System Dynamics Modeling of the Sikorsky Aircraft Design Process 
and Assessment of Process Improvement Initiatives

by
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B.S. Mathematics Central Connecticut State College 1981
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Submitted to System Design and Management Program in Partial 
Fulfillment of the Requirements for the Degree of

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Page 1
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ABSTRACT

The reduction in defense spending compounded by industry consolidation, and increased competition for markets within the helicopter industry has resulted in the necessity for the design, development and production of systems quicker and for less cost. The coupling of industry and company dynamics has resulted in an average increase in Time and Cost to Market for Sikorsky products. This trend is opposite of the goal required for Sikorsky Aircraft to remain a profitable division of United Technologies Corporation. The fear is that these trends will continue to increase while the goal is to reduce these trends.

Due to the large number of process change initiatives under consideration, there is a need to determine an optimized implementation plan. Many individuals and functional disciplines are proponents of single change initiatives. In addition, process changes within one element of the process has numerous feedback into other process elements. An optimization is required to determine the go-no-go decision for implementation, the timing, and the level of implementation. This is necessary in order to prevent optimization within a single process step without assessment of the initiative against the enterprise as a whole.

Four dynamic hypotheses causing the increase in Time to Market and Cost to Market are proposed. An analysis of change initiatives under consideration is provided with respect to their effectiveness in addressing improvement of the enterprise metrics.

Thesis Supervisor: Jim Hines
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Author Biography

Lynn Tinker has been employed with Sikorsky Aircraft as part of Advanced Design and Business Development since 1984. During this time she has participated in design and development activities for current and future Sikorsky Aircraft products.

Professional contributions include membership on the early LHX Team to participate in the LHX Preliminary Design Studies with responsibility for mission effectiveness analyses and trade studies to define the aircraft configuration. In addition, she was responsible for development and implementation of the weapon system optimization methodology. These efforts contributed to the development contract award to Sikorsky Aircraft for the RAH-66 Comanche.

Lynn also served as the Medium Lift Replacement (MLR) Trade Study Manager, and the Medium Lift Replacement (MLR) Special Operations Team Leader. She coordinated mission effectiveness analyses and trade studies to define both the MLR baseline aircraft configuration, and the analyses defining the special operations aircraft concept of operations.

From 1994 to 1996, Lynn served as the Requirements Manager within the RAH-66 Comanche Joint Program Office. In this position she was the lead System Engineer for the RAH-66 Comanche. She was responsible for Weapon System Integration PDT management, the Requirement Traceability/Integration Process, and Weapon System Trade Study Process design and implementation. She lead the Government/Contractor team in development of the RAH-66 Performance Specification Section IV (Verification). She also served as the Crewstation customer point of contact, and coordinated with the customer to fulfill all requirements in order to obtain flight release for the RAH-66.

Lynn is currently the Chief of Requirements for Sikorsky Aircraft. In this role she is responsible for the core competency area of Requirements Analysis. She provides technical leadership to preliminary design activities through the development of advanced analytical and modeling techniques, development and implementation of enterprise Systems Engineering processes, and ensures that aircraft designs meet mission and operational requirements.

Lynn received a Bachelor of Science in Mathematics from Central Connecticut State College, a Master of Science Operations Research from the University of New Haven, and is currently enrolled in the Massachusetts Institute of Technology System Design and Management Program. She has been a member of the International Council on System Engineering (INCOSE) since 1994 and currently holds the position of President for the Constitution Chapter. She is a member of the Institute for Operations Research and Management Sciences (INFORMS), and the American Helicopter Society (AHS). She is a former member of the International Society of Parametric Analysts (ISPA).
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Chapter 1: Introduction

Sikorsky Aircraft, a wholly owned subsidiary of United Technologies, is a world known manufacturer of medium lift helicopters. Our products can be found performing in military, industrial, and commercial applications. Like many other defense oriented manufacturers, reduction in defense spending compounded by industry consolidation, and increased competition for markets, has effected our ability to retain our elite position within the helicopter industry.

Sikorsky is in the process of a change initiative. In the past Sikorsky Aircraft has had a predominant share of the medium lift helicopter market. This has been driven by our strong presence in military aviation programs. In today’s world of declining defense budgets profitable survival has forced a change in our focus from single customers of large “lot” aircraft buys, to international and commercial customers comprised of multiple customers with single or small “lot” buys. This market shift has been further complicated by increased competition. In order to maintain the company goal of retaining significant medium sized helicopter market share, change is essential.

I propose to describe and model the current product design process within Sikorsky Aircraft, and assess the potential for process change initiatives. Insight into strengths and weaknesses of the current design process will support development of recommendations for proposed changes.
Chapter 2 : Problem Statement

A recent corporate initiative to improve corporate performance for United Technologies Corporation identified several corporate metrics to reflect performance. These metrics were communicated to each of the divisions and the divisions are responsible to identify and tie their enterprise metrics to those of the corporation. Sikorsky Aircraft identified the metrics for Time To Market and Cost To Market as best tying to the corporate metrics.

**Time To Market** is tracked for international and commercial sales by platform type. There are three platform types that are tracked. The first is the S-76, which is a relatively small commercially designed helicopter with a payload of six passengers. The second is the H-60 utility configuration, which is marketed internationally to military customers. The third configuration is the H-60 naval configuration. The time from contract signing through delivery are tracked and included in an equation with other parameters such as quantity, and complexity of design to calculate a normalized time per aircraft. This metric is then tracked between programs and platforms to identify design, development, and production issues.

**Cost To Market** is tracked by platform type. A regression equation is used to calculate a cost per aircraft with cost defined as the cost to design, develop, and produce the aircraft. This metric is tracked over time as related to customer and platform type.

The reduction in defense spending compounded by industry consolidation, and increased competition for markets within the helicopter industry has resulted in the necessity for the design, development and production of systems quicker and for less cost. The coupling of industry and company dynamics has resulted in an average increase in Time and Cost to Market for Sikorsky products. This trend is opposite of the goal required for Sikorsky
Aircraft to remain a profitable division of United Technologies Corporation. The fear is that these trends will continue to increase while the goal is to reduce these trends (Figure 2-1).

![Fear and Hope Graphs](image)

**Figure Chapter 2-1 Reference Modes**
Chapter 3: Process Change Initiatives

Multiple alternatives for change to the design process exist at Sikorsky Aircraft. These alternatives impact all phases of the design, development, and production processes for the product. Changes under consideration include the implementation of System Engineering processes, automation of design tools, modularity of designs, and changes in organizational structure. These changes support the hypotheses identified below as potentially improving Time and Cost to Market.

- Put emphasis back on the front-end of the business process
  - Increased emphasis on Marketing
  - Creation of a Skunkworks type of operation
- Development, communication and implementation of a long-term strategic plan
- Understanding the customer’s need better than they do
- Documentation and flowdown of requirements
- Implement 3D design tools (CATIA and EMU) across all programs/projects
- Conversion of legacy data into 3D designs

Due to the large number of process change initiatives under consideration, there is a need to determine an optimized implementation plan. Many individuals and functional disciplines are proponents of single change initiatives. In addition, process changes within one element of the process has numerous feedback into other process elements. An optimization is required to determine the go-no-go decision for implementation, the timing, and the level of implementation. This is necessary in order to prevent optimization within a single process step without assessment of the initiative against the enterprise as a whole.
Chapter 4: The Current Process

The current design, development and production process at Sikorsky Aircraft can be summarized in eight high level steps:

1. Develop Business
2. Receive Request For Proposal (RFP)
3. Prepare Proposal
4. Negotiate Contract
5. Authorize Work
6. Implement Work
7. Deliver and Invoice Work
8. Close Contract

Interviews of individuals in each step of the design, development, and production process were performed to develop the process flow steps described herein. Each of these steps is further described as follows.

The Develop Business Process is the responsibility of the Marketing or Program organizations. It is during this phase that customer contacts and relationships are developed. Requirements are defined and analyses performed to understand customer requirements. Alternative approaches for satisfying a customer’s needs are proposed and evaluated. The duration of this step varies. For large DOD based initiatives, this phase is known as Concept Exploration and may take as long as five years. In International markets, customers typically desire derivative products with some customization of features. The duration of this phase in an International Market is typically one to three years. In Commercial markets, the customer is typically looking for “Off-The-Shelf” or non-developmental products which are considered to be derivatives of current product lines with the mixing of ready made options. The Business Development Phase is usually one year or less with these customers.
The Receive RFP process is also the responsibility of the Marketing or Programs organizations depending on the type and maturity of the customer. There is sometimes a sharing of responsibility between these organizations as the program/project migrates toward being a production contract. There is often a transition of ownership during this phase to the Programs organization who will ultimately be responsible for the execution of a contract. These first two process steps are depicted below in Figure 4-1 Business Development & Request for Proposal Processes.

**BUSINESS DEVELOPMENT & REQUEST FOR PROPOSAL PROCESSES**

1. **Identify Opportunities**
2. **Develop Plan to Obtain Request for Proposal**
3. **Receive RFP & Develop Strategy**
   - **BID Decision**
     - Yes
     - **Estimate Proposal Cost & Develop Schedule**
     - **Release Proposal Notification**

**Figure Chapter 4-1 Business Development & Request for Proposal Processes**

The Proposal Preparation phase (shown below in Figure 4-2) is the responsibility of the Program organization. It is during this phase that individuals who have had contact with the customer act as their representative to communicate the intent of the requirements documented in the RFP and assist in development of the “Win Strategy” for the proposal.
Upon delivery of the completed proposal response to the customer and completion of an evaluation period, we enter the Contract Negotiation phase. The Contract Negotiation, Work Authorization, and Implement Work Process are the responsibility of the Program Organization with support as required from all other enterprise organizations including, the Engineering, Customer Service, and Contracts organizations. These steps are depicted in Figure 4-3 Negotiate Contract & Authorize Work Processes, and Figure 4-4 Implement Work Process. During the Contract Negotiation step, the Program Manager has the authority to modify the program structure, deliverables, and schedule. This step concludes with a signed contract and authorization within Sikorsky Aircraft for core competency areas to begin (implement) work.
The Implement Work step is the point when the interpretation of the customers desires are acted upon, the physical system defined in detail, and physically built. This step involves the most player departments and has the largest quantity of handoffs both within and outside of departments, and within and outside of the enterprise. It is the effectiveness of the work completed during the Implement Work step that has the most significant impact in determining the value of Time and Cost To Market metrics.
The Deliver Product and Contract Closure process (Figure 4-5), is the process step where the final product is evaluated by the customer. This is when Sikorsky Aircraft verifies that the product meets the original requirements established by the Customer and Marketing organization. Upon successful completion of the verification or Customer Acceptance Review, the product title is prepared and product ownership is transferred to the customer. Documentation required to close the contract is prepared and the contract closed.

This process step is iterated upon until successfully completed. It is this step which for a successful program/project, is short and will have no feedback into the Implement Work process. Product inconsistencies and/or issues with requirement interpretation will be identified within this step. These inconsistencies or requirement issues, if not detected
until this phase, can result in a significant negative impact to Time To Market and Cost To Market.

Figure Chapter 4 -5 Deliver and Invoice Work & Contract Closure Processes
Chapter 5: Dynamic Hypotheses

Hypothesis Development

Interviews of individuals in each step of the design, development, and production process were performed to determine where issues exist within the process and what prevents them from performing their job more efficiently. These interviews resulted in a compilation of issues as summarized in Table 5-1 below. These issues were mapped into each of the process steps where they occurred. They were then analyzed to determine at which process step they either first occurred or where they traced to for their information in order to identify all feedback loops.

For example, the Lack Of & Late Definition of Requirements and the Late Identification of Requirements Need were the two issues which had the highest frequency of occurrence and the earliest instance of occurrence. These issues appeared in steps 1, 2, 3, 6 and 7. It was also the Lack Of & Late Definition of Requirements in the early phases that caused issues such as multiple design iterations and rework to occur in the detail design and implementation downstream steps.

This analysis of the issues and mapping to the process steps, provided the basis for development of the dynamic hypotheses relating to Time to Market and Cost to Market. The hypotheses are listed below and further defined in this chapter.

- Average Aircraft Complexity
- Understanding & Flowdown of Requirements
- Employee Experience Level
- Electronic Design Tools

Issues were then categorized and ranked regarding severity. Relative ranking was established as a function of frequency of occurrence, direct impact on Time and Cost to Market, and impact to other process steps. This ranking was later used to assist in
brainstorming potential change initiatives, and to recommend a prioritization of the change initiatives for implementation.

<table>
<thead>
<tr>
<th>Issue Number</th>
<th>Issue Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lack Of &amp; Late Definition of Requirements</td>
</tr>
<tr>
<td>2</td>
<td>Late Identification of Requirements Need</td>
</tr>
<tr>
<td>3</td>
<td>Unclear Hand-offs and Pickups</td>
</tr>
<tr>
<td>4</td>
<td>Complexity (Process is too complex)</td>
</tr>
<tr>
<td>5</td>
<td>Duplication of Responsibilities</td>
</tr>
<tr>
<td>6</td>
<td>Non-Value added audit findings</td>
</tr>
<tr>
<td>7</td>
<td>Lack of Clear Prioritization</td>
</tr>
<tr>
<td>8</td>
<td>Conflicting and Competing Goals</td>
</tr>
<tr>
<td>9</td>
<td>Process ownership Unclear of Conflicting</td>
</tr>
<tr>
<td>10</td>
<td>Prod Mods Obsolescence</td>
</tr>
<tr>
<td>11</td>
<td>Lack of Meaningful Metrics</td>
</tr>
<tr>
<td>12</td>
<td>Excessive Quantity and Revision of Shipment Parts Work</td>
</tr>
<tr>
<td>13</td>
<td>Too Much Tweaking All Processes</td>
</tr>
<tr>
<td>14</td>
<td>Too Many Procedures</td>
</tr>
<tr>
<td>15</td>
<td>Non Documented Workarounds</td>
</tr>
<tr>
<td>16</td>
<td>Lack of Feedback</td>
</tr>
<tr>
<td>17</td>
<td>No Teaming with Suppliers</td>
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<tr>
<td>18</td>
<td>Process Too Long</td>
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<tr>
<td>19</td>
<td>Lack of Cross Training</td>
</tr>
<tr>
<td>20</td>
<td>Cross Training</td>
</tr>
<tr>
<td>21</td>
<td>Existence of Rice Bowls</td>
</tr>
<tr>
<td>22</td>
<td>Reliance of Single Point People (Generalist, Single Skill)</td>
</tr>
<tr>
<td>23</td>
<td>Don’t Do This Job Here</td>
</tr>
<tr>
<td>24</td>
<td>Not Following Procedures</td>
</tr>
<tr>
<td>25</td>
<td>Lack of Flexible Manufacturing</td>
</tr>
<tr>
<td>26</td>
<td>Lack of Emphasis on Cost/Schedule/Quantity</td>
</tr>
<tr>
<td>27</td>
<td>Poor Allocation of Capital Resources</td>
</tr>
<tr>
<td>28</td>
<td>Inefficient and Ineffective Infra Structure</td>
</tr>
<tr>
<td>29</td>
<td>Incorporation of Outside Design</td>
</tr>
<tr>
<td>30</td>
<td>Difficult to Modify Aircraft Existing Models</td>
</tr>
<tr>
<td>31</td>
<td>Inflexibility of Change to Cost Collection System</td>
</tr>
<tr>
<td>32</td>
<td>Existence of Dual Bill Of Material</td>
</tr>
<tr>
<td>33</td>
<td>Lack of Understanding of Certification Requirements</td>
</tr>
<tr>
<td>34</td>
<td>Lack of 3D Models for Existing Aircraft</td>
</tr>
<tr>
<td>35</td>
<td>Lack of Enterprise Alignment</td>
</tr>
<tr>
<td>36</td>
<td>Inadequate Communication of Requirements</td>
</tr>
</tbody>
</table>

Table Chapter 5-1 Process Issues

Dynamic Hypotheses
There are four proposed dynamic hypotheses causing the increase in Time to Market and Cost to Market. These hypotheses have been derived based upon research and identification of issues in the design, development, and production process. The first is that the Average Time and Cost to Market is being negatively impacted by an increase in average aircraft complexity.

As we migrate from few customers with large production buys (10-1200 aircraft) to many customers with small buys (1-10 aircraft), the amount of customized systems and features needing development increases. This requires increased integration with our aircraft’s legacy subsystems and components. These increased integration requirements negatively impact the average time and cost to market for an aircraft.

This first hypothesis is depicted in the causal loop diagram Average Aircraft Complexity (Figure 5-1). As customer orders increase today, the number of customized features required by each customer increases. The development or additional design required as well as the additional integration of these new features combine to increase the development time required per order. Therefore, this increase in development time increases both the Time and Cost to Market which in turn have a negative impact on achieving new customer orders.
The second hypothesis is that the Average Time and Cost to Market is being negatively impacted by the lack of a true understanding of customer needs. A full understanding of customer needs is required to define a configuration that will meet customer expectations. Without this understanding, rework of the design will be required until the system is acceptable to the customer. This increase in rework and therefore development time negatively impacts both the metrics Time and Cost to Market.

This hypothesis is depicted in the causal loop diagram Understanding & Flowdown of Requirements (Figure 5-2). In this reinforcing loop, the effort expended in the activities to acquire and analyze customer needs increases the accuracy of the interpretation of the requirements. Having accurate requirements increases the number of requirements which are communicated effectively which then increases the number of products which ultimately meet customer needs. The more products meet the needs of the customer, the more sales increase. As sales increase so do profits and the amount of funding (IR&D)
available for methodology development and process improvement initiatives to increase the ability to acquire and analyze customer needs.

The third hypothesis is related to employee experience level. It is proposed that the implementation of cost reduction initiatives has included reduction in force which has most significantly impacted senior working level personnel. These personnel had the highest average level of experience. The lack of time and incentive to mentor junior staff combined with the loss of this experienced staff has lead to a loss of efficiency in all parts of the process. This is a factor negatively contributing to both the average time and cost to market for an aircraft.

This hypothesis is depicted in the causal loop diagram Employee Experience Level (Figure 5-3). In this reinforcing loop, as customer orders increase the need for additional staff increases. This staff is comprised of both Junior and Senior level personnel. As the need for additional staff increases the need for experience personnel to perform the

Figure Chapter 5 -2 Understanding & Flowdown of Requirements
design, development and production of these systems. Due to the time delays involved in hiring additional staff, the amount of fatigue and burnout increase. The increase in employee burnout decreases morale and the resulting efficiency level. The availability of incentives and time available to mentor junior level employees directly impact the average employee experience level, degree of burnout, morale and efficiency level. As employee efficiency increases/decreases so does the product time and cost to market. As time and cost to market increase, customer orders decrease. This decrease in orders reduces the need for additional staff.

![Diagram of Employee Experience Level](image)

**Figure Chapter 5 -3 Employee Experience Level**

The final hypothesis to be addressed involves the use of electronic design tools. It is proposed that the current production base is based upon designs that were completed in the mid 1970’s prior to the implementation of electronic design models. Today’s design process is transitioning to a process utilizing these tools. New designs require either translation of legacy drawings into this media or integration of legacy drawings with electronic “drawings”. The slow transition of design models into electronic design models within the enterprise, to have available for program/project use in a timely
manner, is a factor contributing to the average increase in time and cost to market for an aircraft.

This hypothesis is depicted in the causal loop diagram Electronic Design Tools (Figure 5-4). In this reinforcing loop, increasing the enterprise staff level increases the availability of engineers to develop and convert legacy designs to electronic designs and therefore the amount of design automation available. The implementation of new designs in electronic media decreases the time and cost to market, which increases profitability and the ability to increase staff.

Figure Chapter 5-4 Electronic Design Tools
Chapter 6: System Dynamics Model

A system dynamics model for each of the dynamic hypotheses has been developed to assess the validity of the dynamic hypotheses and to develop recommendations to reduce Time and Cost to Market. These models are based upon the data and relationships derived from the interviews of subject matter experts. A description and visual representation of each of the models is presented below.

Average Aircraft Complexity

The Average Aircraft Complexity Model is presented in Figure 6-1. This model is based upon the molecule structure of Level Protected by Level. The quantity of customized features is a stock which is a function of the number of customer orders. Historically, due to the past business base for Sikorsky Aircraft, product sales of derivative aircraft to international and commercial customers have typically required additional development efforts. This development has been required to provide additional equipment/features or to integrate alternative equipment into our product outside of its core configuration. As our customer base expands and the number of alternative features completing development increases it is our goal that additional development efforts will not be required for each new customer order. Initially it is assumed that each new order requires development of three new features. There is a goal that over a period of time this value will be reduced, eventually reaching zero. It is assumed that it would be feasible to reach this goal given that as the quantity of orders increases and more features are designed and integrated into the system, there would be fewer and fewer features never before designed.

Once development of the new features is complete, these features must be physically integrated into the system design. This process is represented within the variable Delay per Customized Feature. The actual delay is a function of many variables including feature complexity, baseline configuration complexity, number of interfaces impacted,
number of hardware versus software interfaces impacted, and type/level of documentation available for baseline design. For simplification, the average delta delay per feature is assumed to be two months. The quantity of features needing development and the amount of time required for that development impact the time and cost to market for the product.

![Diagram of Average Aircraft Complexity Model](image)

**Figure Chapter 6 -1 Average Aircraft Complexity Model**

**Understanding and Flowdown of Customer Requirements**

The Understanding and Flowdown of Customer Requirements Model is represented in Figure 6.2. This model is based upon system engineering principle applications during the design process for rotary wing systems. Two molecule structures have been included in this model, Work Accomplishment and Product Attractiveness. Requirements enter the system as a function of the number of customer orders received. It is assumed that there are a nominal number of one hundred requirements per order. Stocks represent the quantity of stakeholder requirements acquired and analyzed, the amount of work to do, the quantity of work performed correctly, and the amount of undiscovered rework. The number and quality of the requirements captured correctly is a function of the effort expended in the analysis phase.
Quality is quantified as a variable between zero and one, and is measured as a function of both the tools and skills available for the analysis, and the funding available. The product of Quality and the number of requirements to be acquired/analyzed is the amount of work performed correctly or work accomplished. Half of the requirements requiring rework are categorized as “Discovered Rework”, the remainder are “Undiscovered Rework”. The amount of rework drives delivery delays. The degree of the delay and the overall product quality level determine product attractiveness.

If a product is attractive to the customer it is assumed to have met their needs specified at the beginning of the cycle. Quality, attractive products result in sales, profit, and therefore funding available for investment in the tools and skills required to understand stakeholder needs.

This model is integrated with the Employee Experience Level Model through the variables for Customer Orders and Cost To Market. This integration allows for analyses on variables such as workforce size and productivity, to be reflected measures such as quality and work performed correctly.
Employee Experience Level

The Employee Experience Level model is presented in Figure 6-3. This model is based upon several molecule structures including Aging Chain with Productivity, Fatigue, Goal Gap, and Desired Workforce. The stocks representing three levels of experienced employees, their combined level of experience, and amount of productivity is based upon the Aging Chain with Productivity molecule. This molecule was chosen to represent the current workforce with three fairly distinct experience levels (new hires, 10-15 years experience, and 25 plus years of experience). These three levels of employees have differing attrition and production rates. It was assumed that it required twelve months for a new hire to gain enough experience for them to be considered productive. Their initial productivity is assumed to be one unit per month per new hire. Junior personnel require a minimum of four to five years before they are considered to be fully experienced. They are assumed to have a productivity of three units per month per junior level employee. Experienced personnel typically have a retention rate of ten or more years. They carry the majority of the responsibility for directing or leading jobs and executing work requirements. Experience personnel are assumed to have a productivity of four units per month per experienced employee. The Aging Chain with Productivity molecule was also modified to reflect the desire and time allocation for employee mentoring.

The impact of high levels of work requirements versus quantity and experience level of employees is measured using the Overtime and Fatigue molecules. The impact of overtime and the level of experience available to work projects is reflected in the Fatigue function which degrades the average productivity that the company has at any given time. This impact ranges from an increase to productivity if excess manpower exists to a degradation of 15% if overtime has been required for an extended duration.
Goal Gap molecule is used to reflect the gap in the workforce level compared to the workforce required to complete the customer orders. This need (either positive or negative) is then used to calculate the number of employees required. This required level of employees or workforce is reflected in the Desired Workforce molecule. This molecule bases its level from a comparison of the total workforce and the workforce gap.

Electronic Design Tools

The Electronic Design Tools model is presented in Figure 6-4. This model is based upon the molecule structure for a Smooth and combines with the models for Employee Experience Level and Understanding & Flowdown of Requirements presented earlier. The variable for the Time To Model A Design Feature (smooth time) is 1 month. The Gap is equivalent to Gap / Time To Model A Design Feature which represents the time for the amount of design features needing 3D modeling to be available for use. The stock represents the amount of a given product line which is available in an electronic (3D...
model) representation. This variable is a factor in the amount of time required to complete product development and therefore is input into delivery delay within the Average Aircraft Complexity model.

Figure Chapter 6 - 4 Electronic Design Tools Model
Chapter 7: Design Process Sensitivities

Average Aircraft Complexity

Delay Per Requirement Misinterpretation

An analysis of the impact of Design Complexity utilizing system dynamics, identified a significant impact of complexity on system delivery delay and therefore schedule. A sensitivity on the Delay per Customized Feature results in the trends provided in Figure 7-1 below.

Analysis indicates that the impact of delivery delay is responds linearly to the delay per customized feature. The fact that the trend is linear indicates several findings. The first is that adding design complexity lessens the amount of time required to design, develop, and produce a system. Given that employees with the appropriate experience level are available, there is a basic time required to perform these tasks. Adding a significant amount of additional complexity to a design will requires additional staffing and/or increasing the experience level of the employee base assigned to the task. This optimized allocation of staff time results in a reduction in the time for the product to reach delivery to the customer.
The second insight is that the addition of design complexity (number of customized features) results in an increase in product attractiveness. The trend for Product Attractiveness as a function of design complexity is shown below in Figure 7-2. The inclusion of the additional design features and perhaps the required rework given some of those new features into the baseline design, provides the customer with an end product which better meets their needs. This better end product is preferable to the customer even though it may take longer to complete the order when compared to the baseline time. The inclusion of the customized features tailors the base product to the unique needs of the user. This can be a distinct competitive advantage if other products available through other suppliers either do not incorporate an equivalent feature or if competitors are not willing to customize their product to individual customers.
The last observation is regarding the impact on Time To Market. As with Delivery Delay Time, the Time To Market also shows a decrease as design customization increases. Time To Market is directly related to Delivery Delay as shown in Figure 7-3. Analysis indicates that as design complexity increases, the Time To Market decreases. The decrease in Time To Market is counterintuitive. The trend is caused by the feedback into employee staffing levels and implies that the resources applied to the product to address the additional design work required for the higher design complexity, offset the additional complexity and customization of the aircraft.
**Employee Experience Level**

**Employee Mentoring**

An analysis of Employee Experience Level utilizing system dynamics methodology, identified several interesting findings. The first was an insight into employee mentoring policies. Several employee mentoring initiatives have been attempted, some more formal than others. The modification of the Aging Chain with Productivity molecule provided the opportunity to assess the impact of mentoring on employee retention and productivity. As reflected in Figure 7-4 Rookies Workforce Level and Figure 7-5 Total Workforce Level, the workforce decreased significantly as mentoring was implemented.

The degree of mentoring also has a slight effect on the retention rate of experienced employees. This is a result of mentoring having a facilitating effect on workforce experience. If new hires are mentored, they quickly move into the classification of
experienced employee reducing the number of new hires that stay at the "Rookie" level for the average 12 month period (Figure 7-4 Rookies Workforce). The hiring rate to bring in additional new employees is not sufficient at its base level to sustain an equilibrium level of new hires in the company. This effect then carries onto the total workforce.

The Total Workforce level is represented in Figure 7-5. As new hires move rapidly into the experienced employee classification, and eventually on into senior employee status. Because employees move more rapidly as a whole to the senior level of experience the ultimately leave the company sooner. At best this time equates to one or two years sooner per employee. In the worst case, and something which is not represented in the modeling, is the fact that with additional new hires being employed, and these same employees gaining experience sooner, there is less need on the part of the company to retain the higher salaried senior experienced employee. In order for these senior level employees to be of value to the company they must provide value other than that of pure
experience (productivity) such as history, lessons learned, contacts, and leadership to be considered a valued part of the company. These effects result in the need for the company to have a larger total workforce to account for the increase rate of attrition brought upon by mentoring. In addition, the workforce is a more expensive to the company given that the number of lesser paid employees (new hires) quickly become higher paid (experienced) employees, and it is expensive to locate, hire, and train new their replacements.

The implementation of a mentoring program has a negative effect on productivity as seen in Figure 7-6 Mentoring Sensitivity on Productivity. As the total workforce increases in size and each senior level employee spends a fixed amount of time mentoring newly hired or junior staff, the total number of hours mentoring per person increases. This time is taken directly away from their productive time formerly used to produce product. The sensitivity shows that the implementation of a mentoring program causes a significant decrease in productivity. This negative effect and the rapid movement of new hires into a
more productive state only slightly compensate for the additional time required for mentoring as the mentoring levels are increased.

![Graph for Productivity]

**Figure Chapter 7-6 Employee Mentoring Sensitivity on Productivity**

The increase in total experienced and senior workforce has a positive effect on production which can be seen in Figure 7-7 Total Production. As the total workforce increases in size the total measurable production output reflects the same trend. A primary effect of the implementation of a mentoring program is reflected in an increase in production of approximately 30%. This is a significant increase in production for a relatively small investment. Likewise, a workforce increase to 200% the baseline, combined with an increase in initiative and time to mentor of six times the baseline, results in a production increase of over 200%. This increase is counterintuitive due to the decrease in workforce productivity that was shown in the sensitivity above. Due to the change in attrition rate as a result of mentoring implementation, the workforce itself has become larger to compensate. The added quantity of new hires or “Rookie” workforce provides a benefit,
and as those employees progress into experienced and senior classification they provide a significant increase in production capability.

**Graph for production**

<table>
<thead>
<tr>
<th>Time (Month)</th>
<th>0</th>
<th>150</th>
<th>300</th>
<th>450</th>
<th>600</th>
<th>750</th>
<th>900</th>
</tr>
</thead>
<tbody>
<tr>
<td>production: newbase</td>
<td>5,424</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production: mentor2x</td>
<td>4,704</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production: mentor6x</td>
<td>3,984</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production: mentor8x</td>
<td>3,264</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production: mentor10x</td>
<td>2,544</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure Chapter 7 -7 Employee Mentoring Impact on Total Production**

The impact of mentoring on Time to Market is presented in Figure 7-8. As indicated, Time To Market also shows an improvement relative to the effects of mentoring. This sensitivity shows that as mentoring is implemented the product time to market decreases. The effect of additional increases to mentoring initiatives over the base implementation continues to provide a decrease in time to market however it is not a linear effect on decrease. The slope of the curves is another significant point. Without any benefit of mentoring the company average product time to market increases from the initial value of 24 months to an unacceptable level in a short period of time. Although a similar trend is noticed in the mentoring sensitivity curves, they have a more shallow slope and given a large periodic change in company workforce composition, this trend could be further corrected to return back to the initial baseline value or better. Also, it is important to
note that as shown above, although there is a continuing benefit of mentoring to time to market, it also requires a larger workforce to sustain this benefit.

**Graph for Time To Market**

![Graph](image)

<table>
<thead>
<tr>
<th>Time To Market: newbase</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time To Market: mentor2x</td>
<td>Month</td>
</tr>
<tr>
<td>Time To Market: mentor6x</td>
<td>Month</td>
</tr>
</tbody>
</table>

**Figure Chapter 7-8 Employee Mentoring Impact on Time To Market**

The implementation of mentoring programs is shown to have a positive effect on customer orders as shown in Figure 7-9. This insight was initially felt to be counterintuitive due to the decrease in productivity. A causal strip analysis performed on customer orders identified the improvement to be a result of the total production increase and reduction in time to market realized as mentoring initiatives increase.
Higher profitability is realized due to the increase in customer orders combined with the decrease in cost to market as shown in Figure 7-10. In this analysis cost to market is considered to be a direct function of time to market. Although increased staffing assigned to a project to facilitate schedule would result in a higher cost compared to a baseline staff on the same project, it was assumed for this analysis that the effect of the additional staff would be secondary. Historical data shows the primary effect to be the amount of time a project takes to have a larger effect. This is due to the fact that adding ten to twenty percent additional staff to a project over a duration of twenty-four months is significantly less than sustaining a team of several hundred employees for even one month. The variability in workforce level is less the cost driver than the amount of time a workforce with its associated overhead is required to work on a project to complete it.

The implementation of mentoring and increasing its emphasis reduces the cost to market. This is because as the total workforce increases with the level of mentoring implemented, there are more employees to available for a project. These employees are not required to
work extended periods of overtime as there is sufficient numbers of employees available. This means that the employees assigned to any given project are able to produce more product for less cost resulting in increased profit.

Graph for Cost To Market

![Graph for Cost To Market](image)

Cost To Market: mentor6x  millions
Cost To Market: mentor2x  millions
Cost To Market: newbase  millions

Figure Chapter 7-10 Employee Mentoring Impact on Cost To Market

Employee Fatigue

A second analysis performed using the Employee Experience Level Model measured the impact of employee fatigue. Over the past several years, Sikorsky Aircraft has implemented an overtime practice where compensated overtime is granted only if overtime is anticipated to be for an extended period of time. Compensated overtime is to be justified by the core competency manager and approved by senior management. The impact of extended periods of overtime combined with the experience level of employees is assessed in the Employee Experience Level Model through the Overtime and Fatigue molecules. The impact of overtime and the level of experience available to work projects could result in a compounding effect. An observation of the analysis indicates the
combined effect of these to variable results in the degradation of the average productivity that the company has at any given time with extended overtime periods.

A sensitivity to fatigue levels was performed by activating the Fatigue molecule within the Employee Experience Level model. Fatigue is assumed to occur if the overtime period is greater than or equal to one month. The analysis demonstrates that fatigue effects the time to market for the products (Figure 7-11), and the average employee productivity level (Figure 7-12), thereby negatively impacting the quantity of new customer orders as shown in Figure 7-13 Fatigue Impact on New Customer Orders.

Figure Chapter 7-11 Employee Fatigue Impact on Time To Market
Graph for Productivity

Productivity: combat widgets/(people*Month)
Productivity: newbase widgets/(people*Month)

Figure Chapter 7-12 Employee Fatigue Impact on Productivity

Graph for Customer Orders

Customer Orders: newfatigue widgets
Customer Orders: combat fatigue widgets
Customer Orders: newbase widgets

Figure Chapter 7-13 Employee Fatigue Impact on New Customer Orders
There is a compounding effect that occurs in that accounting for the fatigue level of employees performing extended overtime shows an increase in time to market and therefore a reduction in customer orders. This reduction in orders reduces the total workforce size and eliminates the need for employees to work extended periods of overtime as shown in Figure 7-14 Fatigue Impact on Desired Workforce Level. When the impact of fatigue is counteracted, the number of customer orders begins to improve, moving back toward the level of order achieved without fatigue. Actions which the enterprise could undertake which would counteract extended periods of overtime include compensating time off, flexible work schedules, a maximum allowable duration for overtime, or increased quantity of workforce to off-load tasks causing the fatigue. The best balance appears to be with some level of controllable and monitored overtime allowed. This would then provide for the increased short term productivity levels required by some projects, have a stable and sustainable workforce, and would sustain or improve time to market thereby increasing customer orders and profitability.

Graph for DesiredTotalWorkforce

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Another insight found is this analysis is the level of impact workforce fatigue can have on the enterprise operations. Fatigue was found to be such a strong influence that once workforce fatigue sets in, it was shown to be impossible to break through normal channels or by expecting it to be eliminated as a function of time. For this reason the planned sensitivities for schedule pressure were not performed. Significant efforts to either keep from happening or removing the workers impacted from the given project would be required to break the cycle. Experience on multiple project types has found that fatigue typically sets in when overtime greater than five hours per week is required, for periods beyond a couple of months. A low level of overtime (five hours per week) is tolerable over long duration. The issue in the case of small amounts of overtime for extended duration becomes morale and not fatigue.

**Understanding & Flowdown of Requirements**

An analysis of the process for understanding and flowing down stakeholder requirements utilizing system dynamics methodology, was performed in relation to employee mentoring with emphasis on new hire mentoring policies. The integration of the Understanding & Flowdown of Requirements Model with the Employee Experience Level Model allows for analyses on multiple variables within each model.

**Employee Mentoring**

The implementation of employee mentoring policies discussed earlier also has an effect on the requirements analysis phase of product design and the ultimate quality level (both real and perceived) to the stakeholders. As mentoring levels increase, the quantity of stakeholder requirements identified and the accuracy of their interpretation improved (Figure 7-15). This improvement in quality (Figure 7-16), is directly proportional to an improvement in employee productivity. The more time, energy, and better tools or skills...
employed to better understand a system and its intended operations will result in a higher quality understanding of customer needs. A better customer relationship also results from these efforts in that the optimal approach to understanding the customer’s needs is through a direct channel of communication.

**Graph for Accurate Interpretation of Customer Needs**

![Graph](image)

- **Accurate Interpretation of Customer Needs**: 317.94 M
- **Accurate Interpretation of Customer Needs**: 238.45 M
- **Accurate Interpretation of Customer Needs**: 158.97 M
- **Accurate Interpretation of Customer Needs**: 79.48 M

**Figure Chapter 7 - 15 Employee Mentoring Impact on Interpretation of Stakeholder Needs**
Figure Chapter 7 -16 Employee Mentoring Impact on Quality

The increase in quality of work and accurate interpretation of requirements leads to larger quantities of work completed correctly and accurately the first time through. Figures 7-17 Employee Mentoring Impact on Outstanding Work and 7-18 Employee Mentoring Impact on Performing Work Correctly demonstrate this finding. The trends do not have the identical slope because as work is completed better and in less time, as is the case with mentoring, the number of customer orders increases. The existence of larger quantities of work (outstanding work) in this case is a measure of goodness to the enterprise. The larger quantity of outstanding work causes the shallow slope to the curve in Figure 7-19.
Figure Chapter 7-17 Employee Mentoring Impact on Outstanding Work

Figure 7-15 which shows the relative degree work is performed correctly, demonstrates the benefit of employee mentoring programs. The impact of a small mentoring program yields a sustainable benefit to correct work. The implementation of a strong mentoring program shows a significant improvement of approximately 200% to correct work when compared to the small mentoring program.
The amount of rework discovered is found by taking half of the total amount of work less the amount of work performed correctly. In designing and producing products it is not only important to do work correctly the first time, but to identify any rework required as early as possible in the design cycle. Issues identified late in the product's design or production are much more expensive to correct than those identified early in the process. A constant of 50% identification of rework was assumed for purposes of this analysis. Given this assumption, it is shown in Figure 7-16, the impact to rework levels as a function of the level of employee mentoring. The total amount of rework discovered and required as a function of mentoring significantly decreases. The training provided to the new hires improves their skills and ability to utilize various tool sets effectively. In addition, the new hires are training in how to properly document, track, and communicate the requirements they have identified to other employees.
Reduction in the amount of rework required contributes to a project's ability to meet schedule goals. Most programs are planned as success oriented in that they do not provide allowances for technical, cost, schedule or programmatic risks. The better trained and more experienced an employee is contributes to higher quality definition of requirements and work performed as discussed above. This lack of rework supports a program's planning assumption for success and eliminates schedule delays due to rework. Figure 7-17 below shows the relative reduction in delivery delay which directly relates to time to market savings. As shown earlier, mentoring has a positive effect on this aspect of the product development cycle.
Effort to Acquire/Analyze Stakeholder Needs

The amount of effort undertaken to understand a product's stakeholders typically has a significant impact on how well a supplier truly understands their customer. The amount of effort undertaken to understand a product's stakeholders has a significant effect on the requirements analysis phase of product design and the ultimate quality level of the product. As the effort to understand the customer increases, the quantity of stakeholder requirements identified and the accuracy of their interpretation improved. This results in directly proportional to an improvement in quality (Figure 7-21). A doubling of the amount of effort (equivalent to either time or manpower) results in a 100% increase in product quality. It is assumed for this analysis, that all the effort being spend to understand the customer's requirements is effective.
Figure Chapter 7 -21 Effort to Understand Requirements Impact on Quality
Chapter 8 : Implications to Proposed Design Process Changes

The last major change initiative within Sikorsky Engineering took place during the late 1960’s to early 1970’s. At that time the engineering organization transferred from a team based structure to the functional core competency structure which has been in place for the last 20 years. It has been the structure during the highly successful years of the H-60, H-53, S-76, and beginning of the RAH-66, and S-92 product lines. Recently there has been a change back to a team based structure.

The analyses performed all assumed acceptance and support from within the enterprise for change initiatives. In order to implement any new initiative the political, cultural, and strategic aspects must be addressed. Sikorsky Aircraft is a company with an extremely strong culture. Sikorsky has tried several change initiatives aimed at improving the company’s competitive position. In the past it has been difficult to fully accept and implement change initiatives in compressed amounts of time due to our strong cultural heredity. Past initiatives which should have taken three to six months for implementation have actually taken up to two years. This was because buy-in by upper management was never complete. Many more initiatives begin than are fully realized due to the extended amount of time and commitment required to achieve implementation. Parties involved in the implementation get frustrated or get shifted to other priorities hindering their efforts. They are not provided the opportunity to focus on a single task and seeing it through its execution. This again relates back to the issues of buy-in by senior and middle management. Previous failures of change initiatives have undermined attempts to convince employees that “this change is really going to happen”. To realize the true benefit assumed in this analysis, rapid implementation and directed acceptance through executive management will be critical. The executive management followed by senior and middle management will have to “walk the talk”. One approach to achieving this could be to start the process through the strategic goals of the enterprise.
These Enterprise-wide strategic issues are applicable to both military and commercial products on both existing and new aircraft platforms. For the past several years, the strategic goal of the company has not been formally developed, documented, and communicated to enterprise employees. This lack of a clear vision has been identified as a significant shortcoming of the current organization and has resulted in individuals or departments within the organization establishing goals for their areas independently. These independent goals often conflict with those of other areas or potentially the goal of the enterprise itself. It is evident that sub-optimizations have occurred which are contributing to the current deterioration of metrics such as Time and Cost To Market.

A simplistic example of an enterprise alignment would be to communicate the return of superior profit margin as a strategic goal for Sikorsky. In Sikorsky Aircraft's case, achievement of this goal satisfies stockholders, ensures new product development, technology advances for existing platforms, advancement of methodologies which assist in execution of core competency areas, and enterprise information flow updates. In establishing and communicating the enterprise strategic goal(s) the enablers identified above can be verified and prioritized for implementation. It would align, prioritize or totally eliminate the independent goals that are currently consuming the enterprise.

Much focus has been placed on the early stages of the product design, development and production process. This is due to the assessment of downstream issues and their tie back to early problems with the lack of understanding customer needs, lack or late definition of requirements, and unclear hand-offs and pick-ups being identified as the most prevalent issues as discussed in Chapter 5. Formalized process such as those to develop, document, and communicate requirements were demonstrated as having significant benefit to product quality and overall time to market.

The system dynamics analysis of the design and development process at Sikorsky Aircraft identifies insights and partially addresses the process improvement initiatives to:

- Put emphasis back on the front-end of the business process
• Understanding the customer’s need better than they do
• Documentation and flowdown of requirements
• Implement 3D design tools (CATIA and EMU) across all programs/projects
• Conversion of legacy data into 3D designs

The company initiatives to understand the customer’s need better than they do, and to improve documentation and flowdown of requirements, reside within the initiative to formalize our system engineering process. The elements comprising System Engineering Process implementation include Communication of Long Term Strategic Plan, and increased emphasis on formalized processes for Requirements Analysis, Functional Analysis & Allocation, and System Analysis & Control. Specifically, the greatest emphasis is on the rebuilding of the Strategic Planning organization and Requirements Analysis core competency areas where operations analysis skills are resident to better focus on customer needs, and mandating the implementation of system engineering processes across our programs.

The design process is driven by defined requirements. These requirements can be classified into technical, operational, financial, and programmatic categories. Requirements drive the generation of design concept alternatives. Alternatives are then assessed against the requirements to determine compliance. Additional alternatives may be developed as a result of this analysis but eventually these estimates allow the designer to select the most promising alternative for further definition and refinement of the next level of detailed requirements. To increase customer satisfaction, product quality, and customer orders, the enterprise must learn to adapt our product offerings to the customer’s requirements rather than attempting to convince the customer that the existing product is really what they were looking for. The competency of Requirements Analysis is one area where this communication is supported.

Typical methods used in requirements analysis range from discussions directly with the customer, to research, and complex modeling and simulation of systems in their
operational environment. As stated earlier, the more time, energy, and better tools or skills employed to better understand a system and its intended operations will result in a higher quality understanding of customer needs. Utilization of modeling and simulation tools also provide a vehicle for the supplier to communicate back to the customer their interpretation of the customer's needs. This visualization is extremely effective in verifying the supplier's understanding back to the customer. A better customer relationship also results from these efforts in that the optimal approach to understanding the customer's needs is through a direct channel of communication.

As supported through the analysis utilizing system dynamics the accurate understanding of customer needs and requirements plays a significant role in the health and well being of a company. Excelling in this area could mean the difference between making an excellent product which is profitable. The benefit to performing this step well is often difficult to quantify. Through the analysis it was demonstrated that as the enterprise improved its capability to identify stakeholder requirements it ultimately resulted in an improvement in product quality.

Many alternative approaches and methods exist for learning about customer needs. One approach may be to utilize discussions directly with the procuring customer and the user community. This approach is used by most companies and in high technology industries is one of the best methods to determine the existence of a need. However it often requires additional efforts to fully understand the needs for high technology, high investment products such as aerospace.

A second approach is to utilize physical mockups of the end product. Customers and users can then be invited to evaluate the product and provide feedback on the design. Products which have a large amount of man-machine interface use this method to elicit discussion on design features. In this manner the human can observe or verify physical interface points. Products which rely heavily on aesthetics also benefit from this method.
Another approach would be to utilize simulation models to replicate the end product in its operational environment to determine its effectiveness. This approach is highly effective however it is also costly to sustain the capability. It is typically utilized within aerospace and government (DoD) business based companies where development is expensive and extends over a long duration. This type of analysis then becomes cost-effective as requirements need to be verified on a continual basis and multiple design alternatives exist which would be expensive to develop into prototypes.

Mentoring policies also have a significant impact on the enterprise's capability to understand customer requirements. The sensitivity to mentoring policies indicated the benefit to early education of new employees and the importance of retaining experienced employees. It is also important to note that it will be highly likely that if mentoring policies are employed, either additional efforts to retain employees once they become experienced will be required, or the mentoring effort should be for a small period of time and not extended. In the past when retention rates have been a concern, the company has established task teams to address the challenge of employee attraction and retention.

The earlier and better models of conceptual designs can be built and assessed the better the resulting design will be. State of the art toolsets today consist of 3D model simulations which allow the design engineer to develop their system in a virtual environment. The implementation for 3D design tools and conversion of legacy data into 3D designs is addressed through a mandate to utilize CATIA and digital mockups for any new design effort. Additionally, as a need arises to work or develop derivative aircraft there is an effort to convert the applicable legacy designs to 3D. A company investment is required for the legacy data conversion. The pay-offs can be significant if the designs converted have significant change, are used on multiple aircraft buys, or are applicable to more than one customer. A large training effort to refresh or build 3D design skills will be required in order to eliminate the burden of the legacy design conversion on a few individuals or a few limited groups.
Data and process definition is an aggregate of many helicopter programs, with the focus on military programs. In the past most process improvement initiatives were conceptualized and started in the military sector. Today, the initiatives stem primarily from commercial practices where the company has had to develop and implement practices with their own investment in order to remain competitive. It is recognized that process improvements from commercial programs may be applicable to military but given the culture of Sikorsky Aircraft as a military developer, in order to change much of the embedded bureaucracy we need to change the military processes. This should be the optimum time given government initiatives with Acquisition Reform to apply some of the commercial practices and simplify current military practices.
Chapter 9: Recommendations

Multiple alternatives for change to the design process exist at Sikorsky Aircraft. As stated changes under consideration include the implementation of System Engineering processes, automation of design tools, modularity of designs, and changes in organizational structure. These changes support the hypotheses identified of improving Time and Cost to Market.

Successful change initiatives are created by first establishing a sense of urgency. The current state of the industry combined with the status of the enterprise support this. Sikorsky is in the process of downsizing and establishing a new organizational structure. Currently, critical core competency areas are the only areas expanding or at a minimum sustaining their size. This and other company guidelines regarding purchasing, travel, etc... are the first steps toward conveying a sense of urgency. Executive management must be the principle messenger. A concerted effort to convey this message and to then follow through with periodic campaigns and continual reinforcement is required.

The establishment and communication of the enterprise goals and metrics are the string which will bring the vision into reality. It is critical to tie a metric for each functional organization to the enterprise metric, and then make each employee accountable for achieving and supporting each other in achieving the goal. In establishing the functional organization metrics using a top down approach, executive management can eliminate conflicting agendas. It should also be noted how each functional organization enables or supports other interfacing organization’s metrics. By making all functional organizations partially responsible for their integrating organization’s metric, this would force the integration of functional organizations and eliminate the potential issue of one organization to focus only on their specific metric and ignore their required support of another. This integrated network of metrics would be very powerful in coordinating the change initiatives within a short amount of time as well as measuring their effectiveness.
Compensation across the enterprise needs to be restructured. To succeed in changing the organization a strong team atmosphere is required. Rewards should not be provided to individuals, rather they should not be awarded based upon teams or large groups meeting goals. This method would pull the organization together as well as aiding the communication about the effectiveness of change. Another alternative would be to provide a bonus to every individual in the enterprise dependent on enterprise achieving the goal. Either method would require success to be measured in small steps in order to gain momentum.

The ability for change agents to be allowed to focus on the change initiatives through full implementation is desired. The change agents selected should be individuals who are thought to be high potential candidates. They should be augmented by staff whose charter it is to publicize what the change agents goals are, their implementation plan, progress, and successes. It is important that these individuals not be tied to the old regime.

Sufficient budget to implement the change initiatives is an implied requirement. This budget needs to include salary for the change agents, enterprise training budget, capital and overhead expense to initiate the change required. For example, the conversion of legacy design data into 3D models requires enterprise funding. This funding must be sufficient enough to cover the training, mentoring, and man-hours for the conversion, as well as the capital investment for computer hardware and software.

Specific change initiatives recommended for implementation include a strong emphasis on both marketing initiatives and the technical aspect of understanding customer requirements, formalizing system engineering processes, a short focused period for employee mentoring, conversion of a significant amount of legacy design data, and implementation of a small skunk-works operation. Based on the analysis provided, these initiatives would all benefit company product lines, reputation, customer relationships, and metrics for time and cost to market. The initiatives which would have the largest
positive impact are those related to improving the customer interface. Marketing which is the first voice and image of the company to the customer. Marketing is the voice of the customer to the company. The relationship built between the marketing representative and the customer can often help to make or break deals. The better the reputation with the customer the better the information on what the customer's needs are.

The core competency providing analysis of technical requirements has been shown to a significant impact. Although many methods and analysis techniques are similar across industries, this skill set is highly specialized on product performance characteristics, missions, and product operational environments. For example, the tactics, techniques, and procedures for operation of a rotary wing system operating in a low altitude covert operation will be drastically different from a tank in the desert transporting material between posts, or a fixed wing aircraft flying at high altitude transporting thousands of passengers from point A to B. The ability to simulate a conceptual product in its ultimate environment is both a design and marketing tool that can provide a competitive advantage. This initiative is the one which will require the most investment and care in building, however it will be one of the most beneficial to the future of the company.

Initiatives to improve productivity through either implementing overtime policies, or mentoring junior level employees both provide short term benefits. The analysis was revealing in that these initiatives were thought to both be positive. The effects were found to have positive effects on time and cost to market, or the understanding or customer needs, if the mentoring occurred for a period of no more than one year. This is caused by the effect where facilitating the rate that employees acquire experience, given everything else equal, also facilitates the rate at which they will pursue alternative employment. If it is found that initiatives such as mentoring are required for longer durations to sustain a high level of experience, counter acting efforts will be necessary in order to balance the workforce. The risk to the workforce if the counter acting efforts are not implemented with ultimately be a high work level for all employees and burnout from trying to meet work and schedule commitments. Therefore the recommendation stands
that as workforce attrition is facilitated with mentoring, mentoring is not a strong alternative to improve productivity over a long period of time.

Product complexity causes the largest delay in product delivery and therefore the largest negative impact on time and cost to market. Initiatives to update legacy data into 3D modeling to facilitate product design, tooling, inspection, and maintenance require significant investment and are required in this environment to simply make the product competitive again. With the industry moving toward more and more customers procuring only one or two uniquely configured aircraft 3D modeling during the design pay off significantly in later phases or when customized features may be requested by other customers. Utilization of 3D design modeling provides the capability to configure aircraft with customer driven options with little or no impact on profit margin, time to market, and quality. This could ultimately turn into a key strategic competitive advantage. Both military and commercial customers desire this improved response. Both customer satisfaction and compliance to customer specification requirements are metrics tied to this strategy. As a result, it flows down to all levels of the enterprise.

A recognition of the importance of system engineering processes supported by the analyses performed as part of this research, Sikorsky Aircraft has begun formalizing system engineering processes across all products and activities in the company. This initiative includes activities to understand customer requirements, requirements management, functional allocation, synthesis, and system analysis & control. The formalizing of this process has required determining the best practices and adaptation of practices for our specific application, followed by training and guidance in implementation. This initiative, as with many others, has received resistance in the initial attempts at implementation. However, executive management buy-in and support is slowly leading toward acceptance by programs, and functional organizations. It is expected that although some additional expense may be incurred in early phases of the product development cycle, this effort will result in improved understanding, communication, and control of stakeholder requirements.
The final recommendation is for an overall focus on the entire process phase initiated at early project definition and continuing through program award to provide the optimum process solution. The approach to optimizing the selection and implementation of system processes should be equivalent to that of optimizing the design of an effective system. It is often the desire of an engineer to optimize their individual pieces of the product. An effective leader will resist this tendency and will instead always have the ultimate performance of the system as the goal.
Appendix A
Simulation Variables

DeliveryDelay =
   IF THEN ELSE((1.5*UndiscoveredRework*Delay per Requirement Misinterpretation) >= 0, 1.5 * UndiscoveredRework * Delay per Requirement Misinterpretation + (Developmental Customized Features - Electronic Design Available for Use) * Delay per Customized Feature, 1)
   ~ Month
   ~

WorkToDo = INTEG (DiscoveringRework - AccomplishingWork, 100000)
   ~ reqt
   ~ ~ :SUPPLEMENTARY

updating Design Available Quantity =
   Gap / Time To Model A Design Feature
   ~ widgets/Month
   ~

Time To Model A Design Feature = 1
   ~ Month
   ~

Gap = quantity - Electronic Design Available for Use
   ~ widgets
   ~

Electronic Design Available for Use = INTEG (updating Design Available Quantity, 0)
   ~ widgets
   ~

quantity = 100
   ~ widgets
   ~

Developmental Customized Features = INTEG (Customer Orders with Dev Required - Completing Development, Desired Number of Developmental Customized Features)
   ~ widgets
   ~

Delay per Customized Feature = 2
Month/widgets

Customer Orders with Dev Required=
Customer Ordering
~ widgets/Month

Desired Completion of Developmental Customized Features=
~ widgets/Month

Desired Number of Developmental Customized Features=
0.01 widgets/Month

Effect of level on completion f((0,0)-(2,1.1),(0,0),(0.201031,0.513816),(0.319588,0.716447),(0.521907,0.904605),(0.742268,0.97335),(1,1),(1.98969,1))

Effect of level on completions = Effect of level on completion f(Relative Level)

Completing Development=
Desired Completion of Developmental Customized Features * Effect of level on completions
*0.5
~ widgets/Month

Relative Level = Developmental Customized Features / Desired Number of Developmental Customized Features
~

Overtime=
Overtime f(Indicated Overtime)+"Need for Additional Staff (Gap)"
~ people

Productivity=
AverageProductivity*1*Effect of fatigue on PDY
~ widgets/(people*Month)
~ NormalProductivity*Effect of fatigue on PDY*Effect Of Schedule Pressure On PDY*Effect of Staff Experience Level on Productivity

Hiring and Firing=
replacement hiring+"Need for Additional Staff (Gap)"/time to hire or fire
Effect of Profit On Funding \( f(\text{Profit}/1e+006) \) 
\[
((0,0)-(10,1]),(0.0302115,0),(1.11782,0.0394737),(2.68882,0.105263),(3.62538,0.175439),
(4.7432,0.298246),(5.86103,0.45614),(6.61631,0.640351),(7.31118,0.811404),(8.00604,
0.899123),(8.82175,0.964912),(9.93958,1))
\]

Effect of Profit on Gray Retirement Time = 
IF THEN ELSE(Profit>=3, 1, 3/120 )

Retiring = 
0.8*( GrayHairs / TimeForGrayHairToRetire)+0.2*GrayHairs/Time for Old Boys to Retire

Time for Old Boys to Retire = 
Base Gray Retirement Time*Effect of Profit on Gray Retirement Time

Base Gray Retirement Time = 120

Funding Available = 
Effect of Profit On Funding \( f(\text{Profit}/1e+006) \)

DiscoveringRework = 
0.5*AccomplishingIncorrectly

Time To Market = 
Development Time*Relative Time To Market+DeliveryDelay

Cost To Market = 
Time To Market*Cost per Month

\[\text{people/Month}\]
\[\text{months}\]
\[\text{millions}\]
Requirements per Order=
100
~ reqt/widgets
~

Requirements every Month=
Customer Orders*Requirements per Order
~ reqt
~

Orders=
6
~ widgets
~

Accurate Interpretation of Customer Needs=
"Acquire / Analyze Customer Needs"
~ reqt
~

Completed Orders=
Orders/Development Time
~ widgets/Month
~

Customer Orders= INTEG (
Customer Ordering-Completed Orders,
initial perceived retiring * Development Time * NormalProductivity *
(TimeForRookieToMature\)
+ TimeForExperiencedToGainWisdom + TimeForGrayHairToRetire))
~ widgets
~

Requirements Analysis=
Requirements every Month/Time To Analyze Requirements
~ reqt/Month
~

Completed Requirements=
"Acquire / Analyze Customer Needs"/Time To Complete Requirements
~ reqt/Month
~

Time To Complete Requirements=
0.02
~ Month
~

Time To Analyze Requirements=
0.01
~ Month
~
"Acquire / Analyze Customer Needs" = \text{INTEG (}
\max (\text{Funding Available} \times \text{Effort To Understand Customer Needs} \times \text{Requirements Analysis-Completed Requirements})

\sim \text{reqt}

\sim \text{reqt}

\text{replacement hiring} =
\text{Perceived Retiring}
\sim \text{people/Month}
\sim

\text{initial perceived retiring} =
4
\sim \text{people/Month}
\sim

\text{Time to Smooth Retiring} =
\frac{1}{24}
\sim \text{Month}
\sim

\text{Perceived Retiring} =
\text{SMOOTHI} (\text{Retiring}, \text{Time to Smooth Retiring}, \text{initial perceived retiring})
\sim \text{people/Month}
\sim

\text{Profit} =
\text{Sales-Cost To Market}
\sim \text{millions}
\sim

\text{Acceptable Delivery Delay} =
1
\sim \text{Month}
\sim

\text{Acceptable Price} = 65$
\sim \text{$/widget}
\sim

\text{Accomplishing Correctly} =
\text{Accomplishing Work} \times \text{quality}
\sim \text{reqt/Month}
\sim

\text{Accomplishing Incorrectly} =
\text{Accomplishing Work} \times (1 - \text{quality})
\sim \text{reqt/Month}
\sim

\text{Accomplishing Work} = 10
EffectOfDeliveryDelayOnAttractiveness 
\[ \text{EffectOfDeliveryDelayOnAttractiveness} = \text{EffectOfDeliveryDelayOnAttractiveness} f(\text{RelativeDeliveryDelay}) \]
\[ \sim \text{dmnl} \]
\[ \sim \]
CorrectWork = \text{INTEG}\text{(AccomplishingCorrectly, 0)}
\[ \sim \text{reqt} \sim \text{SUPPLEMENTARY} \]
\[ \sim \]
EffectOfPriceOnAttractiveness = \text{EffectOfPriceOnAttractiveness} f(\text{RelativePrice})
\[ \sim \text{dmnl} \]
\[ \sim \]
EffectOfPriceOnAttractiveness \text{f ([(1,0)-(2,1)](1,1),(1.20103,0.911184)} \]
\[ , (1.33505,0.769737),(1.44845,0.430921),(1.63402,0.141447),(1.78608,0.0690789) \]
\[ (2,0.05) \]
\[ \sim \text{dmnl} \]
\[ \sim \]
EffectOfQualityOnAttractiveness = \text{EffectOfQualityOnAttractiveness} f(\text{quality})
\[ \sim \text{dmnl} \]
\[ \sim \]
EffectOfQualityOnAttractiveness \text{f ([(0.5,0)-(1,1)](0.5,0.01)} \]
\[ , (0.561856,0.0263158),(0.631443,0.0690789),(0.681701,0.131579) \]
\[ , (0.725515,0.259868),(0.780928,0.634868),(0.824742,0.828947) \]
\[ , (0.880155,0.934211),(0.917526,0.973684),(0.962629,0.983553) \]
\[ , (1,1) \]
\[ \sim \text{dmnl} \]
\[ \sim \]
Delay per Requirement Misinterpretation=
\[ 0.05 \]
\[ \sim \text{Month/reqt} \]
\[ \sim \]
Product Meets Customer Needs=
\[ \text{ProductAttractiveness} \]
\[ \sim \text{dmnl} \]
\[ \sim \]
ProductAttractiveness=
\[ \text{MaximumAttractiveness} * (0.1* \text{EffectOfDeliveryDelayOnAttractiveness} + \]
\[ 0.1* \text{EffectOfPriceOnAttractiveness} + 0.8* \text{EffectOfQualityOnAttractiveness}) \]
\[ \sim \text{dmnl} \]
\[ \sim \]
quality=
\[ \text{Effect of Requirements Analysis On Quality f(Accurate Intrepretation of Customer Needs/} \]
\[ /9e-008) \]
RelativeDeliveryDelay = DeliveryDelay/AcceptableDeliveryDelay

Effect Of Requirements Analysis On Quality f((0,0)-(10,10)),(0,0),(0.2,0.2),(0.4,0.4),(0.6,0.6),(0.8,0.8),(1,1))

Effort To Understand Customer Needs = 1

Price per Sale = 1.9e+007 millions

MaximumAttractiveness = 1

Sales = Product Meets Customer Needs * Price per Sale

RelativePrice = Price/AcceptablePrice

EffectOfDeliveryDelayOnAttractiveness f((1,0)-(4,1)),(1,1)

UndiscoveredRework = INTEG(AccomplishingIncorrectly - DiscoveringRework, 0)

Price = 75 $/widget

Time to Order = 1 Month
Relative Time To Market=
  NormalProductivity/Productivity 
  \sim \text{dmnl} 

Customer Ordering=
  Effect of Time To Mkt On Cust Orders*Normal Ordering Rate/Time to Order 
  \sim \text{widgets/Month} 
  \sim \text{Normal Ordering Rate*(Effect of Cst To Mkt On Cust Orders*Effect of Tme To \ Mkt On Cust Orders)} 

AverageProductivity=
  production/Workforce 
  \sim \text{widgets/(people*Month)} 

Cost per Month= 
  0.58 
  \sim \text{millions/Month} 

DesiredTotalWorkforce=
  "Need for Additional Staff (Gap)+Workforce 
  \sim \text{people} 

Development Time= 
  24 
  \sim \text{Month} 

Effect of Cst To Mkt On Cust Orders=
  IF THEN ELSE(Cost To Market>96,0.5,1) 
  \sim \text{dmnl} 
  \sim \sim \sim \text{:SUPPLEMENTARY} 

Effect of fatigue on PDY = Effect of fatigue on PDY f(Fatigue) 
  \sim \text{dmnl} 
  \sim \sim \sim \text{:SUPPLEMENTARY} 

Effect of fatigue on PDY f( 
  \([-2, -2)- (4, 1.5), (0, 1.15), (0.21134, 1.14145), (0.362538, 1.14035), (0.530928, 1.12171), (0.783505, 1.06908), (1, 1), (1.19072, 0.924342), (1.43299, 0.833882), (1.63918, 0.779605), (1.96979, 0.640351), (2.36858, 0.333333), (2.71299, 0.041667), (2.89426, -0.188596), (3, -0.5)) 
  \sim \text{dmnl} 
  \sim \sim \sim \text{\textbf{}} 

Effect of Sched Pressure On PDY f(
Effect Of Schedule Pressure On PDY =  
Effect of Sched Pressure On PDY f(SchedulePressure)  
\sim dmnl  
\sim \sim :SUPPLEMENTARY  

Effect of Tme To Mkt On Cust Orders =  
-1*Effect of TTM on Cust Orders f(Relative Time To Market)  
\sim dmnl  
\sim \sim  

Effect of TTM on Cust Orders f(  
[(0,0)-(4,1.75)],(0,0),(0.217523,0.0997807),(0.410876,0.253289),(0.567976,0.445175),
(0.821752,0.744518),(1,1),(1.196137,1.15899),(1.46224,1.2/412),(1.7281,1.3432),(2.06647,
,1.39693),(2.33233,1.42763),(2.68278,1.46601),(3.33,1.5))  
\sim dmnl  
\sim \sim  

Experienced = INTEG (  
Maturing - GainingWisdom,  
initial perceived retiring*TimeForExperiencedToGainWisdom)  
\sim people  
\sim Initial Value = Maturing *TimeForExperiencedToGainWisdom  
\sim \sim  

ExperiencedProductivity = 3  
\sim widgets/people/Month  
\sim \sim  

Fatigue = INTEG (  
GettingFatigued,  
1)  
\sim Fraction  
\sim \sim  

GainingWisdom =  
Experienced / TimeForExperiencedToGainWisdom  
\sim people/Month  
\sim \sim  

GettingFatigued =  
(Overtime*"Normal Mth/Person" - Fatigue) / TimeToGetFatigued  
\sim Fraction / Month  
\sim \sim  

GrayHairProductivity =
GrayHairs = INTEG (GainingWisdom - Retiring, initial perceived retiring*Base Gray Retirement Time) ~ people ~ Initial Value = initial perceived retiring*TimeForGrayHairToRetire

Incentive to Mentor Junior Staff =
1 ~ Fraction ~ 0.5

IndicatedOvertime =
IF THEN ELSE(DesiredTotalWorkforce<0,0,DesiredTotalWorkforce/Workers)
~ dmnl
~ DesiredWorkers/Workers

Maturing =
Rookies / TimeForRookieToMature ~ people/Month
~

"Need for Additional Staff (Gap)" =
Customer Orders/Development Time/NormalProductivity-Workforce
~ people
~

"Normal Mth/Person" =
i
~ Month/(people*Month)
~

Normal Ordering Rate =
2 ~ widgets
~

NormalProductivity =
4 ~ widgets/(people*Month)
~

Overtime f(
[(0,0)-(2,2.6)],(0,0),(0.175258,0.290789),(0.417526,0.598684),(0.747423,0.880921),(1,1),(1.35052,1.23158),(1.51031,1.40263),(1.65979,1.666),(1.74742,1.96711),(1.78866,2.13816),(1.85567,2.34342),(1.92268,2.47171),(2.2,2.58289))
~ people
~
production =
  Rookies * RookieProductivity + Experienced * ExperiencedProductivity +
  GrayHairs * GrayHairProductivity
  ~ widgets/Month
  ~

RookieProductivity =
  1
  ~ widgets/people/Month
  ~

Rookies = INTEG (IF THEN ELSE((Hiring and Firing - Maturing) >= 0, Hiring and Firing - Maturing, 0),
  initial perceived retiring * TimeForRookieToMature)
  ~ people
  ~

SchedulePressure = 1
  ~ Fraction
  ~

time to hire or fire = 2
  ~ Month
  ~

TimeToMentorJuniorStaff =
  1
  ~ Month
  ~ 0.5
  ~

TimeForExperiencedToGainWisdom =
  48 * Incentive to Mentor Junior Staff * TimeToMentorJuniorStaff
  ~ Month
  ~

TimeForRookieToMature =
  12
  ~ Month
  ~

TimeToGetFatigued = 1
  ~ Month
  ~

Workers = 10
  ~ people
  ~

Workforce = Rookies + Experienced + GrayHairs
  ~ people
  ~
Simulation Control Parameters

FINAL TIME = 1000  
  ~ Month  
  ~ The final time for the simulation.

INITIAL TIME = 0  
  ~ Month  
  ~ The initial time for the simulation.

SAVEPER =  
  TIME STEP  
  ~ Month  
  ~ The frequency with which output is stored.

TIME STEP = 1  
  ~ Month  
  ~ The time step for the simulation.
REFERENCES


Sikorsky Aircraft System Engineering Guidebook, Lynn Tinker, 1999

VENSIM System Dynamics Model