Application of an engineering and management approach to the incorporation of an information management system at a manufacturing company.

by

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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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Abstract

Application of an engineering and management approach to the incorporation of an information management system at a manufacturing company.

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Sikorsky Aircraft Corporation, a helicopter manufacturing company, is in the process of implementing a new enterprise product data management (PDM) system. This PDM system is a commercial product that will affect Sikorsky in both the system design and management behaviors of the company's current business processes. As PDM systems do not simply unwrap themselves within a company, potential implementation issues will be examined and evaluated. Principles, processes, and tools for system design and management of large, complex systems learned in the SDM program will be used to assist in this effort.

This thesis will examine the system architecture and engineering of key interfaces between the PDM system and other mission critical systems and processes at Sikorsky.

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Introduction

Product Data Management (PDM) systems offer many services to a company's enterprise. One of the key services of PDM is data distribution through the integration of the commercial 'out of the box' PDM system with the company's specific current printing and viewing assets. How should the company define, develop and support such an enterprise service? This thesis will evaluate a product design and development methodology for creating this service.

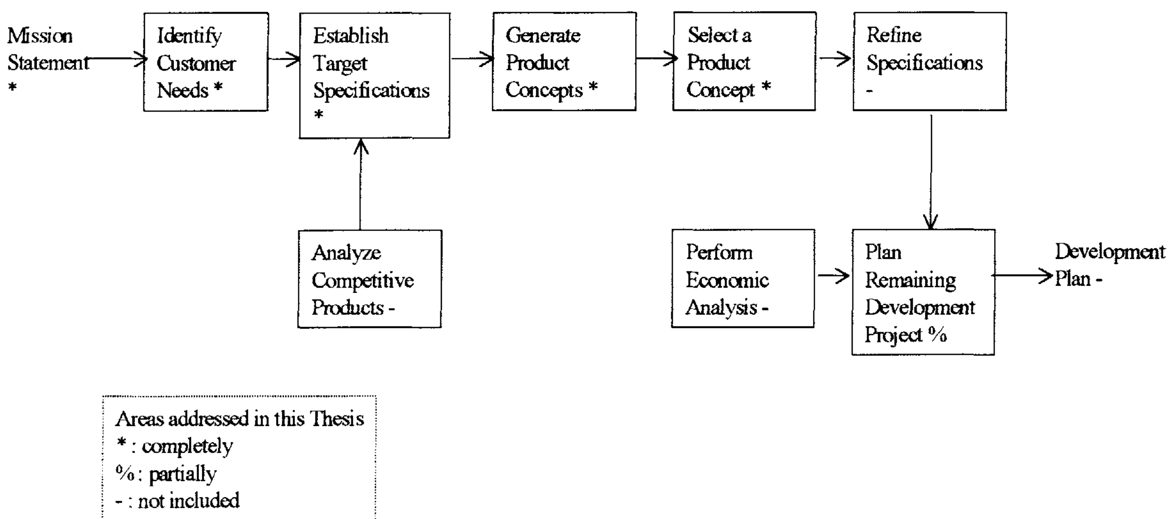
The company today generates over a half million CAD drawings a year from the current document (legacy) system. Stand alone microfilm (legacy) centers output another 1500 drawing prints a year. Non-CAD drawings, and NT file server based (legacy) Microsoft Office documents are printed at a rate four times the drawing output quantities. A mainframe-based bill of material (legacy) system generates large amounts of aircraft configuration reports also.

The PDM system is one system that combines multiple business processes in one central location. The new PDM system will manage bill of material, drawing/document, configuration, and data distribution. Upon implementation of the new system, the company's plan is to phase out the above mentioned legacy systems. Sikorsky's data needs to be used worldwide at all company sites and shared with its partners, sub-contractors and suppliers. The current legacy systems do not support this business goal efficiently.

The most common and popular way to access part data is by requesting a hardcopy, even though the company has support for online viewing of technical information; the data is being printed at high rates. This is owing to the complexity of the information. Online viewing reportedly is most frequently used only to assist in the identification of the document being requested.

In the text "Product Design and Development", Ulrich and Eppinger outline product design methodologies to provide structure to the product development process. The Product Design and Development (PDD) concept development activities are depicted in Figure 1. This thesis will examine the steps to generate a mission statement, identify customer needs, establish target specifications, generate product concepts, select a product concept and plan remaining development projects. Furthermore, this thesis will evaluate system engineering and system architecture tools and PDD structured methodologies to enhance Sikorsky's (current) Information Technology (IT) methodology processes.

Figure 1
Concept Development Activities
(reference Ulrich and Eppinger "Product Design and Development")



Mission Statement

A mission statement generally describes the scope of the product or service being developed. Specifics regarding the tasks and directions of the development effort are added later as the process proceeds.

This first step is to define the focus of the PDM printing system project for the project's complete life cycle.

Mission Statement: Create a printing service for the Product Data Management (PDM) system that compliments the PDM viewing service.

Service Description: Single PDM panel that supports the company's multiple functional data distribution needs.

Key Business goals: Critical in house integration for making the PDM system a success in the first release.

Primary Market: Eighty percent of the company's personnel, suppliers and partners will need to read (print/view) PDM information.

Secondary Market: Company's aircraft government and commercial customers would like to contract the company for this service.

Assumptions: Easy to use interface.
Protects the company's data.
Remembers user personal profile settings.
Multi-platform support.

Stakeholders: User groups
Security department
Intellect Property Section
Information Technology administrators
Legal department

Identify Customer Needs

Customer needs are identified and compiled through discussions with the stakeholders. The needs are then ranked in order of their importance to the customer.

The customer needs data, Table 1, compiles the customer desires through a question and answer discussion to determine the service requirements.

The customer needs matrix, Table 2, numbers the needs, describes the needs, and applies an importance to each.

The data presented herein was collected at Sikorsky Aircraft for the PDM system's printing and viewing requirements through a series of multi-functional / departmental meetings. Data collection started in 1995 and continued to be further defined and refined, but is being presented and analyzed using system engineering methodologies for the first time in this paper. The PDM printing system project meetings focused on the technical requirements of the system without financial considerations, which were agreed to be secondary in importance to the technical definition of the optimum system.

The benefit of collaborative meetings to identify customer needs is to build team unity between the customers, software developers and system administrators while defining and prioritizing the needs for the service being generated and implemented.

The needs-metrics matrix represents the relationship between the needs and metrics. It assures that all of the customer needs are considered. In a simple needs-metric matrix a mark in a cell indicates that the need and metric are associated. The performance relative to the metric will also show the amount the product satisfies the customer need. This matrix is derived from the House of Quality, a graphical technique used in the Quality Function Deployment (QFD) of Hauser and Clausing, in 1988. This is a simplified version of the QFD. Professor Charlie Boppe of MIT has demonstrated that QFD can be used throughout the product life cycle.

The simple needs-metric matrix, Table 3, uses X's to map the needs to the metrics. The metrics are the potential software and hardware components of the service.

The detail needs-metrics matrix, Table 4, uses an importance weighting approach when mapping the needs to the metrics. The relationship weightings of strong, moderate and weak are utilized. The relative weight highlights areas of future focus in the design phase of the project. The detail needs-metrics matrix, Table 4, is a powerful tool, as it numerically ranks the mapping.

Customer Needs Data Table 1

Question/Prompt	Customer Statement	Interpreted Need
What are the current printing requirements?	Review drawing before signoff and release.	Printing drawing from PDM system is a division procedure.
	Review documents before signoff and release.	Printing document from PDM system is a division procedure.
	Review part list before signoff and release.	Printing part list from PDM system is a division procedure.
	Review application list before signoff and release.	Printing application list from PDM system is a division procedure.
	Review part list before building aircraft in support of material procurement and op sheet generation	Verify part list while building aircraft.
	Review application list before building aircraft in support of material procurement and op sheet generation.	Verify application list while building aircraft.
	Review drawing before building aircraft in support of facility design, tooling design, and op sheet generation	Verify drawing while building aircraft.
	Review document before building aircraft in support of facility design, tooling design, and op sheet generation	Verify document while building aircraft.
What are the advantages/ benefits of the current printing system?	Drawing plots delivered to desk instead of picking plots up at central plotter location	Kaizen event recommended maximizing skilled labor time.
	User specified drawing plot number of copies.	Reproduction needs to submit many copies to customer.
	User receives print status email.	Read and print mail messages.
	User specified drawing plot scale.	Users need scaled down plots to review information on desk.
What are the dis-advantages of, or drawbacks to the current printing system?	Slow turn around	Multiple hour plot turn around time is too long.
	No way to set priority.	Users would plan print orders.
	Cannot select range of document pages.	Users would request subsets of document.
	Cannot select range of drawing sheets.	Users would request subset of drawing.
	Personal preferences not saved off.	Intelligent, simple user interface saves redundant key strokes.
	Cannot select multiple drawings and documents at on time.	User needs to request all or a subset of the information describing a part in a single operation.
What improvements coul be suggested for a future printing system?	Need submittal number for tracking.	Job tracking number would assist determining job status.
	Need to know plotter or printer status.	Output device operational status would assist user prior to print submittal.
	Need to charge back for service.	Program management needs to track print operation costs.
	Need to stamp output.	Divisional procedures required stamping of output.
	Need to log output for metrics.	IT and management groups need to monitor print performance.
	Need to log output for security audits.	Export license, intellectual properties and security groups need to monitor where information is being distributed.
	Support Continuous Acquisition and Life Cycle Support.	CALS directive.
	Support Electronic Data Delivery.	EDD contract requirements.
	Support Sikorsky's Paperless Factory.	Sikorsky digital data vision

Customer Needs Matrix Table 2

Need No.	Need	Importance
1	Print drawing from PDM system (generate).	5
2	Print document from PDM system (generate).	5
3	Verify drawing while building aircraft (reuse).	4
4	Verify document while building aircraft (reuse).	4
5	Drawing and document output delivered to convenient location.	4
6	Print many copies of drawings and documents.	5
7	Scale down drawings to review information on desk.	5
8	Quick drawing and document turn around time (reuse).	5
9	Set priority to plan print orders.	3
10	Select range of drawing sheets or document pages.	3
11	Save redundant key strokes with intelligent, simple user interface	4
12	Request all or a subset of the information in a single operation.	4
13	Determine job status with job tracking number.	3
14	Know printer or plotter operational status prior to submittal.	3
15	Charge back service to track print operation.	4
16	Stamp print output per divisional procedures.	5
17	Log print metrics to monitor performance (generate).	4
18	Log print requests for security audits (reuse).	5
19	CALS directive.	5
20	EDD contract requirement.	5
21	Sikorsky digital vision.	4
22	Read and print mail messages.	5

Importance scale.

1. Feature is undesirable. The company would not consider the service with this feature.
2. Feature is not important, but the company would not mind having it.
3. Feature would be nice to have, but is not necessary.
4. Feature is highly desirable, but the company would consider the service without it.
5. Feature is critical, the company would not consider the service without this feature.

Simple Needs-Metrics Table 3

Needs \ Metrics	Graphical User Interface (interactions)	Application routines (no.)	Database server (cpu, memory)	Client workstation (cpu, memory)	UNIX application server (cpu, memory)	NT Application server (cpu, memory)	Mail system server (cpu, memory)	UNIX file system (disk access)	NT file system (disk access)	Network capacity (bytes/second)	Printer capacity (prints/minute)	Plotter capacity (plots/minute)	Output staff (no.)
Print drawing from PDM system (generate).	X	X	X	X	X		X	X		X		X	X
Print document from PDM system (generate).	X	X	X	X		X	X	X	X	X	X		X
Verify drawing while building aircraft (reuse).	X	X	X	X			X	X				X	X
Verify document while building aircraft (reuse).	X	X	X	X			X	X			X		X
Drawing and document output delivered to convenient location	X	X		X				X					X
Print many copies of drawings and documents.	X	X		X				X			X	X	
Scale down drawings to review information on desk.	X	X		X				X				X	
Quick drawing and document turn around time (reuse).	X	X	X	X			X	X		X	X	X	X
Set priority to plan print orders.	X	X		X							X	X	
Select range of drawing sheets or document pages.	X	X		X									
Save redundant key strokes with intelligent, simple user interfac	X	X		X									
Request all or a subset of the information in a single operation.	X	X		X									
Determine job status with job tracking number.	X	X		X									
Know printer or plotter operational status prior to submittal.	X	X		X						X	X	X	
Charge back service to track print operation.	X	X		X					X				
Stamp print output per divisional procedures.	X	X			X	X					X	X	
Log print metrics to monitor performance (generate).	X	X			X	X			X				
Log print requests for security audits (reuse).	X	X							X				
CALS directive.	X	X		X				X					
EDD contract requirement.	X	X		X				X					
Sikorsky digital vision.	X	X		X				X					
Read and print mail messages.	X	X		X			X						

Detail Needs-Metrics Table 4

Needs-Metrics Matrix

Relationship Weightings: Strong = 3, Moderate = 2, Weak = 1

Need No.	Needs \ Metric No.	Importance	1	2	3	4	5	6	7	8	9	10	11	12	13
	Metrics		Graphical User Interface (interactions)	Application routines (no.)	Database server (cpu, memory)	Client workstation (cpu, memory)	UNIX application server (cpu, memory)	NT Application server (cpu, memory)	Mail system server (cpu, memory)	UNIX file system (disk access)	NT file system (disk access)	Network capacity (bytes/second)	Printer capacity (prints/minute)	Plotter capacity (plots/minute)	Output staff (no.)
1	Print drawing from PDM system (generate).	3	2	3	2	1	3		2	3		3		3	3
2	Print document from PDM system (generate).	3	2	3	2	1		3	2	3	3	3	3		3
3	Verify drawing while building aircraft (reuse).	3	2	3	2	1			2	3				3	3
4	Verify document while building aircraft (reuse).	3	2	3	2	1			2	3			3		3
5	Drawing and document output delivered to convenient location.	5	2	3		1				3					3
6	Print many copies of drawings and documents.	5	2	3		1				3			3	3	
7	Scale down drawings to review information on desk.	5	2	3		1				3				3	
8	Quick drawing and document turn around time (reuse).	5	2	3	3	2			3	3		3	3	3	3
9	Set priority to plan print orders.	3	2	3		1							3	3	
10	Select range of drawing sheets or document pages.	5	2	3		1									
11	Save redundant key strokes with intelligent, simple user interfac	5	2	3		1									
12	Request all or a subset of the information in a single operation.	5	2	3		1									
13	Determine job status with job tracking number.	3	2	3		1									
14	Know printer or plotter operational status prior to submittal.	5	2	3		1						3	3	3	
15	Charge back service to track print operation.	3	2	3		1					3				
16	Stamp print output per divisional procedures.	5	2	3			2	2					2	2	
17	Log print metrics to monitor performance (generate).	3	1	3			2	2			2				
18	Log print requests for security audits (reuse).	3	1	3							2				
19	CALS directive.	9	2	3		1				3					
20	EDD contract requirement.	7	2	3		1				3					
21	Sikorsky digital vision.	7	2	3		1				3					
22	Read and print mail messages.	5	2	3		1			3						
	Total Importance	100													
	Importance Weight		194	300	39	94	25	25	54	165	30	48	82	97	66
	Relative Weight (%)		15.9	24.6	3.2	7.7	2.1	2.1	4.4	13.5	2.5	3.9	6.7	8.0	5.4

Establish Target Specifications

A target technical specification consists of the metrics of the product or service components, which indicate if the product or service meets the customer requirements. The specification is created by translating customer / end user needs into system and technical requirements.

The target technical specification, Table 5, ranks each service component metric. Each metric has units and a range of values the development team will attempt to satisfy.

Much like the importance ranking of customer requirements, this effort allows for primary product and "non-negotiable" requirements to be identified and distinguished from secondary attributes.

The linking of customer needs to the computer software and hardware components provides valuable insight for the developers, administrators and users. The target specification will become an early benchmark for verifying and validating that the promised service is adequately and satisfactorily achieved.

Target Technical Specification Table 5

Metric No.	Need No. (ref)	Metric	Importance	Units	Marginal Value	Ideal Value
1	1-16,19-22	Graphical User Interface	5	Interactions	5	3
2	1-16,19-22	Application routines	3	Number	5	3
3	1-4,8	Database server	5	Transactions/second	85%<1second	95%<1second
4	8	Client workstation	4	Applications/session	3	5
5	2,16-17	UNIX application server	5	Prints/minute	1	3
6	2,16-17	NT Application server	5	Plots/minute	1	3
7	1-4,8,22	Mail system server	5	MailMessages/minute	12	24
8	1-8,22	UNIX file system	5	MegaBytes/second	40 (Raid 5)	40 (Raid 5)
9	2,14,17-18	NT file system	5	MegaBytes/second	40 (Raid 5)	40 (Raid 5)
10	1-2,8,14	Network capacity	5	MegaBytes/second	45	100
11	1,4,6,8-9,14,16	Printer capacity	5	Prints/minute	2	6
12	1,3,6-9,14,16	Plotter capacity	5	Plots/minute	2	6
13	1-5,8	Output staff	4	Number	3	2

Importance scale.

1. Metric is undesirable. The company would not consider the service with this metric.
2. Metric is not important, but the company would not mind having it.
3. Metric would be nice to have, but is not necessary.
4. Metric is highly desirable, but the company would consider the service without it.
5. Metric is critical, the company would not consider the service without this metric.

Generate Product Concepts

During the product concept generation phase, the development team members can share different technical approaches to solving the problem with the customers and users of the service. By reviewing several concepts and their descriptions, the customers and users can start to visualize the full potential, and strengths and weaknesses, of each technical concept. Understanding the current problems, clients gain insight to the solutions possible and develop a shared interest in assisting further in the completion of the product development process.

Concept descriptions and sketches

Three technical concepts were developed at Sikorsky Aircraft for the PDM printing and viewing system after a series of product reviews and refinements.

Concept one for the PDM project is sketched in Figure 2. In this concept, output files are generated continuously from scratch on demand. Similar to the current printing and viewing system used in the company today, this concept requires extensive computer processing capacity, involving many application systems.

Concept two for the PDM project is sketched in Figure 3. Concept two saves the output files for reuse. This concept starts to balance the computer process load with an additional coordinated hardware file output system.

Concept three for the project sketched is Figure 4. Concept three also saves the output files for reuse. This concept adds replicated PDM databases in several plant locations and attempts to balance the computer process and network availability loads with proper amounts of hardware database and file systems.

Figure 2

Concept 1 – Current style.

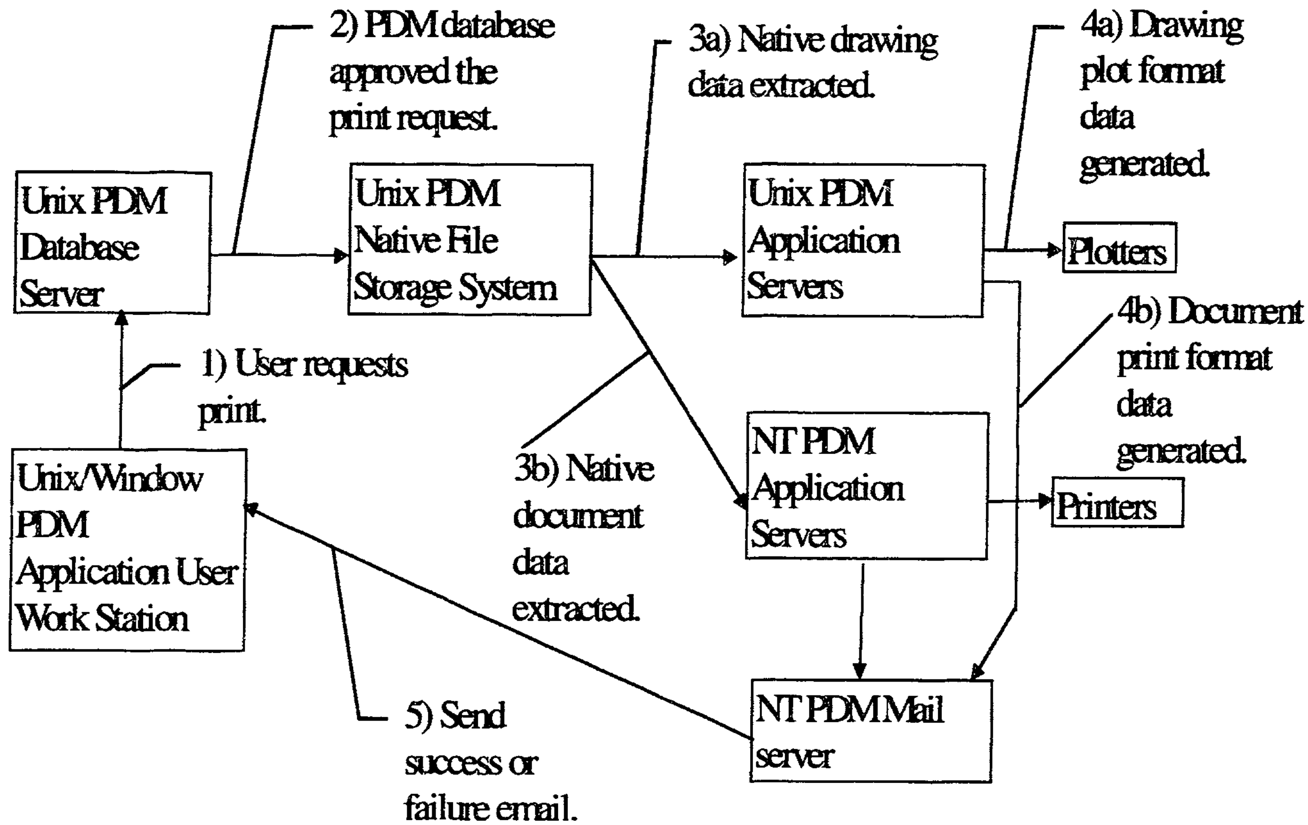


Figure 3

Concept 2 – Current style but save output results.
The event occurs when a user requests a drawing or document.

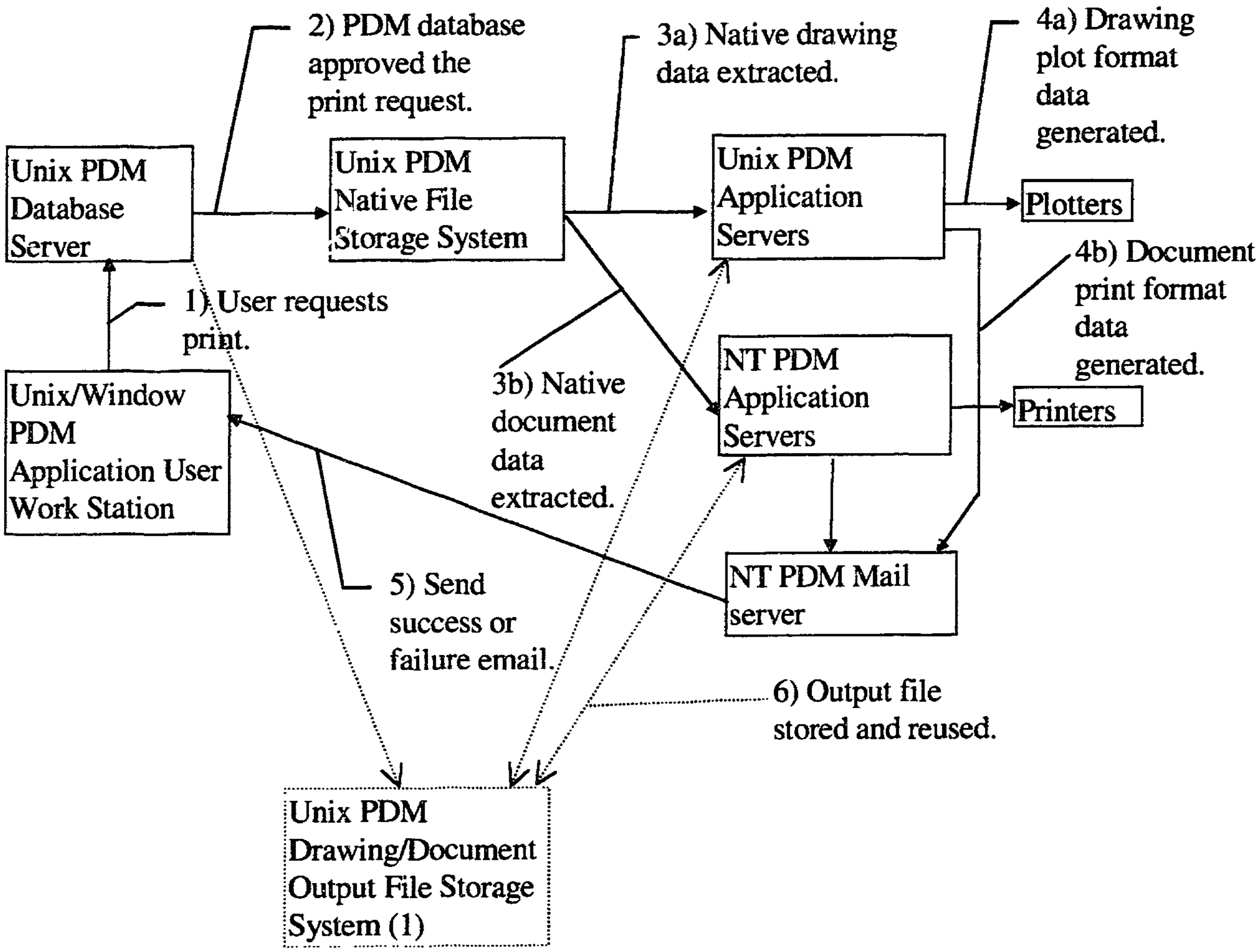
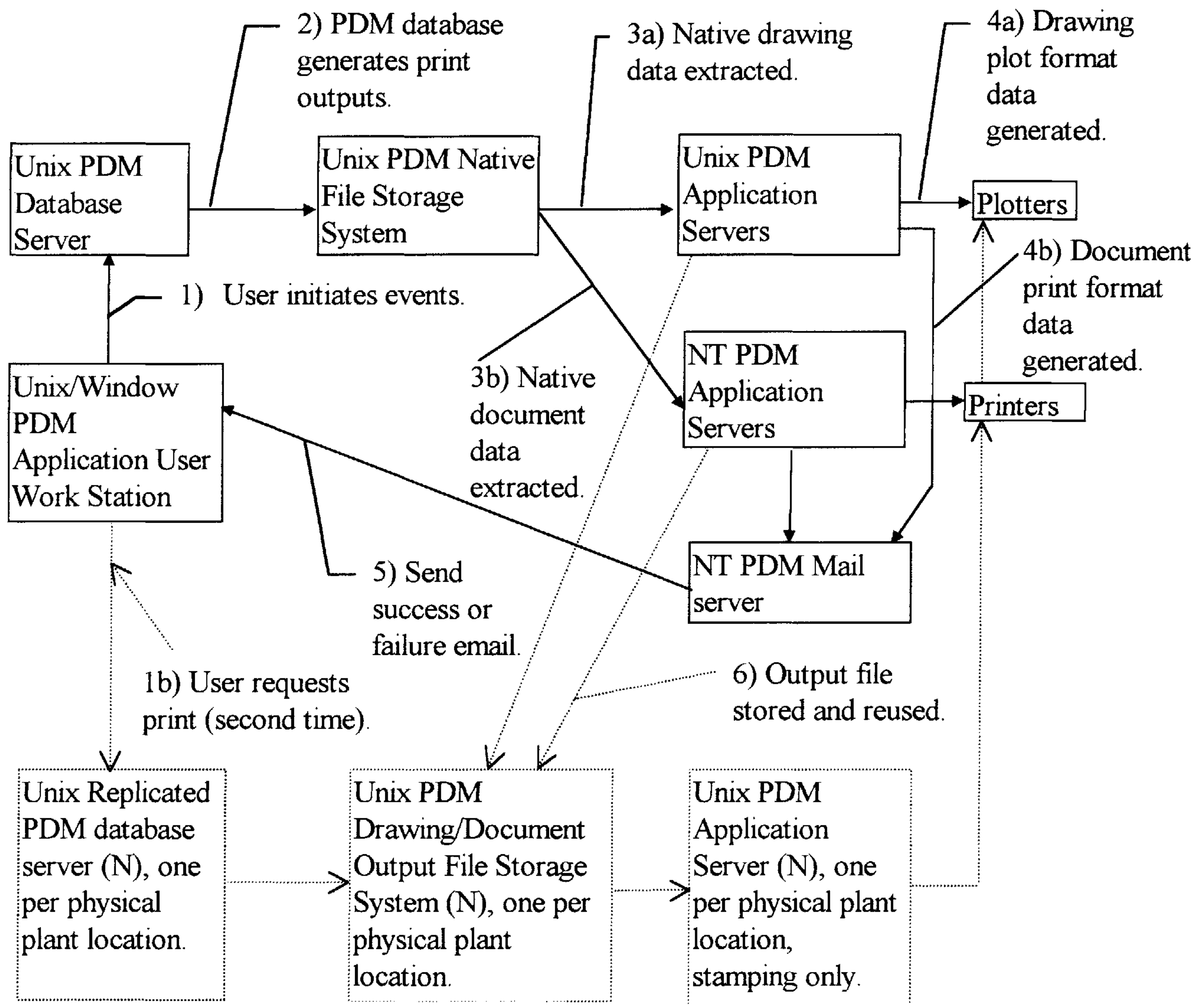


Figure 4

Concept 3 – Save output results automatically.
Automatic events occur. Events including native file check-in, off-board signoff, native file modification, etc. automatically trigger generation of output formats.



System-level design – Product Architecture

Design Structure Matrix (DSM), a system architecture tool, was used to design and integrate the components of the drawings and documents printing service within a commercial Product Data Management system.

DECOMPOSING A SYSTEM INTO IT'S ELEMENTS

The goals, functions and forms of this PDM service were identified and decomposed. The definition of the product concept was determined. Design structure matrices assisted in the decomposition of the system's physical elements and to identify interactions between them.

Three steps using the DSM method are to first decompose the system/service into elements, secondly document the interactions of the system into elements and thirdly cluster the elements into architectural and team chunks.

The first step in using the DSM technique is to decompose a system into its elements. The system specification describes the input and is used as the starting point in decomposing the PDM printing service. A second level decomposition further details the printing service for drawings and documents. Printing goals of the complete PDM system are decomposed as shown in Tables 6.1, 7.1, and 8.1 for Concepts 1, 2, and 3, respectively.

First and second levels of each concept's functional decomposition of the PDM system break the overall printing function into smaller functions, as seen in Tables 6.2, 7.2, and 8.2 for Concepts 1, 2, and 3.

The PDM system, first and second levels of form decomposition break the overall printing form into smaller form elements. Tables 6.3, 7.3, and 8.3 detail the form decomposition for Concepts 1, 2, and 3. These elements indicate that speed is a critical characteristic. The upstream influence of rapid communication to minimize the waiting time of the company's users needing information is important.

The database server speed indicates that the user request of a particular drawing must be extracted in a timely fashion from the relational database and the secure Unix file system. The information files (e.g. drawing status, plotter selection, plot scale, plot copies) and the actual CAD file to be processed need to be packaged. The decomposed elements for this database server form are the server memory, server computer processor units, and server disk access time.

The client workstation speed determines how well the PDM client application will run. If the user is a CAD or Word application user, the load from the PDM client application should be less than the user's authoring drawing or document tools. The decomposed elements for this client workstation form are the client memory, client computer processor units, client disk access time. This is where the print form, print form C trap and print related operating system calls execute.

The network speed will be important in determining how well the native source drawing/document and alternative source plot format data transfers between the different computer hardware in the PDM print service process. The decomposed elements for this network form are the network backbone bandwidth capacity and server/client network card capacity.

The process speed of an application server for converting drawing or document data into print data format will determine how many of the Unix or NT servers will be required to meet peak hour printing requirements. Distributed queuing software (DQS) will be used to balance the load between multiple application servers. Due to the individual behaviors of every CAD or Office product the DQS will need to manage the unique queue properties for each product (e.g. job limit of one or multiple). The decomposed elements for this application server form are the server memory, server computer processor units, and server disk access time.

The decomposed elements for the plotter device form are the plotter memory, plotter computer processor units, and plotter disk access time. The plotter device actually outputs the digital drawing/document file to paper.

The decomposed elements for the mailer server form are the server memory, server computer processor units, and server disk access time. The mailer server delivers the success or failure mail message to the user who requested the print in the first place.

DESIGN STRUCTURE MATRICES

The purpose of a design structure matrix (DSM) is to identify the major boundaries and interaction between the elements or chunks of a system. DSMs can assist in the partitioning and integrating processes of system architecting. A DSM is a square matrix of system elements, where the elements are listed and labeled alphabetically to define the rows and the identical letters are used to label the columns. The cell formed at the intersection of a row and a column is used to record interactions between the two elements. The Thomas Pimmler and Steven Eppinger paper, "Integration Analysis of Product Decompositions", describes how element interactions can be typed and quantified: The types are described as spatial, energy, information, and material, where a spatial-type interaction identifies needs for adjacency or orientation, an energy-type interaction identifies needs for energy transfer, an information-type interaction identifies needs for information or signal exchange, and a material-type interaction identifies needs for materials exchange between two elements. The degree of interaction is quantified by assigning each interaction a score of +2 to -2. A +2 indicates required interaction, +1 desired interaction, 0 no affect, -1 undesired interaction, and -2 detrimental interaction. (The cells are left blank when no interactions are present.) Two or more elements are sequential if an interaction appears below the diagonal in the row and the column of the other. Two or more elements are described as being parallel if there are no interactions linking them together. Coupled elements are identified by square blocks on the matrix diagonal that contain interactions both above and below the matrix diagonal. An interaction appearing above the diagonal indicates that the element is dependent upon the spatial, information, energy and material association from another element. If the matrix were a lower triangular, no interaction would appear above the diagonal and all elements may be designed in sequence or parallel. A goal is to try to reorder the rows and columns of the matrix to define all the elements before determining a specific element. This goal is idealistic and difficult to attain with complex systems. For highly complex systems, computer algorithms have been developed to assist in clustering of the interactions in a matrix. A more detailed description of the DSM is included in Appendix 1.

IDENTIFYING INTERACTIONS BETWEEN ELEMENTS

Each of these elements has been assembled into a DSM for Concept 3's PDM printing system, as shown in Table 9. (DSMs for Concepts 1 and 2 would be similar and are not included herein.) The second step in the Pimmler/Eppinger method is to identify interactions between the elements as being spatial (associations of physical space and alignment), energy (associations of energy exchange), information (associations of information exchange), and material (associations of materials exchange). Once the interaction type is determined, the quantification score is assigned to the interaction, in accord with the scoring scheme detailed in Table 9. As shown in Table 9, strongest interactions are found between coupled groupings (e.g. (A, B, C, D, E, F), (G, H, I), (I, J, K), (L, M, N), (O, P, Q), (R, S, T)), which are therefore assigned scores of +2.

CLUSTERING OF ELEMENTS

The third and final step in the Pimmler/Eppinger method is to use the interaction matrix to cluster elements into chunks. The physical architecture of the product and the product development team structure will be defined by the clustering. Independent views of each individual interaction type can assist in building the product architecture and in organizing the development and operation teams. If the elements are clustered where the interactions occur within chunks instead of between chunks, engineering team coordination efforts will be reduced. The lead system architects and system engineers can focus on the interfaces between the chunks.

A Concept 3 sketch of the proposed PDM architecture for the printing service, reflecting the use of the DSM, is shown in Figure 4.

The coupled memory/cpu/disk groupings of (A,B,C,D,E,F), (G,H,I), (L,M,N), (O,P,Q) and (R,S,T) are logical, as these elements need to optimized for speed together. This coupled grouping contains the interaction types of spatial and information with a 'Required' (+2) quantification score. The network J and K elements affect every users' workstation and system servers' ability to move data between the computers of the PDM printing process. The workstations' and servers' F, I, N, Q, and T disk element's ability to read and write data will affect the overall speed of the PDM printing process. The coupled groupings and network elements should be managed by one group in the Sikorsky Information Technology to ensure the beginning to end PDM printing process is efficient. Interactions between the print form (graphical user interface), print form C trap, and print form operating system calls (A,B,C) with the workstation's memory, cpu, and disk (D,E,F) are intensely coupled together, as logically these form elements need to function together also.

In this effort, a design structure matrix was used as a tool to assist in decomposing a complex system, the printing of drawings and documents in a commercial PDM system, into appropriate chunks or tasks on the basis of interactions between the elements. The DSM provided a comprehensive view of the overall system, allowing for a structured approach to the printing goals to be planned.

Table 6.1
Concept 1

PDM Communication Goal Decomposition		
System Level Goal	First Level Decomposition	Second Level Decomposition
communication of information between organizations and people at Sikorsky, suppliers, partners and customers	maintain security rules to allow and disallow access to data	model the employee's business roles and the drawing/document release procedures
	desktop availability of all data in the right format	print drawings and documents view drawings and documents checkout drawings and documents checkin drawings and documents
	send and receive data	Request, batch load data

The upstream influences of viewing drawing/document data in 5 seconds, printing drawing/document data in 20 minutes and sharing electronic (computer) through out the company effect the system in several ways.

Table 6.2

Concept 1

PDM Communication Functional Decomposition		
System Level Function	First Level Decomposition	Second Level Decomposition
print drawings and documents	validate drawing/document identification validate user's access to drawing/document validate printer choice for drawing/document authoring tool capture user's number of copies, scale and delivery address values	
	submit print request to batch	send copy of drawing/document to application server generate the plotter (hpgl) or printer (ps) format required send success or failure email to user transfer output file to output device

Table 6.3

Concept 1

PDM Communication Form Decomposition		
System Level Form	First Level Decomposition	Second Level Decomposition
Print form (client workstation speed)	Print form C trap routine (client workstation speed)	System routines (workstation client speed)
Extract drawing CAD data from secure database file storage to Unix file system (database server speed)	CAD drawing data sent to Unix application server (network speed)	File system (disk speed)
Load CAD printing routine	CAD application print utility to generate plot format (process speed)	File system (disk speed)
Printer/Plotter job status routine	Append individual print job statistics to print log	Send print status email to user (mail server speed)
Transfer output file to printer/plotter device	Output file sent from Unix application server to plotter's spooler (network speed, disk speed)	Output file sent from plotter's spooler to plotter (disk speed, plotter speed)

Table 7.1

Concept 2

PDM Communication Goal Decomposition		
System Level Goal	First Level Decomposition	Second Level Decomposition
communication of information between organizations and people at Sikorsky, suppliers, partners and customers	maintain security rules to allow and disallow access to data	model the employee's business roles and the drawing/document release procedures
	desktop availability of all data in the right format	print drawings and documents view drawings and documents checkout drawings and documents checkin drawings and documents
	send and receive data	Request, batch load data

The upstream influences of viewing drawing/document data in 5 seconds, printing drawing/document data in 20 minutes and sharing electronic (computer) through out the company effect the system in several ways.

Table 7.2

Concept 2

PDM Communication Functional Decomposition		
System Level Function	First Level Decomposition	Second Level Decomposition
print drawings and documents	validate drawing/document identification validate user's access to drawing/document validate printer choice for drawing/document authoring tool capture user's number of copies, scale and delivery address values	
	submit print request to batch	send copy of drawing/document to application server generate the plotter (hpgl) or printer (ps) format required send success or failure email to user transfer output file to output device

Table 7.3
Concept 2

PDM Communication Form Decomposition		
System Level Form	First Level Decomposition	Second Level Decomposition
Print form (client workstation speed)	Print form C trap routine (client workstation speed)	System routines (workstation client speed)
Extract drawing/document data from secure database file storage to Unix/NT file system (database server speed)	Drawing/document data sent to Unix/NT application server (network speed)	File system (disk speed)
Load Drawing/Document printing routine	Drawing/Document application print utility to generate output format	File system (disk speed)
Printer/Plotter job status routine	Append individual print job statistics to print log	Send print status email to user (mail server speed)
Transfer output file to plotter/printer device	Output file sent from Unix/NT application server to plotter's spooler (network speed, disk speed)	Output file sent from plotter's spooler to plotter (disk speed, plotter speed)
Transfer output file to PDM Drawing/Document File Storage System	Output file sent from Unix/NT application server to Drawing/Document File Storage System (network speed, disk speed)	File system (disk speed)

Table 8.1

Concept 3

PDM Communication Goal Decomposition		
System Level Goal	First Level Decomposition	Second Level Decomposition
communication of information between organizations and people at Sikorsky, suppliers, partners and customers	maintain security rules to allow and disallow access to data	model the employee's business roles and the drawing/document release procedures
	desktop availability of all data in the right format	print drawings and documents view drawings and documents checkout drawings and documents checkin drawings and documents
	send and receive data	event trigger, request, batch load data

The upstream influences of viewing drawing/document data in 5 seconds, printing drawing/document data in 20 minutes and sharing electronic (computer) through out the company effect the system in several ways.

Table 8.2

Concept 3

PDM Communication Functional Decomposition		
System Level Function	First Level Decomposition	Second Level Decomposition
print drawings and documents	validate drawing/document identification validate user's access to drawing/document validate printer choice for drawing/document authoring tool capture user's number of copies, scale and delivery address values	
	submit print request to batch	send copy of drawing/document to application server generate the plotter (hpgl) or printer (ps) format required send success or failure email to user transfer output file to output device
event trigger, request, batch load data	submit print request to batch for permanent storage	send copy of drawing/document to application server generate the plotter (hpgl) or printer (ps) format required transfer output file to storage device

Table 8.3
Concept 3

PDM Communication Form Decomposition		
System Level Form	First Level Decomposition	Second Level Decomposition
Event trigger (client workstation speed)	Event trigger C trap routine (database server speed)	File system (disk speed)
Print form (client workstation speed)	Print form C trap routine (client workstation speed)	System routines (workstation client speed)
Extract drawing/document data from secure database file storage to Unix/NT file system (database server speed)	Drawing/document data sent to Unix/NT application server (network speed)	File system (disk speed)
Load Drawing/Document printing routine	Drawing/Document application print utility to generate output format (process speed)	File system (disk speed)
Printer/Plotter job status routine	Append individual print job statistics to print log	Send printer status email to user (mail server speed)
Transfer output file to printer/plotter device	Output file sent from Unix/NT application server to plotter's spooler (network speed, disk speed)	Output file sent from plotter's spooler to plotter (disk speed, plotter speed)
Transfer output file to many PDM Drawing/Document File Storage Systems, one per physical plant location	Output file sent from Unix/NT application server to Drawing/Document File Storage System (network speed, disk speed)	File system (disk speed)
Metadata information send from Unix Replicated PDM database server (N) to Unix PDM application server (N), one per physical plant location, print request second time (database server speed)	Transfer output file from PDM Drawing/Document File Storage System to Unix application server for stamping only (network, process, & disk speeds)	Transfer output file to printer/plotter device (network & disk speeds)

Table 9

Concept 3 - Design Structure Matrix - Architecture

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Print form	A	A A	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0														
Print form C trap	B	2 0 2 0	B B	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 2			0 0 2 0											
Print operating system calls	C	2 0 2 0	2 0 2 0	C C	2 0 2 0	2 0 2 0	2 0 2 2			0 0 2 2	2 0 2 2	2 0 2 2									
Client workstation memory	D	2 0 2 0	2 0 2 0	2 0 2 0	D D	2 0 2 0	2 0 2 2														
Client workstation CPU	E	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	E E	2 0 2 0														
Client workstation disk access	F	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	2 0 2 0	F F				2 0 2 2	2 0 2 2									0 0 2 0
Database/Replicated server memory	G		0 0 2 0	0 0 2 0				G G	2 0 2 0	2 0 2 2											
Database/Replicated server CPU	H		0 0 2 0	0 0 2 0				2 0 2 0	H H	2 0 2 0											
Database/Replicated server disk access	I		0 0 2 0	0 0 2 0				2 0 2 2	2 0 2 0	I I	2 0 2 2	2 0 2 2			2 0 2 2						
Network bandwidth	J			2 0 2 0			2 0 2 2			2 0 2 2	J J	2 0 2 2			2 0 2 2			2 0 2 2			2 0 2 2
Server/client network card	K			2 0 2 0			2 0 2 2			2 0 2 2	2 0 2 2	K K			2 0 2 2			2 0 2 2			2 0 2 2
Application/File server memory (UNIX/NT)	L												L L	2 0 2 0	2 0 2 0						
Application/File server CPU (UNIX/NT)	M												2 0 2 0	M M	2 0 2 0						
Application/File server disk access (UNIX/NT)	N									2 0 2 2	2 0 2 2	2 0 2 2	2 0 2 0	2 0 2 0	N N			2 0 2 2			2 0 2 2
Printer/Printer memory	O															O O	2 0 2 0	2 0 2 0			
Printer/Plotter CPU	P															2 0 2 0	P P	2 0 2 0			
Printer/Plotter disk access	Q									2 0 2 2	2 0 2 2					2 0 2 0	2 0 2 0	Q Q			
Mail server memory	R																		R R	2 0 2 0	2 0 2 0
Mail server CPU	S																		2 0 2 0	S S	2 0 2 0
Mail server disk access	T									2 0 2 2	2 0 2 2								2 0 2 0	2 0 2 0	T T

S E	S=Spatial, E=Energy
I M	I=Information, M=Materials

Effective Prototyping

In software prototyping, the concept that "seeing is believing" is important in all phases of the project. Even in the concept development phase it is beneficial to create a screen layout mockup for the customers and users of the printing service to facilitate discussion of the up front requirements prior to beginning detailed design and coding. The company and its users do not have a true PDM system in the plant today. As such, this new behavior of surfing an aircraft bill of material, exploding to all the drawings and documents describing a part, and requesting a print of all or a subset of the drawings and document objects selected (reference Figures 5 and 6) benefits from effective prototyping. Even though the greatest system modifications will not be visible to the user, previewing the part that is presented will allow the user to "see" the transition from the old ways of printing and viewing and increase the comfort level with the new.

In the design phase of the project the software prototype will be a working version of the system in which the users can actually "touch" the solution and gain confidence that their concerns are being included.

Figure 5
Effective Prototyping - Graphical Part Structure Data

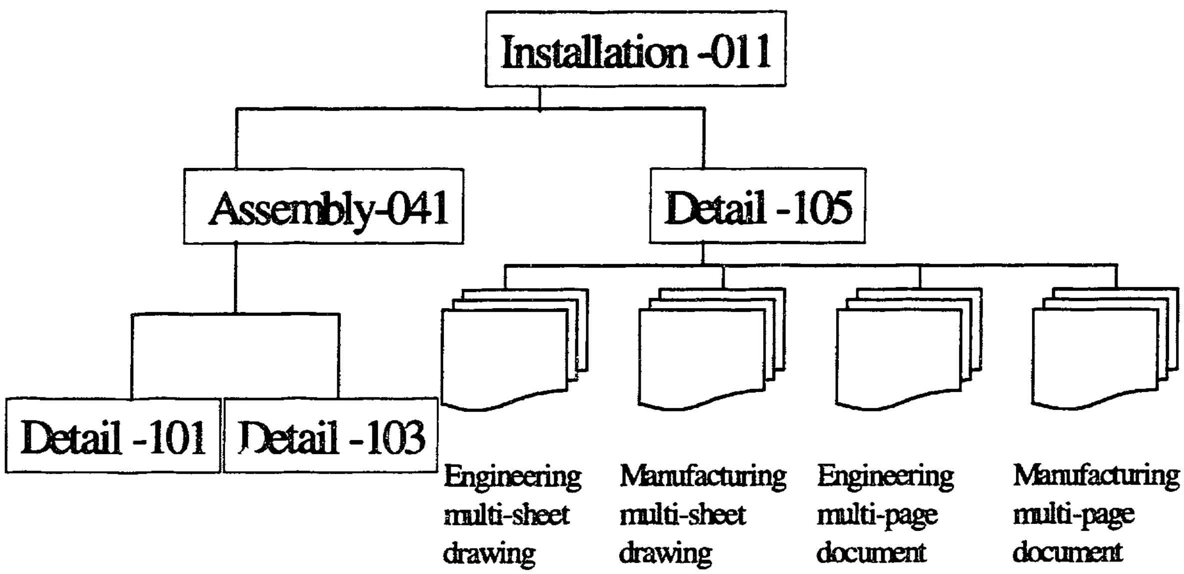
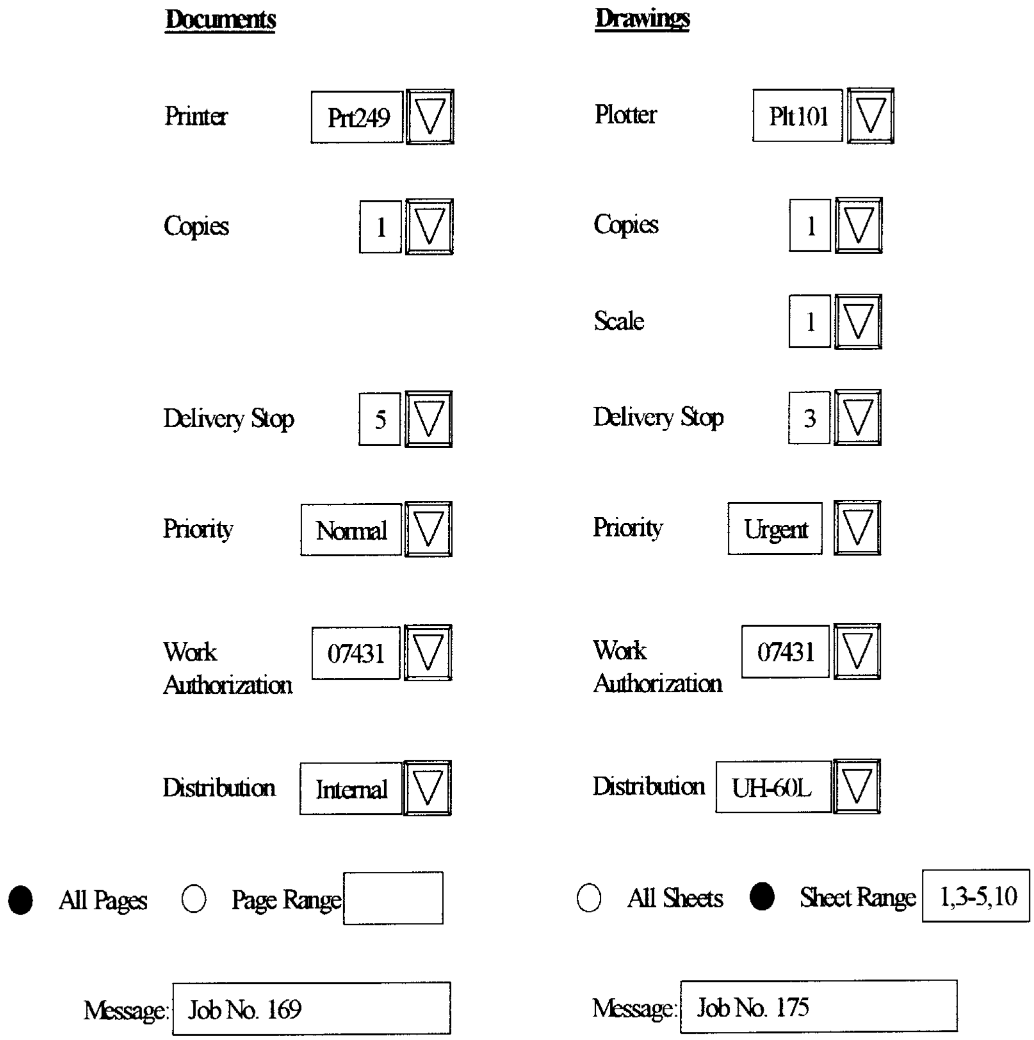


Figure 6
Effective Prototyping - User Interface



Select a Product Concept

The concept screening and concept scoring techniques applied herein are based on Stuart Pugh's methods of the 1980s. These techniques assist in narrowing the number of concepts considered and improving each concept. In the simpler version, concept screening, the selection matrix is constructed only with the selection criteria as rows and the concepts as columns. A ranking of the concepts is performed by scoring the concepts with a simple relative criteria comparison score of "better than" (+), "same as" (0), or "worse than" (-) depending how the concepts rate to a reference concept. Improvement of the concepts is achieved by combining the features of several concepts to create a new concept to be ranked.

The concept scoring techniques increase the resolution by adding relative importance to the selection criteria. This assists in differentiating between competing concepts. The development team can focus on refined comparisons with respect to each criterion. Again, improvement of the concepts could be discovered by combining features of current concepts to generate new ideas to be evaluated.

A concept scoring matrix in our printing service problem for the PDM project is detailed in Table 10. Concept 1, the current method in house drawing management system used in production today, is the reference for comparison of Concepts 2 and 3.

The highest scoring concept as shown by the matrix is Concept 3 because it most successfully meets the company's internal goals and external business contract requirements. In addition, this concept best services the enterprise customer community by isolating them from computer infrastructure downtime.

Table 10

Concept Scoring

Selection Criteria	Weigh	Concept 1 (reference) Rating	Concept 1 Weighted Score	Concept 2 Rating	Concept 2 Weighted Score	Concept 3 Rating	Concept 3 Weighted Score
Meets CALS directive	12	3	0.36	4	0.48	5	0.60
Support EDD contract requirement	12	3	0.36	4	0.48	5	0.60
Satisfies Sikorsky digital vision	12	3	0.36	4	0.48	5	0.60
Intelligent, simple user interface	9	3	0.27	4	0.36	4	0.36
Fast drawing and document delivery	9	3	0.27	4	0.36	5	0.45
Less network dependency	7	3	0.21	4	0.28	5	0.35
Less Unix server dependency	7	3	0.21	4	0.28	5	0.35
Less NT server dependency	7	3	0.21	4	0.28	5	0.35
Disk space requirements	3	3	0.09	2	0.06	2	0.06
Administration efforts	4	3	0.12	2	0.08	2	0.08
Backup required	3	3	0.09	2	0.06	2	0.06
Recovery required	3	3	0.09	2	0.06	2	0.06
Overall service availability	12	3	0.36	4	0.48	5	0.60
Total Score	100		3.00		3.74		4.52
Rank			3		4		5
Continue?		No		No		Develop	

Relative Performance	**Rating**
Much worse than reference concept	1
Worse than reference concept	2
Same as reference concept	3
Better than reference concept	4
Much better than reference concept	5

Plan Remaining Development Project

Task list and staffing requirements

In an effort to organize and plan the phases of the project development, system engineering methods and tools, especially the DSM matrix, assist in ordering and identifying the many tasks necessary to accomplish the project. A top level listing of the tasks for the PDM print service project is outlined in Table 11. An estimate of the manpower required to complete each task is included to approximate the magnitude of the effort, which allows the team to define budgeting and staffing requirements.

Table 11

Task List	Estimated Person-Weeks
Concept Development	
Receive and accept specification	4
Concept generation/selection	8
Detail Design	
Design interface forms	2
Design print routines	4
Document design	1
Develop testing plans	1
Testing	
Unit testing	1
Integration Testing	1
System Testing	1
Document testing	1
Develop production plans	1
Production	
Install printing service	1
Evaluate print service	1
Total	27

Design structure matrix – task mode

A Design Structure Matrix, Table 12, can also be used as a powerful project management tool. The matrix diagrams information flows in a complex project. It provides insights for managing a complex project. It highlights issues of information needs and requirements, task sequencing, and iterations visually on a single page. The matrix describes the information items required to start a certain activity and what the information generated by the activity feeds into. Design Structure Matrix Table 13 is sorted to reduce the unnecessary feedback iteration loops.

Table 12

Concept 3 - Design Structure Matrix - Unsorted Activities

Responsible	Activity		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
System	Setup development environment (hardware/software)	A	A		x	x	x							x				x	x
System	Setup production environment (hardware/software)	B	X	B	x		x											x	x
Development	Write print design specification	C	x		C														
Development	Write print test specification	D			X	D													
Development	Create estimated print service activity information	E			X		E												
Development	Write print user interface	F			X			F											
Development	Add picklists to user interface	G			X				G										
Development	Write user interface trap routine	H			X					H									
Development	Write print processing routines	I			X	x					I								
Development	Perform unit testing of print service	J				X						J							
Development	Integrate print service into PDM	K			X								K						
Development	Perform integration testing of print service	L			x	X								L					
User	Approval by user of print service	M			x	x									M				
User	Document print service	N			x	x										N			
System	Move print service from development to production	O													X	x	O		
Development	Collect actual print service activity information	P															X	P	
Development	Evaluate print service activity information	Q					x											X	Q

X: High input

x: Low input

Table 13

Concept 3 - Design Structure Matrix - Sorted Activities

Responsible	Activity		C	D	E	A	F	G	H	I	J	K	L	M	N	B	O	P	Q
Development	Write print design specification	C	C			x													
Development	Write print test specification	D	X	D															
Development	Create estimated print service activity information	E	X		E														
System	Setup development environment (hardware/software)	A	x	x	x	A							x					x	x
Development	Write print user interface	F	X				F												
Development	Add picklists to user interface	G	X					G											
Development	Write user interface trap routine	H	X						H										
Development	Write print processing routines	I	X	x						I									
Development	Perform unit testing of print service	J		X							J								
Development	Integrate print service into PDM	K	X									K							
Development	Perform integration testing of print service	L	x	X									L						
User	Approval by user of print service	M	x	x										M					
User	Document print service	N	x	x											N				
System	Setup production environment (hardware/software)	B	x		x	X										B		x	x
System	Move print service from development to production	O												X	x		O		
Development	Collect actual print service activity information	P															X	P	
Development	Evaluate print service activity information	Q			x													X	Q

X: High input

x: Low input

Risk analysis

Almost every project has associated risks. A system engineering approach encourages analysis of all the project's concepts from the concept generation, along with the spatial, energy, information, and materials flows between the components of the selected concept to identify potential risks to the project. The importance of risk management was emphasized in Machine Design's February 1996 "Why PDM Projects Go Astray" article. Awareness allows specific risks to be monitored throughout the program and minimized by proactive trouble shooting efforts. Potential problem areas for the PDM project are identified in Table 14.

Table 14

Risk	Risk Level	Actions to Minimize Risk
Change in customer specifications	Moderate	Involve the customer in the process of refining specifications.
		Work with the customer to estimate time and cost penalties of changes.
Poor user interface	Moderate	Work with end users to clarify the interface.
Poor print process performance	High	Create a multi-discipline team to optimize the process's information and data flows.
		Create full process benchmarks to monitor and validate performance requirements.
Sponsor support	Low	Schedule monthly status meetings with executives.

Sikorsky software engineering methodology

In the Information Technology (IT) group at Sikorsky, application engineers initially determine the scope of the project. The scope of the project determines whether it will be classified as a Type I, II, or III. Type classifications identify the complexity and business impact of a project, with a Type I project defined as simplest and Type III as the most weighty. It is difficult to determine the scope of a project accurately.

The Quality Functional Deployment (QFD) capability to map the project's needs to the project's technical metrics would assist in understanding the project scope. The Pugh Concept Selection method would enhance the discussion of the concepts generated and eventually determine the concept selected. The Design Structure Matrix in both the architecture and task modes would highlight the infrastructure requirements and indicate the technical and business teams needing to be formed to develop and implement the project tasks in a timely fashion.

Product Data Management Issues

Articles appearing in technical publications regarding Product Data Management (PDM) frequently reference a number of common issues. One issue is the organizational team makeup and teamwork that must be present to successfully complete the project phases. A second common issue is that the requirements and business processes required need to be defined and understood by the entire team at the beginning of a project. A third issue is the importance of the integration and interfaces between the PDM and other technical applications in the company.

As shown in this review, the Quality Functional Deployment (QFD) matrix assists in capturing the business requirements and processes that need to be mapped in the technical components of the PDM system. The QFD is also useful in educating the team in the need importance priority and relative weighting of each of the needs.

The architectural Design Structure Matrix (DSM) assists in capturing the information, spatial, energy and material input and output flows between the components of the PDM system. The matrix will support the decision whether to interface or integrate any two systems together. The DSM will highlight the coupled groupings of various components that will require project teams and meetings to resolve these opportunity groups. The Pugh method of concept selection and scoring will evaluate and document all the possible alternates objectively.

System engineering tools will assist in the development and support of an enterprise PDM system because the tools allow for improvement in communication and coordination with other departments and work groups involved with the project. Also, the tools facilitate the information gathering, the inclusion of everyone in the process, and the better understanding of the project picture being created.

Lessons Learned

System engineering tools have been applied successfully in product design and development in many diverse fields including the automotive, aerospace, and defense industries. Fewer examples of the application of these tools in the software-engineering field exist: At NASA, the DeMaid application utilizes design structure matrix (DSM) methodology extensively in very complex designs. At the Software Engineering Institute (SEI), their Software - Capability Maturity Model supports implementing the Quality Functional Deployment (QFD) to elicit requirements. QFD is recommended to capture the "Voice of the Customer" and then the proposed requirements of the system to be validated based on whether or not the requirements reflect the expressed customer needs. SEI also agrees that the QFD documents the requirements rated by the user that might receive little attention from the developer proposed features. At the www.problematics.com website, Donald Steward, the original inventor of Design Structure Matrix, has created software to assist in using DSM in a complex application. At MIT, the Sloan School is also building Microsoft Excel macros and programs to enhance Excel DSM spreadsheet functionality for complex applications. While MIT does not have a DSM course today, it is offering DSM workshops and executive management courses on DSM to spread knowledge of DSM.

As illustrated herein, the industry proven system-engineering tools of QFD, DSM and the Pugh Concept Selection method can enhance software engineering projects. These tools can be beneficial by: emphasizing designing for quality by focusing on the customer's needs, promoting team building, improving cross-functional communication, addressing high priority items early, reducing costs through decreased start-up problems, enhancing design reliability, and increasing customer satisfaction.

Using system engineering tools in determining the best piece of equipment, or process flow, or software system to implement allows individuals to remain objective during the information gathering stages of the decision making process. It allows individuals on the team to understand the importance of attributes to the system from the perspective of all potential end users. The structure afforded by system engineering methodology allows data to be the focus and basis for decision making. This will prove an effective argument for its implementation, especially in complex or politically controversial projects when the importance of a decision can paralyze a manager / company fearing the downside possibilities of the 'wrong' decision.

System engineering tools could most effectively be used in Information Technology (IT) projects that have the following attributes: medium to high complexity, existing or new technology, internal/limited external to extensive external data structure changes, medium to high business process impact, significant business systems applications impact, medium to high data center impact, extensive data conversion/initialization requirements, medium to low confidence in project estimates, and extensive user involvement. Unless the project exhibits many of these characteristics the structure provided by the tools will appear as an impediment – the practical benefits would be hard to sell to an individual or a group. Benefits of the tools will be most apparent in the context of a large mission critical project, where the success of the detailed design development phase is heavily dependent on up front planning efforts in the concept phase. If these tools are used properly, they will save resources in project rework cycles and reduce the possibility of project cancellations.

In this PDM project example, an IT team working with the key stakeholders of the project, met to discuss the requirements, objectives, goals, 'whats' and 'hows' of the PDM printing service. Completion of the Quality Functional Deployment based needs metrics matrix allowed characteristics and measurements of the customer requirements for the printing service to be established. Ranking the importance of their needs (what items) and the relationship of their needs to the metrics technical (how item) requirements in a spreadsheet format, ensured that customer requirements have been met. Establishing marginal and ideal target values for the technical specifications for the how metrics assisted in the development phase. The strong, moderate and weak relationships identified potential conflicts early in the planning process stage, allowing for conflict resolution through trade-off decision making or by development of new technology to better address the issue. Team unity and shared responsibility in working together toward the same goals was achieved through communication of the QFD exercise and experience.

Once the QFD process was planned and made visible to the team, several design concepts were generated to satisfy the technical requirements. While preliminary cost concerns would usually be evaluated at this time, for this particular concept generation effort the cost analysis and budgets were predetermined to be available and adequate for the proper solution to satisfy this business problem. Each concept was sketched out and decomposed into goal-function-form elements. The sketches and decompositions assisted in dividing the problem into sub problems, permitting team members to see and intellectually discuss the positive and negative attributes of each concept.

The Design Structure Matrix (DSM) assisted in identifying the spatial, material, energy, and information flows between the form components of a concept. DSM makes flow types visible to all team members on a single spreadsheet. The DSM with its coupled groupings showed the project's management staff that cross-functional representation to make key development decisions and adequate resources to complete development tasks will be required. The DSM supplied important educational information to all the team members and feedback to the project management. Proper planning of mini-reviews to verify processes around the DSM and with small team meetings to focus on specific problem areas can save project time and money.

Oftentimes in projects of this magnitude, key individual or team based decisions are not well documented, and the reasoning for the decisions forgotten with time. This can be the case in the downselecting of concepts, as it can be difficult to determine which design concept should be selected and developed. Concepts evolve from considering customer requirements and the existing and new technology available to the project. The Pugh Concept Selection matrix methodology provided an efficient and effective way to compare candidate concepts on a single spreadsheet, evaluating and reducing a number of concepts to one. The Pugh Concept Selection provided a means to select the most appropriate concept from both external customer requirements and internal functional requirements. Utilizing this tool on an IT project clearly states and publicly documents the basis and evolution of the concept selection process. There is no hiding from the facts.

DSM as a project management tool focused on the information that drives the tasks and the tasks that produce the information to plan and manage a project. DSM's single spreadsheet represents and analyzes information task dependencies uniquely. The matrix modeled sequential, parallel and coupled tasks including iterative feedback loops. Utilizing partitioning techniques the order of the tasks could be modified to their task's sequential dependencies, affording a project manager a clearer view of the project's status by looking at the informational dependencies and flows.

The task of developing IT services to meet and exceed customer requirements requires planning in the concept development phase. Two indications of a well planned IT project are that the service provided contains the right features and performs optimally. These tools assist in achieving that goal.

Despite apparent benefits, implementation could still be challenging to the IT community, and other similar organizations, for a number of reasons: It is never easy to convince people of the need for change, it appears to conflict with the "It's not created here" paradigm, and it could be challenging to individuals who have a comfort level dealing with other decision management styles. Proper and well-coordinated training will insure senior managers and key personnel understand the tools and their benefits to assist in producing the reliable, high quality software the customer requests.

Summary

The product data management (PDM) enterprise print service is a mission critical service for executing the daily business of Sikorsky. Its internal and external customers need access to helicopter data to build the aircraft anytime, anywhere, worldwide. The product design and development methodology highlights the critical behaviors between the hardware and software components of the service. This indicates the need for staffing multi-disciplined organizations and investing in highly reliable computer hardware and software infrastructure to continuously enhance and support this service 24 hours a day, 7 days a week worldwide.

System engineering methodology and tools were shown to be valid and beneficial in the implementation of a quality PDM system printing service: These methods and tools objectively provide individual and group contributors with better information, enabling them to share that information with the entire team of developers, administrators and above all, the customers of the PDM service.

Throughout this thesis it was demonstrated that the system engineering tools of QFD, PUGH, and DSM can become the common communication languages for interacting with the customer to ensure their satisfaction with the final product. In a complex project, communication and organization between members is critical for the project's success. Utilizing the same tools that its customers use when collecting requirements and deciding how to build a complex helicopter product will greatly assist the IT staff in deploying an information management system to control and manage data describing the helicopter worldwide.

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Appendices

Appendix 1 - Design Structure Matrix Elements and Interactions

Spatial: A spatial-type interaction identifies needs for adjacency or orientation between two elements.
Energy: An energy-type interaction identifies needs for energy transfer between two elements.
Information: An information-type interaction identifies needs for information or signal exchange between two element
Materials: A material-type interaction identifies needs for materials exchange between two elements.

Spatial		
Required:	(+2)	Physical adjacency is necessary for functionality
Desired:	(+1)	Physical adjacency is beneficial, but not absolutely necessary for functionality.
Indifferent:	(0)	Physical adjacency does not affect functionality.
Undesired:	(-1)	Physical adjacency causes negative effects but does not prevent functionality.
Detrimental	(-2)	Physical adjacency must be prevented to achieve functionality.
Energy		
Required:	(+2)	Energy transfer is necessary for functionality
Desired:	(+1)	Energy transfer is beneficial, but not absolutely necessary for functionality.
Indifferent:	(0)	Energy transfer does not affect functionality.
Undesired:	(-1)	Energy transfer causes negative effects but does not prevent functionality.
Detrimental	(-2)	Energy transfer must be prevented to achieve functionality.
Information		
Required:	(+2)	Information exchange is necessary for functionality
Desired:	(+1)	Information exchange is beneficial, but not absolutely necessary for functionality.
Indifferent:	(0)	Information exchange does not affect functionality.
Undesired:	(-1)	Information exchange causes negative effects but does not prevent functionality.
Detrimental	(-2)	Information exchange must be prevented to achieve functionality.
Materials		
Required:	(+2)	Materials exchange is necessary for functionality
Desired:	(+1)	Materials exchange is beneficial, but not absolutely necessary for functionality.
Indifferent:	(0)	Materials exchange does not affect functionality.
Undesired:	(-1)	Materials exchange causes negative effects but does not prevent functionality.
Detrimental	(-2)	Materials exchange must be prevented to achieve functionality.