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Effective Collaboration through Multi user CAx by Implementing New Methods of Product Specification and Management

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ABSTRACT

This paper presents a new design process in which design specifications and task distribution are determined from a parallel multi user prospective. Using this method, projects are more easily decomposed into tasks that can be performed concurrently, thus decreasing the design time. Also, a framework is provided to determine the correct distribution of available talent and stakeholders that can be utilized on a given project. The research suggests that by involving the necessary stakeholders in a multi user setting, changes can be made quickly and without additional approval wait time. By including individuals from the various areas of required talent, persons of expertise will be able to work together in a mode of shared design rather than an iterative design process. Decreasing iterations as well as reducing wait time for approval will reduce the overall design time significantly. This method has been tested and validated utilizing controlled tests simulating real life situations of much larger scale. The validation results show that the new method does in fact improve design time and overall achievement of initial design goals

Keywords: multi user CAx, collaboration, design process, specification gathering, task decomposition, task distribution.

1. INTRODUCTION

While success of a designed product can be measured in a variety of ways, the three most commonly accepted success metrics are: cost, performance, and completion time [8]. The challenge in creating a successful design is the fact that these factors are very rarely independent of each other, but rather are almost always in direct competition. For example, often as a result of making improvements to a products performance, costs will increase due to additional manufacturing costs or a more rigorous design process.

In an effort to improve the product design, a large amount of research has been performed into the design process itself, and more recently, a great deal of focus on concurrent engineering or collaboration. Recent research into multi user computer aided engineering (CAx) tools has provided preliminary prototypes allowing multiple designers to enter and work in the same design space simultaneously [9,11]. It is the hope of these researchers, that by allowing multiple users to work in parallel on the same model, that design completion time will improve. However, due to the complex nature of CAx tools, design conflicts will likely occur between multiple designers, possibly increasing dramatically with each distinct user in the design session [3]. It is our belief that when advanced multi user software tools are coupled with collaboration focused project management techniques, significant design conflicts will be mitigated, and significant improvement will be found in design completion time, product costs, as well as product performance.

2. BACKGROUND

A vast amount of research has been compiled relating to product management and the engineering design process. In preparation for this work, an in depth study of this literature was performed with the focus of implementing collaborative design. As a result of this study, tools were gathered that would be of benefit to a multi user managerial approach. Also, a main area of needed improvement emerged. A large percentage of all design time is taken up by iteration cycles. These iteration cycles are inherent in any design, as tradeoffs must be made between basic

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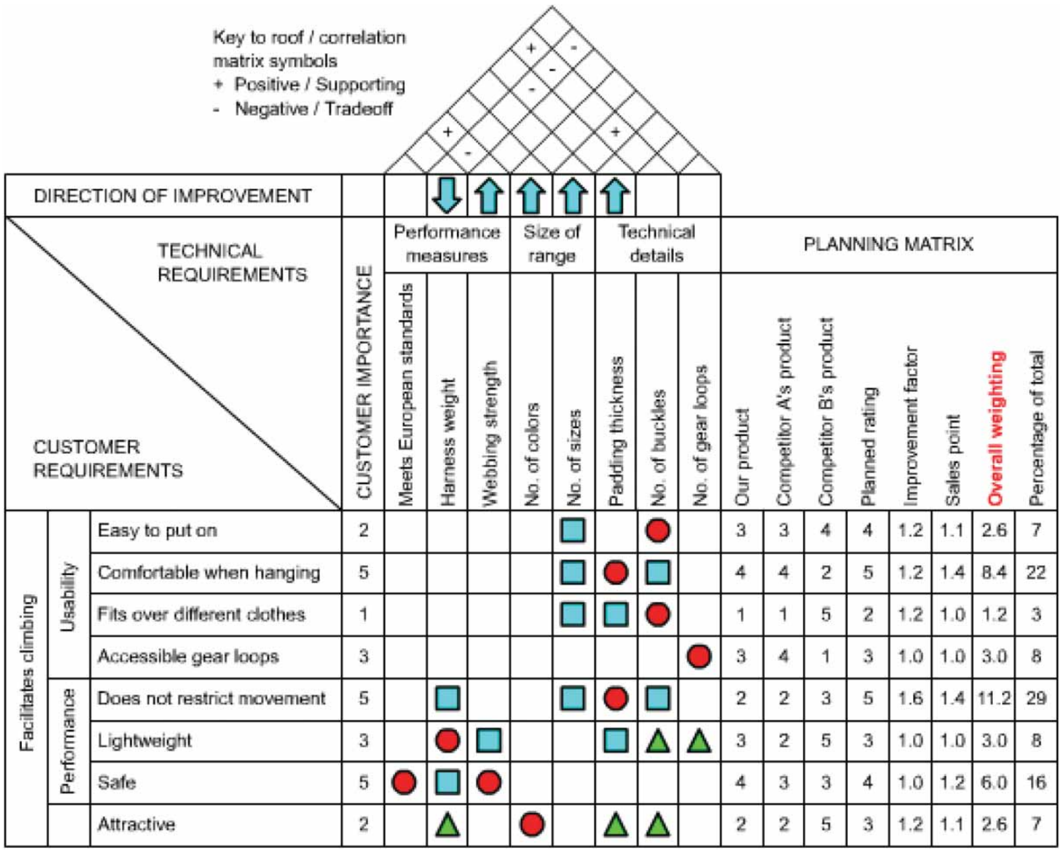

Fig. 1: Example house of quality.

design requirements. However, the detrimental effect of iterative cycles is compounded by the serial nature of product design and the lack of collaboration during product design.

Effective collaboration focused project management begins at the early stages of the design process. As design specifications are gathered and defined, independent relationships begin to emerge. Tools such as the House of Quality (HOQ) have been commonly used to help with the specification definition phase. A lesser utilized portion of the HOQ tool is located in the roof of the house, and provides an opportunity to rate specification interdependencies [5]. A similar tool called an interaction matrix, defined by Kotonya and Sommerville, allows project management to define conflicting and overlapping requirements [7].

Later in the design process, the project is decomposed into separate tasks. Tasks are most often broken up using functional decomposition. However, by utilizing an approach of decomposition by key customer needs, or specifications, knowledge gained about specification interdependencies can be correlated to the resulting tasks. Using this approach, tasks are determined each of which addresses a number of the design specifications previously defined [16]. At the task level, there exists a secondary layer of interdependencies. Tang and coauthors note three types of relationships between design tasks: uncoupled, coupled, and decoupled [13]. Uncoupled tasks have low interdependency and can be performed in parallel. Coupled tasks are highly dependent and are to be performed concurrently utilizing iterative cycles to solve conflicts. Tasks that are decoupled can be performed sequentially and contain only one way dependencies. Earlier decisions affect downstream tasks, but iterations are not required. A Design Structure Matrix (DSM) is utilized to determine relationships between tasks. These relationships have been leveraged in prior research to determine task sequence and opportunities for parallel completion [13].

In industry today, many efforts are being made at collaboration with goals of improving product design time, and performance. However, the design tools are a significant bottleneck to the collaborative effort [11]. Engineering tools are historically almost exclusively single user based, discouraging collaboration where it would be most beneficial, the design environment.

As technology has improved a strong push is being made toward true multi user applications [1]. This collaborative technology has been extended into the CAx tools for engineering, where designers can work simultaneously in the same file [4]. Examples of multi user CAx software prototypes include COCADCAM [6] CyberCAD [15] and the more recent, WebCAD [12]. The commercially available software package SolidWorks has also made advancements in collaboration, allowing multiple users to view a part simultaneously, but granting only one designer the ability to make modifications at any given time [2].

In recent years, In order to perform this and other related collaborative research, the prototype collaborative CAD system named NXConnect was developed as an add-on to the commercially available CAD software package Siemens NX. NX Connect allows multiple users to open and actively manipulate and make modifications to a part file simultaneously. By providing the tools to allow collaboration within the design session, new possibilities can be explored in the design process to gain improvements in design, and streamline the process.

Applying new research into multi user CAx applications and providing a framework to organize project tasks into managed multi user groups, the main issues associated with design iterations can be minimized and more effective design and collaboration is achieved.

3. METHOD

Running in parallel to accepted steps of the engineering design process, a series of guidelines have been developed to capture and leverage important correlation information. Task Lists generated from specification decomposition methods will utilize this correlation information to group tasks based upon the interdependencies between those in the list. Each task group will then be performed by a corresponding personnel group made up of designers and decision makers specifically qualified to perform the tasks.

3.1. Collect Specification Data

For any design task it is critical to gather all the required specifications to fully define the end goal of the project. To best organize a specific project to take advantage of the benefits of multi user concurrent design it is necessary to begin in this early stage of product development. Information regarding the expertise or talent necessary to successfully design for each specification as well as the correlations between each must be determined.

Talent refers to the area of expertise or responsibility within the company that a product designer possesses. For example, a company may operate with three separate departments: Mechanical Engineering, Manufacturing, and Marketing and Sales. It is likely that each of the departments will contain the necessary expertise to make decisions on one or more of the design specifications. The project management team is tasked with the determination of the required talent for each specification.

Specs	a1	a2	a3	b1	b2	b3	c1	c2	c3
a1		1	1	1	1	1	9	1	1
a2	1		1	1	1	1	1	9	1
a3	1	1		1	1	1	1	1	9
b1	9	1	1		1	1	1	1	1
b2	1	9	1	1		1	1	1	1
b3	1	1	9	1	1		1	1	1
c1	3	1	1	1	1	1		1	1
c2	1	3	1	1	1	1	1		1
c3	1	1	9	1	1	1	1	1	

Fig. 2: Sample specifications requirements matrix (SRM).

Each specification is then to be evaluated individually against all other design specifications to determine its set of correlation values. As a specification is evaluated, the manager is to determine how much the current specification is affected by a change in each of the other specifications. This implies that a set of two specifications will have two separate values defining the relationship between the two. One value will correlate how the first is affected by the second, and the next value will correlate how the second is affected by a change in the first. A Specification Rating Matrix (SRM) matrix has been defined using principles from the roof of the house of quality as well as the interaction matrix, to collect and store this specification relationship data.

Unlike the interaction matrix, the SRM looks solely into the affect a change in one requirement will have on another and utilizes a multiple scoring values to define the extent of that relationship. For this research a rating scale of 1-3-9 has been chosen. The greatest correlation between two specifications corresponds to a nine, moderate correlation corresponds to a three, with one denoting little or no correlation. The chosen scale helps to put emphasis on requirements with a larger correlation. Park and Kim utilized this same scale after finding a variety of commonly used scales through a random survey.

3.2. Decompose Project into Discrete Subtasks and Calculate Optimal Completion Groups and Sequence

For complex parts it is important to break the design problem into subtasks to organize the design. This research utilizes a decomposition based on design specifications approach, best allowing for the linking of design tasks with specifications that correspond to them.

This step will draw upon the information gathered in the previous steps; however, the management team is still required to determine the tasks required to

Tasks	a1	a2	a3	b1	b2	b3	c1	c2	c3
A	1	1	1	0	0	0	0	0	0
B	0	0	0	1	1	1	0	0	0
C	0	0	0	0	0	0	1	1	1

Fig. 3: Example of a specification utilization matrix (SUM).

$T_{ab} = Value\ in\ the\ TRM\ matrix\ at\ row\ a\ column\ b$
$Rij = Value\ in\ the\ SRM\ matrix\ at\ row\ i\ column\ j$
$Sbj = Value\ in\ the\ SUM\ matrix\ at\ row\ b\ column\ j$
$Sai = Value\ in\ the\ SUM\ matrix\ at\ row\ a\ column\ i$

$$T_{ab} = \sum_{i=0}^{n}\left(\sum_{j=0}^{n} R_{ij}S_{bj}\right)S_{ai}$$

Task Relationships			
	A	B	C
A		9	33
B	33		9
C	21	9	

Fig. 4: Task relationship matrix calculated from the above SRM and SUM.

complete the design. Initially, the management team will view each specification and determine design tasks to address the specific requirements. Each specification will be assigned to at least one task with the possibility of numerous tasks being required to fully address a single specification. Conversely, a single task can also incorporate multiple design specifications as important considerations while completing the given task.

A new matrix, defined as the specification utilization matrix (SUM) is used to store binary information detailing for each task whether it references each specification. The SUM represents which specifications are used in each task and will be labeled matrix S.

Utilizing the previously defined SRM, labeled R, together with the SUM, a third matrix, a task relationships matrix (TRM) will be created for this research that is similar to a DSM except with quantified correlation values between tasks as opposed to specifications. The TRM provides correlation information between tasks that allows for the calculation of the optimal task sequence. This matrix will be labeled T and is derived and shown below. In this Equation the terms a, b, i, and j correspond to the indices in each respective matrix.

To better illustrate how to move from The Task Relationships Matrix to an optimized sequence a more complex TRM is introduced below.

Task Relationships										
	A	B	C	D	E	F	G	H	I	J
A		6	8	12	11	6	6	2	4	4
B	6		28	12	12	9	16	4	3	3
C	8	26		21	16	11	24	5	4	4
D	25	12	21		14	6	10	3	8	8
E	12	12	16	14		11	10	4	8	8
F	8	9	11	6	11		7	2	6	6
G	8	16	24	10	12	7		2	4	4
H	4	4	5	3	5	2	2		3	3
I	4	3	4	8	8	6	3	1		1
J	4	3	4	8	8	6	3	1	1	

Fig. 5: A more complex task relationship matrix (TRM).

As can be seen from the TRM above, when a more complex project is used, the optimal sequence of tasks is not immediately apparent. Also, with the large number of interdependencies, each task has some correlation to the others. To calculate the significant task dependencies a threshold value must be determined below which correlations are assumed to be insignificant. This threshold is defined as follows: $Val_{sig} = Mean + Stdv$.

Also, while it is recognized that some iteration may still be necessary, it is the goal of this research to minimize this necessity. Notice that on the above matrix, many of the correlations factors with significance have corresponding correlation factors directly across the diagonals that are also significant. For example, Cell BC = 28 and CB = 26. Because only one task can feasibly be completed first, the larger of the two correlation factors is used while the lower is ignored. Also, often identical correlations factors exist. For example, correlation CD = DC = 21. If this is the case, only the correlation factor appearing closest to the top of the matrix will be utilized.

With the TRM calculated, task dependencies are now defined and an optimal sequence can be determined. Using the correlation significance rules from above, preliminary task dependence is shown in Fig. 6.

The left column represents a task that should be performed before the corresponding tasks on the left. Note on row B, both C and G should be completed after B, but it is not necessarily true that C needs to be completed before G, although we do see on row C that this is indeed the case.

At this point the depth first algorithm, a tool used in graph theory, will be utilized to arrive at the final task sequence [14]. This algorithm is a branching algorithm that explores each branch as it leaves from a central root. In depth first algorithms, a path is followed out as far to its furthest extents before backtracking. For this research, each task becomes the

Dependencies			
A			
B	C	G	
C	D	E	G
D	A	E	
E			
F			
G			
H			
I			
J			

Fig. 6: Task dependencies chart based on the data from the TRM.

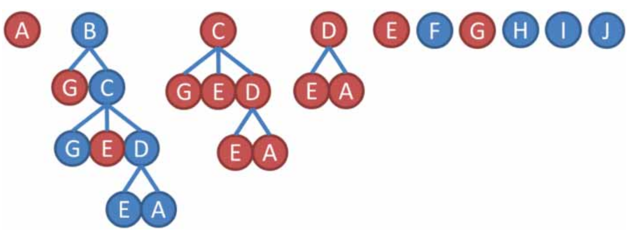

Fig. 7: Path trees created from utilizing the depth first algorithm.

root of the depth first algorithm and a path tree is created from each task as shown in Fig. 7.

Starting with task A, it can be seen from Fig. 6 that task A has no dependent tasks. B however, has G and C tasks with dependency. G has no further dependents so the branch does not extend in that direction, however C has multiple dependents. Each time a dependent is found, the depth algorithm continues down the dependency line. For example, when looking at the dependencies of C, if you were to address D before G, then you would continue down the branch and address E and A, before returning to address G.

Also, by creating a path tree for each task, duplicates will be created. In order to determine which route is the correct route to follow, the duplicate furthest to the bottom is to be used. For example, E is dependent on both C and D. But by using the path furthest to the bottom, you ensure E is performed after both D and C. Tasks that are shown on the same level can be performed in parallel. All of the duplicates that happen higher on the path trees are marked red to show that they will not be used. The remaining path trees make up what is the final optimized task sequence and is shown in Fig. 8.

Tasks that line up vertically can be performed in parallel while those lined up horizontally have a dependent relationship and must be performed

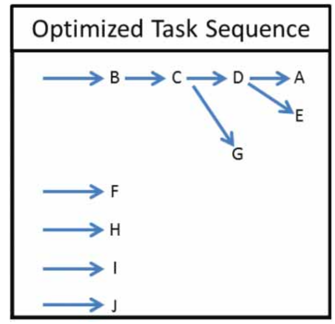

Fig. 8: The optimized task sequence.

in order. Following this task sequence will enable a design team to complete a project more efficiently.

When items can be performed in parallel, separate design groups are created to perform each branch in the task sequence map. In the above example, assuming the tasks are similar duration, it makes sense to break the task into at least two groups. One group will be assigned to perform the task sequence beginning with task B, and other groups can be created and assigned to perform the tasks F through J.

3.3. Compose Personnel Groups of Required talent

To create these Personnel groups, the needs of each task within the design group are taken into account. Within the task groups each task will have a required set of individuals representing talent. This talent set will be derived from the needs of the specifications driving each task.

Once all tasks within a task group have an associated talent set, those talent sets are joined together in a Talent Group. The Talent group will then have all necessary expertise and decision authority to complete each task in a given task group.

3.4. Each Talent Group will Perform Corresponding Design Tasks within a Multi User CAx Environment

The preceding steps are the means to arriving at the actual design of the product. At this stage, each talent group has a specified set of tasks to complete as well as a specific sequence in which they should be accomplished. The true value of the method lies in the ability of the design group to perform the tasks in a manner that improves overall design time, and fosters the development of a superior design.

The members of the talent group now become the individual users within the multi user CAD environment. Each user will have access to design tools that will allow them to manipulate the part file. These changes will be reflected upon the screens of each user within the design environment. Within the task list, each user required to perform the active task will focus solely on its completion. The task will remain

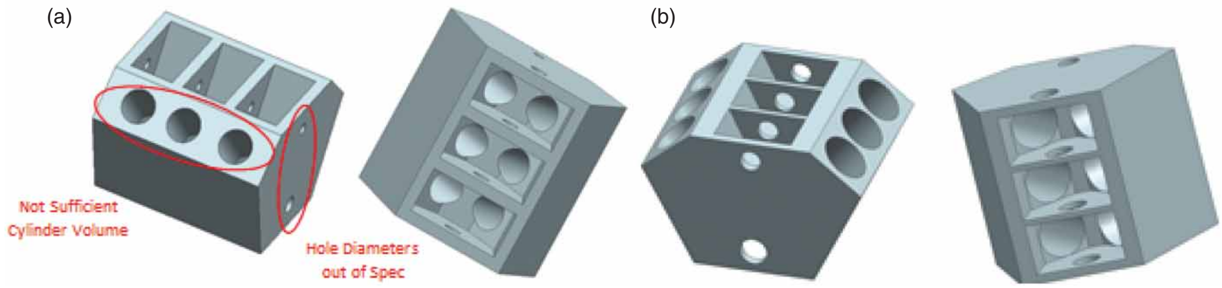

Fig. 9: Sample test trials: (a) iterative approach, and (b) multi user approach.

active until all required users determine the task has been completed and they are ready to move to the next phase.

The great benefit of including all required talent and decision authority into the design session is the ability to communicate the design rationale behind every decision. This communication facilitates the compromise of conflicting design parameters that are each controlled by separate areas of expertise. By bringing each of the designers together in the same design environment, any conflicts that arise will be addressed immediately. Design iterations will still occur, but they will now be resolved in a single sitting while providing for a more effective environment for compromise and innovation.

In the end, all tasks will be completed in less time than the conventional method, with a high probability of having arrived at a superior solution.

3.5. Implementation and Testing

The method presented here was implemented and tested on a small scale utilizing software developed to lead a project manager through the before mentioned steps. NXConnect, the software add-on to NX was also used to provide a multi user design environment.

Due to a lack of resources, qualified testers, software robustness, and time it was not feasible to perform a large scale test on a complex part. Therefore, a simplified, simulated test was developed that represents a design on a more complex level. This allowed primarily for the testing of the effectiveness of predefined task groups with defined roles to perform in a multi user environment as opposed to individual designers working in an iterative manner.

The test consisted of the design and modeling of an engine block. The target specifications for the engine block were defined and talent was assigned to each specification. Utilizing the methods outlined earlier to the extent possible within the simplified context of the test, a sequence of tasks was defined along with required personnel for each task.

In the trials, each user represented a member of a design group with a specific talent or expertise. For each trial, three users were selected and each received a different portion of the design specifications for the design of the engine block. The specifications they received corresponded to a specific talent simulating the idea that each user had expertise in a certain area of the design. While an identical task sequence was provided for both trials, information linking design tasks to the corresponding talent personnel was made available to only those of trial two, the multiuser collaborative group.

In the first trial, the users were instructed not to converse with each other about their respective specifications. One user would first design the engine block using as guiding values only those specification that have been provided. User two would then receive the model and make modifications to satisfy his/her respective specifications. User three would do the same in turn and then pass back to user one to review and perform iterations on the design. This continued until the design was complete or the test session time had expired.

In contrast, the second trial follows the pattern specified in section 3.4 in which each of the required talent or stakeholders are placed in a collaborative design environment. They have the same task list, but now each designer has a clear idea of his/her role in the design, the roles of the other members of the design session, and communication facilitated by VOIP software.

3.6. Testing Results

The first trial iterative design runs varied a great deal. The number and extent of modifications required between users varied greatly from one case to the other. Some of the designs required enormous modifications to meet the design requirements of subsequent designers in the iterative cycle, while in others the initial design required only slight modifications to meet the specifications of the later designers.

The multi user test produced much better and more consistent design scores, and the completion times were significantly better than those of the groups working serially. The test users were able to complete the design without the need to return and make major modifications later due to improved organization, better defined roles between the designers,

Single Users - Iterative Design			
Case	Time (min)	Total	Notes
1	48.4	7	Model was completed, but specifications for piston angle offset, external wall thickness, and cam shaft bearing diameter fell out of scope
2	34.12	7	Model was completed, but specifications for total cylinder volume, cam shaft bearing diameter and crank shaft bearing diameter fell out of scope
3	47.4	5	Model blew up while users were trying to fix the part to reflect their specifications
4	46.88	9	Complete part but some surfaces, and extrusions are not clean and do not extend all the way through
5	37.07	7	Part is non-symmetrical and the pistons do not extrude through the entire block
6	32.37	7	Interior reinforcing ridges were not fully created, external wall thickness specification not met, and cylinder locations were inconsistent.
	41.04	**7.17**	**AVG.**

Tab. 1: Test trial results for the iterative approach.

Multi User - Collaborative Design			
Case	Time (min)	Total	Notes
1	35.77	9	Completed part, extruded reinforcing ridges not uniting with body
2	30.7	10	Complete part, within all specifications
3	26.3	10	Complete part, within all specifications
	30.92	**9.67**	**AVG.**

Tab. 2: Test trial results for the multi user approach.

and the ability to communicate the design needs during each stage of the design process.

The sample multi user cases show that the engines were completed and upon initial inspection, they passed the eye test. Also, upon further examination, the specifications were met completely in all cases.

4. CONCLUSIONS

The value of the presented method lies in the determination of each necessary individual required for approval to move forward with design, and placing each of those individuals in a collaborative environment with clear direction to complete the design. Each of the designers is uniquely qualified in their respective areas to make decisions and provide input to help achieve the target specifications. Where the specifications seem to conflict and compromises must be made, each designer has had the opportunity to observe the rationale of the design and can better weigh the importance of specifications pertaining to their area of expertise. Instead of going through a long iterative process, designers can communicate directly to each other and arrive at the required compromise in a minimal amount of time. This is in stark contrast to the idea of figuratively “throwing the design over the wall” to the designer from a different discipline and background and waiting for it to return.

The testing performed on this method has supported this claim. In each of the test cases, a multi user design session outperformed a multiple single user iterative process. The multi user designs were superior in quality, as well as the overall time to arrive at the finished design.

While the current testing provides evidence of improvement, it is recognized that further testing can provide a more complete understanding of the benefits of this method. Current multi user prototypes continue to lack robustness, and the size and scale of large design projects exceeded the available resources to complete comprehensive testing. It is suggested that continued improvement be made to the multi user prototype NXConnect, and a minimum of two further tests should be performed. The first test is to be a significantly more complex part, which would require large sets of specifications and of required talent to complete the design. The second would be a test utilizing a complex assembly that could be designed and assembled in a multi user environment. These tests should fully incorporate the method of project management presented to define the task sequence and talent required.

In conclusion, this research provides a valuable method to organize a design project into sequentially optimized task lists, complete with the required set of personnel to address the issues and conflicts that may arise during the design process. When these tasks are performed with each designer present and participating in a multi user setting the results are far superior to those of the traditional single user iterative design process.

REFERENCES

[1] Google Docs. (2011, May 22). Retrieved May 27, 2011, from Wikipedia: http://en.wikipedia.org/wiki/Google_Docs

[2] SolidWorks Help - Multi-User Environment: Dassault Systems - SolidWorks. (2013). Retrieved May 6, 2013, from Dassault Systems - SolidWorks Web site: http://help.solidworks.com/2012/English/SolidWorks/slworks/Multi-user_Environment.htm

[3] Feng, L.; Chen, L.: September). Achieving Online Coordination in Real-Time Collaborative Assembly Modeling: A Supervisory Control Approach, Journal of Computing and Information Science in engineering, 6(3), 2006, 252–263.

[4] Fuh, J.; Li, W.: Advances in collaborative CAD: the-state-of-the-art, Camputer-Aided Design, 2005, 571–581.

[5] Hauser, J. R.; Clausing, D.: The House of Quality, Harcard Business Review, 1988.

[6] Kao, Y.-C.; Lin, G. C.: Development of a collaborative CAD/CAM system, Robotics and Computer-Integrated Manufacturing, 1998, 55–68.

[7] Kotonya, G.; Sommerville, I.: Requirements Engineering: Processes and Techniques, New York, NY: John Wiley & Sons, Inc., 1998.

[8] Lock, D.: Project Management (9th ed.), Burlington: Gower Publishing Company, 2007.

[9] Mishra, P.; Varshney, A.; Kaufman, A.: CollabCAD: A Toolkit for Integrated Synchronous and Asynchronous Sharing of CAD Applications, TeamCAD: GVU/NIST workshop on collaborative design, 1997, 131–137.

[10] Park, T.; Kim, K.-J.: Determination of an Optimal Set of Design Requirements using House of Quality, Journal of Operations Management, 1998, 569–581.

[11] Red, E.; Holyoak, V.; Jensen, G.; Marshall, F.; Ryskamp, J.; Xu, Y.: v-Cax: A Research Agenda for Collaboration Computer-aided Applications, Brigham Young University, 2009.

[12] Shen, L.; Liu, H.; Li, M.; Hao, Y.; Wang, M.; Li, J. et al.: Collaborative 3D CAD System for Multiple User Design, Computer Supported Cooperative Work in Design, 2010, 548–552.

[13] Tang, D.; Zheng, L.; Li, Z.; Li, D.; Zhang, S.: Re-engineering the Design Process for Concurrent Engineering, Computers and Industrial Engineering, 2000, 479–491.

[14] Tarjan, R.: Depth-First Search and Linear Graph Algorithms, SIAM journal on computing, 1972, 146–160.

[15] Tay, F. E.; Roy, A.: CyberCAD: a collaborative approach in 3D-CAD technology in a multimedia-supported environment, Computers In Industry, 2003, 127–145.

[16] Ulrich, K. T.; Eppinger, S.: Product Design and Development, New York: McGraw-Hill Companies, Inc., 2004.