Quality) is assumed.
- (08) Avg Staff per Month = (Actual Staff Level / TIME STEP) \* Project Finished  
Units: person/Month
- (09) Changes Introduced at Mid Project = PULSE (13, 0.5) \* Total Amount of Requirement Changes \* Changes Introduced vs Time Table (2)  
Units: percent tasks/Month
- (10) Changes Introduced Early in Project = PULSE (7, 0.5) \* Total Amount of Requirement Changes \* Changes Introduced vs Time Table (1)  
Units: percent tasks/Month
- (11) Changes Introduced Late in Project = PULSE (20, 0.5) \* Total Amount of Requirement Changes \* Changes Introduced vs Time Table (3)  
Units: percent tasks/Month

- (12) Changes Introduced vs Time Table  $((1,0)-(3,1)),(1,0.33),(2,0.33),(3,0.33))$   
 Units: Dimensionless  
 Table which distributes the new requirement changes across the three time periods, early in project, at mid project and late in the project. On the "X" axis, "1", "2" and "3" represent early in project, mid project and late in project respectively. The corresponding value on the "Y" axis represents the percentage of the total new requirement changes introduced.
- (13) Changes to Requirements = INTEG (Rate of Introducing Requirement Changes-Rate of Effect for Requirement Changes, 0)  
 Units: percent tasks
- (14) Cumulative Person Months of Experience = INTEG ( Add Experience-Reduce Experience, Initial Experience \* Initial Staff)  
 Units: person\*Months
- (15) Cumulative Work Done = INTEG ( Rate of Doing Work, 0)  
 Units: percent tasks
- (16) Desired Staff Level = ( Perceived Remaining Person Months\*Project Finished) / MAX (1, Time Remaining - TIME STEP )  
 Units: person
- (17) Effect of Experience on Productivity = Productivity vs Project Exp Months(Average Experience)  
 Units: 1
- (18) Effect of Experience on Quality = Quality vs Project Exp Table (Average Experience)  
 Units: 1
- (19) Effect of Quality on Productivity = Productivity vs Quality Table( MAX (1,Quality) )  
 Units: 1
- (20) Engineering Costs per Person Month = (Hourly Overhead Cost per Person \* Work Hours per Person Month) / Normalization factor  
 Units: Dollars/(Month\*person)
- (21) Excess Staff = MAX( 0, Actual Staff Level-Desired Staff Level )  
 Units: person
- (22) FINAL TIME = 50  
 Units: Month  
 The final time for the simulation.

- (23) Gain per month = 1  
Units: Months/Month
- (24) Hire Staff Delay = 1  
Units: Month  
Time to interview, relocate and train new staff
- (25) Hourly Overhead Cost per Person = 100  
Units: Dollars/Hour
- (26) Ideal Schedule Completion =  $(\text{Initial Work to Do} / \text{Normal Productivity}) / \text{Max Staff}$   
+ Hire Staff Delay  
Units: Month
- (27) Increase Staff Rate = Need Staff / Hire Staff Delay  
Units: person/Month
- (28) Initial Experience = 36  
Units: Months
- (29) Initial Staff =  $0.1 * \text{Max Staff}$   
Units: person
- (30) INITIAL TIME = 0  
Units: Month  
The initial time for the simulation.
- (31) Initial Work to Do = 100  
Units: percent tasks
- (32) Max Staff = 50  
Units: person
- (33) Need Staff =  $\text{MAX}(0, \text{MIN}(\text{Desired Staff Level} - \text{Actual Staff Level}, \text{Max Staff} - \text{Actual Staff Level}))$   
Units: person
- (34) New hire experience = 0  
Units: Months
- (35) Normal Productivity = 0.75  
Units: percent tasks/(person\*Month)

- (36) Normal Quality = 0.5  
Units: 1
- (37) Normalization factor = 100000  
Units: Dimensionless  
Note: Inorder to synchronize with the Revenue Table, the units are based on \$100,000.
- (38) Perceived Remaining Person Months = Work to Do \* Project Finished / Productivity  
Units: person\*Month
- (39) Percent of Work Obsolesce = 0.1  
Units: Dimensionless
- (40) Potential Work Rate = Productivity \* Actual Staff Level  
Units: percent tasks/Month
- (41) Productivity = Normal Productivity \* Effect of Experience on Productivity \* Effect of Quality on Productivity  
Units: percent tasks/(Month\*person)
- (42) Productivity vs Project Exp Months ( [(0,0.4)-(200,1)], (0,0.5), (4.22961,0.592105), (12.6888,0.684211), (28.3988, 0.789474), (45.3172,0.833333), (66.4653,0.877193), (84.5921,0.916667), (106.344 ,0.951754), (122.659,0.969298), (135.952,0.973684), (149.849,0.97807), (157.704 ,0.97807), (200,0.9781))  
Units: 1
- (43) Productivity vs Quality Table ( [(0,0)-(1,1)], (0,0.45614), (0.0453172,0.561404), (0.0966767,0.649123), (0.175227,0.732456), (0.238671,0.780702), (0.332326,0.846491), (0.453172,0.890351), (0.58006,0.921053), (0.700906,0.929825), (0.797583,0.938596), (0.912387,0.938596), (1,0.9386))  
Units: 1
- (44) Profit Analysis with Additional Staff = (Projected Revenues with Additional Staff - Projected Cost with Additional Staff) / Projected Revenues with Additional Staff  
Units: Dimensionless
- (45) Profit Analysis with Schedule Delay = (Projected Revenues with Schedule Delay - Projected Cost with Schedule Delay) / Projected Revenues with Schedule Delay  
Units: Dimensionless
- (46) Project Finished = IF THEN ELSE (Work Done>99,0,1)  
Units: 1

- (47) Projected Completion Date = IF THEN ELSE (Time=0, Schedule Completion Date, (Time + (Perceived Remaining Person Months / Actual Staff Level) ) \* Project Finished) )  
Units: Month
- (48) Projected Cost with Additional Staff = Total Project Costs + ( ( Perceived Remaining Person Months + (Actual Staff Level \*Time Remaining) ) \* Engineering Costs per Person Month )  
Units: Dollars
- (49) Projected Cost with Schedule Delay = Total Project Costs + (Projected Schedule Delay \* Actual Staff Level \* Engineering Costs per Person Month)  
Units: Dollars
- (50) Projected Revenues vs Time Table ((0,0)-(50,1e+006)], (0,1e+006), (1,950000), (2,900000), (3,850000),(4,800000), (5,750000), (6,700000), (8,500000), (10,300000), (20,100000), (50,50000))  
Units: Dollars  
Note: The revenue table has units based on \$100,000 dollars.
- (51) Projected Revenues with Additional Staff = Projected Revenues vs Time Table (Ideal Schedule Completion/Ideal Schedule Completion)  
Units: Dollars
- (52) Projected Revenues with Schedule Delay = Projected Revenues vs Time Table (MAX (Projected Schedule Delay/ MAX (Projected Completion Date ,1) , 0) )  
Units: Dollars
- (53) Projected Schedule Delay = Schedule Slip needed + Adjustment Delay  
Units: Month
- (54) Quality = Average Quality\*Effect of Experience on Quality  
Units: 1  
Dimensionless
- (55) Quality vs Project Exp Table ((0,0.4)-(200,1)], (0,0.6), (6.0423,0.719298), (16.3142,0.877193), (32.0242,0.95614), (53.1722,0.969298), (74.3202,0.969298), (200,0.9693))  
Units: 1
- (56) Rate of Doing Work = Rate of Rework Generation+Rate of Work Being Done  
Units: percent tasks/Month

- (57) Rate of Effect for Requirement Changes = Changes to Requirements/Time to Evaluate Changes  
Units: percent tasks/Month
- (58) Rate of Introducing Requirement Changes = (Changes Introduced Early in Project + Changes Introduced at Mid Project + Changes Introduced Late in Project) + IF THEN ELSE ( (Changes Introduced Early in Project + Changes Introduced at Mid Project + Changes Introduced Late in Project ) > 0 , Percent of Work Obsolesce \* Work Done /Time to Evaluate Changes, 0 ) ) \* Project Finished  
Units: percent tasks/Month
- (59) Rate of Rework Discovery = (Undiscovered Rework/Time to Discover Rework) \*Project Finished  
Units: percent tasks/Month
- (60) Rate of Rework Generation = MIN ((1-Quality)\*Potential Work Rate,(1-Quality)\*Work to Do/TIME STEP)\*Project Finished  
Units: percent tasks/Month
- (61) Rate of Work Being Done = MIN (Quality\*Potential Work Rate,Quality\*Work to Do/TIME STEP)\*Project Finished  
Units: percent tasks/Month
- (62) Reduce Experience = Average Experience\*Reduce Staff Rate  
Units: person\*Months/Month
- (63) Reduce Staff Delay = 1  
Units: Month  
Time to transfer, layoff or fire staff
- (64) Reduce Staff Rate = Excess Staff / Reduce Staff Delay  
Units: person/Month
- (65) Reporting Period = IF THEN ELSE (Actual Staff Level<=1,Hire Staff Delay,1)  
Units: Month
- (66) SAVEPER = 0.25  
Units: Month  
The frequency with which output is stored.
- (67) Schedule Adjustment = IF THEN ELSE (Schedule Slip needed > 0, ((Schedule Slip needed + Adjustment Delay) \* Willingness to Slip) / Adjustment Delay, 0 )  
Units: Month/Month



- (68) Schedule Completion Date = INTEG ( Schedule Adjustment, Ideal Schedule Completion)  
Units: Month
- (69) Schedule Slip needed = IF THEN ELSE (Schedule Completion Date>=Projected Completion Date,0,Projected Completion Date - Schedule Completion Date)  
Units: Month
- (70) Time Remaining = IF THEN ELSE (Schedule Completion Date-Time>=0,Schedule Completion Date-Time, 0)  
Units: Month
- (71) TIME STEP = 0.0078125  
Units: Month  
The time step for the simulation.
- (72) Time to Discover Rework = 3  
Units: Month
- (73) Time to Evaluate Changes = 0.5  
Units: Month
- (74) Total Amount of Requirement Changes = 20  
Units: percent tasks
- (75) Total Profit = Projected Revenues vs Time Table (Projected Completion Date/Ideal Schedule Completion) - Total Project Costs  
Units: Dollars
- (76) Total Project Costs = Total Staff Used in Project \* Engineering Costs per Person Month \* Projected Completion Date  
Units: Dollars
- (77) Total Staff Used in Project = INTEG (Avg Staff per Month, 0)  
Units: person
- (78) Undiscovered Rework = INTEG (Rate of Rework Generation-Rate of Rework Discovery, 0)  
Units: percent tasks

- (79) Willingness to Slip = IF THEN ELSE (Profit Analysis with Schedule Delay-Profit Analysis with Additional Staff >= 0, 1, 0)  
Units: Dimensionless  
Range between 0 and 1 where 0 means NOT willing to slip so continue to increase Staff and 1 means slip schedule but do NOT increase Staff.
- (80) Work Done= INTEG (Rate of Work Being Done-Rate of Introducing Requirement Changes, 0)  
Units: percent tasks
- (81) Work Hours per Person Month = 73.33  
Units: Hour / (Month\*person)  
Billable monthly hours based on: 40 hours/wk \* 52 wks / 12 months
- (82) Work to Do = INTEG ( (Rate of Rework Discovery + Rate of Effect for Requirement Changes) - Rate of Rework Generation - Rate of Work Being Done, Initial Work to Do)  
Units: percent tasks

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