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Implementation of Slide Lock Design Process at Central Industrial Supply

A Major Qualifying Project Report

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by

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1. design process
2. conceptual design
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Abstract

A design process for linear slide mechanisms was developed and synthesized into a manual to be used as a reference by design engineers at Central Industrial Supply. The usage of conceptual design software was incorporated into the design process to enhance creativity and reduce lead time. The created design process manual was used to create and prototype a new rear lock mechanism that reduced push/pull force by 68%, while passing Central Industrial Supply's standardized durability test.

Acknowledgments

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Introduction

Many types of appliances, hardware, and computer equipment rely on linear slide mechanisms to provide controlled movement for supported equipment. In addition to supporting heavy loads, the slide mechanisms create accessibility and flexibility for mounting and removing equipment. These linear slide mechanisms have been accepted as a standard component in computer server rack solutions worldwide.

Central Industrial Supply (CIS) is a provider of linear slide mechanisms and cable routing solutions, providing equipment to top selling computer technology companies including Dell Computers, Hewlett-Packard, and IBM. These companies require customized linear slide mechanisms, as every application contains varying structural and functional requirements.

In order to create new linear slide mechanisms, CIS employs a full staff of design engineers. CIS also uses a general standardized design process to ensure thorough product development and quality. The most unclear and demanding part of any design process is the conceptualization phase. Currently at CIS, engineers rely solely on their engineering experience to create and develop new design concepts. While this method has not stopped CIS from being successful, it has been a factor in the limitation of creativity. In order to remain competitive in the global marketplace, CIS has determined that a new standardized design process that places an emphasis on the conceptual design phase will increase the creativity of its designs as well as reduce lead time in the design phase.

The scope of this project was to provide CIS with the necessary information and instructions to implement a standardized design process, using previous work done by a WPI MQP. The previous work, completed in 2007 at CIS, thoroughly outlined a design process that included methodology for conceptual design and redesign. However, it was determined that CIS needed a design process manual to use as an instructional reference during the design process. Furthermore, it was determined necessary to include specific instructions on the usage of kinematic software to quickly generate and visualize new mechanisms.

Several methods were used to present the deliverables, as well as improve upon existing work done in 2007. These include research, interviews, and extensive testing to ensure that the design process manual was appropriate for CIS engineers. A new linear slide lock mechanism was developed and prototyped, and tested for functionality, performance, and reliability using the proposed design process manual.

Problem Statement

CIS has not implemented a sufficient standardized design process for its slide locks, which is needed to create locks more efficiently.

Goal Statement

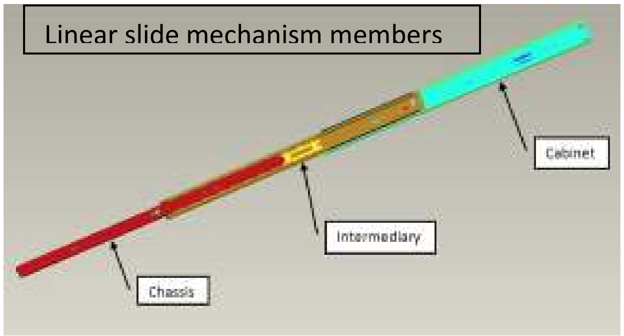
Assess the current proposed conceptual design process for CIS slide lock mechanisms and resolve the integration problems for the purpose of implementation.

Background

Linear Slide Mechanisms

Linear slide mechanisms are telescoping members that provide controlled movement along one-axis. The slide mechanisms are designed for many types of applications- home appliances, commercial, industrial, and electronics. Slide mechanisms typically incorporate a combination of features, depending on their application. Features can include locking mechanisms to restrict movement, disconnect mechanisms for quick servicing, and multiple members to allow for long slide extensions.

The slides of interest of this project are the three-member ball bearing slides for computer server applications. The slides are used to support servers in a large rack, and allow the servers to slide out for maintenance and replacement. As implied, the linear slide mechanism consists of three members- cabinet, intermediary, and chassis. Refer to Appendix I for pictures of linear slide mechanisms.



Cabinet

The cabinet member is mounted to the server rack by a combination of thumb screws, bolts, or spring-loaded pins. The cabinet member is the largest member, as it contains all the slide components. It is also the strongest member, as it supports the load and contains the largest bending moment when the slide is fully extended.

Intermediary

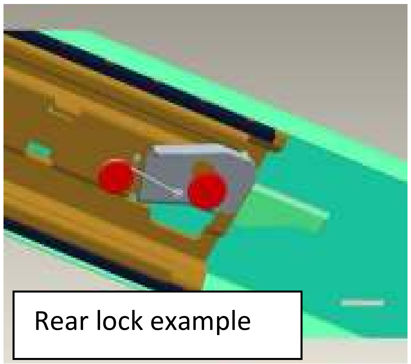
The intermediary member is the second largest member, and slides on a set of ball bearings. The intermediary member usually extends up to half its length. Extensions more than half its length are avoided to avoid instability in the slide mechanism due to large bending moments at the intermediary-cabinet interface.

Chassis

The chassis is the smallest member and provides additional extension for the slide. It slides on a set of ball bearings, and contains a set of mounting holes to support the server assembly. Like the intermediary member, it extends up to half of its length, to minimize bending moment on the intermediary member.

Locking Mechanisms

Several types of locking mechanisms are used to restrict movement of slide members. They include the rear lock, staging lock, front lock, and disconnect mechanism.



Rear lock example

Rear Lock

The rear lock restricts movement between the cabinet and intermediary members. The rear lock consists of a locking element, housing, and release mechanism. The locking element is engaged when the intermediary fully extends, when the chassis member fully retracts into the intermediary via the rear lock mechanism. All movement results from the pushing and pulling forces from the operator.

Staging Lock

The staging lock ensures that the chassis and intermediary member remain locked together until the intermediary member fully extends and the rear lock engages. The staging lock is used to guarantee consistent movement of all the members.

Front Lock

The front lock prevents the chassis from being pushed back into the intermediary. The front lock automatically engages when the chassis member is fully extended. It is at this point that the whole slide assembly is at its maximum extension. The front lock is disengaged manually by the operator, using a release mechanism. Release mechanisms are usually operated by fingers, or by applying a significant push force on the chassis member.

Disconnect Mechanism

The disconnect mechanism allows the operator to completely remove the server and attached chassis members from the intermediary members. The disconnect mechanism allows servers to be relocated to different racks or positions, without any tools.

Self-closing Mechanism

The self-closing mechanism is an optional feature that aids in the complete retraction of the chassis and intermediary members. When the two members have retracted almost completely into the cabinet member, the self-closing mechanism guarantees the completion of the retraction, even if the operator ceases to apply a push force to the members.

Central Industrial Supply

Central Industrial Supply is a contract manufacturer of electromechanical components and assemblies for Fortune 100 OEM’s (original equipment manufacturers). With over 1300 employees worldwide, CIS has become a world leader in the server rack and telecommunications industries. Much of the company’s success has come with its low-cost overseas manufacturing facilities, which has allowed CIS to provide a quality product at a low price (Central Industrial Supply, 2008).

In 1955 CIS was founded in Grand Prairie, Texas, USA. Starting as a manufacturer of small mechanical components serving the telecom industry, overtime it expanded its capabilities to sheet metal stamping and die cut manufacturing giving the company the ability to produce its own products. In 1996 CIS established facilities in Singapore to provide logistical services including planning, materials, management, and assembly and sales. In 2000 CIS expanded its manufacturing to Wuxi, China. With low labor costs CIS expanded metal stamping, fabrication, and assembly. Since then CIS has moved all of its manufacturing to Wuxi, China.

Current locations include:

- Tucson, Arizona
- Singapore
- Wuxi, China
- Glasgow, Scotland
- Thailand
- Fort Worth, Texas

CIS highlights include (Central Industrial Supply, 2008):

- Founded in 1955 in Texas, USA (privately held)
- Over 25 years experience in serving the datacom, telecom, and consumer products industries
- Global headquarters in Tucson, Arizona USA
- Manufacturing and integration in Wuxi, China
- 1300+ employees worldwide in 5 countries
- More than 20 patents and numerous patents pending

- Annual sales in excess of $100 million USD

Precision ball bearing slide products are the main focus of CIS' products. The QualSlide® product line is an assortment of slides for a variety of customers including Kenmore, Hewlett-Packard, Dell Computers, and IBM. Each customer requires customized designs, as functional and structural requirements vary amongst intended applications. CIS meets customer needs by creating innovative designs that cater uniquely to each customer.

Design Processes

Purpose of the Design Process

Products today are the result of lengthy, detailed processes, optimized to create a successful, marketable item. The purpose of the design process is "to provide a methodology for a reliable and effective design of mechanism solutions to real-world, unstructured engineering problems (Sosnovsky, Windsor, Yunfei, Qi,, & Xiaobo, 2007)." Design, as Dixon says, is "the series of activities by which the information known and recorded about a designed object is added to, refined, modified, or made more or less certain (Dixon & Poli, 1995)." Successful design is the narrowing down of ideas and specifications, so that the information and specifications for the designed object are detailed and concise. A general methodology for design is as follows (Dixon & Poli, 1995):

1. Problem formulation
2. Alternative solution generation
3. Determining which alternatives are unacceptable and evaluating the acceptable ones
4. Redesign, with the guide of the previous evaluations

As the National Research Council suggests, engineering design is a "loosely structured, open-ended activity that includes problem definition, learning processes, representation, and decision making (National Research Council, 2002)." In a typical engineering design process, engineers must fulfill certain functional requirements, while being constrained to technical specifications, which may be physical, electrical, or cosmetic. Before the globalization of business, many designs were the result of simple modifications to existing products. Such practices resulted in adequate products, and continued to bring in revenue for businesses. The importance of design practices can be seen in the 1991 study by the National Research Council, *Improving Engineering Design* where the decreasing revenue of US businesses is due to thriving practices in Asia. The NRC points this to poor design practices by US businesses. Engineering design is critical in today's global environment because increased competition brings a need for new products that are better, inexpensive, and introduced rapidly to the market (National Research Council, 2002).

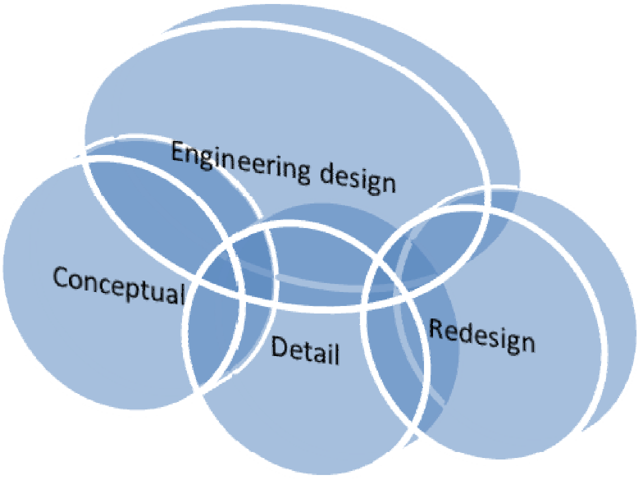


Figure 1: The Design Process

As figure 1 suggests, engineering design is an integration of three sub-designs: conceptual design, detailed design, and redesign. These sub-designs are overlapping, as the boundaries between them are not explicit, nor are they fully independent of each other. The goals of any design process are to optimize quality, cost, lead-time, and marketing flexibility. The term quality includes environmental, performance, and reliability factors. Marketing flexibility is simply the ability of a design process to accommodate to individual customer needs (Dixon & Poli, 1995).

Conceptual Design

A design process generally initiates with a customer need. Next, a list of specifications is provided by the customer that are identified and analyzed by the designer. Analysis includes questions pertaining to timeframe, codes of practice, limitations in manufacturing, and major costs. Conceptual design is the initial phase of design which takes the design problem and generates a few possible solutions, or schemes. During this stage the designer understands the customer specifications and identifies the problems to establish functional diagrams that help with finding solutions. Creativity and abstraction are important qualities in generating inventive solutions. The early stages in a design process serve to create a few outline solutions which include detailed information approximating costs, weights, overall dimensions, and feasibility.

By evaluating all of the solutions the designer can decide which concept to advance to further design stages. Communication between the designers during this part of conceptual design can allow for choosing the best scheme.

Detailed Design

After a final choice is made between the various schemes generated during conceptual design, many decisions about the chosen design are yet to be decided. Detailed design transforms previously generated concepts into a fully dimensioned and modeled design. With current software capabilities, the detailed design is created with computer aided design software (CAD). Prior to CAD work, traditional engineering calculations may be performed to determine material, shapes, and sizes of structures. Making a solid model can be followed by finite element analysis. Software such as ProMechanica can perform necessary structural, thermal, and functional analysis to ensure the reliability of a proposed design.

Redesign

Rapid redesign is a concept aimed to quickly design mechanisms using previously designed mechanisms with similar functional and performance parameters. Redesign is best utilized with a Design Dependency Matrix (DDM) (Sosnovsky, Windsor, Yunfei, Qi,, & Xiaobo, 2007). DDM is not to be confused with Design Structure Matrix (DSM), as their applications vary. DSM is a matrix representation of a system. The purpose of the DSM is to track the dependencies of activities during processes (DSM Tutorial, 2008). Common interpretations of a DSM would include which activities are necessary in order to begin another activity in a process. DDM is similar, visually, to DSM, but looks at design parameters, instead of a sequential system process. The two parameters in DDM are performance and design parameters. The DDM provides answers to:

- Is this performance parameter dependent on this design parameter?
- What is the optimal order of making changes during redesign?
- What parameters interact with each other?
- What parameters are independent?

Usage of the DDM can be broken down into the following steps (Sosnovsky, Windsor, Yunfei, Qi,, & Xiaobo, 2007):

1. Create list of design parameters and performance parameters of the component to be redesigned
    - The design and performance parameters can be both qualitative and quantitative, but the design parameters must be independent of each other. The performance parameters should reflect upon the customer's specifications.
2. Create a matrix, with design parameters as columns, and performance parameters as rows
    - The purpose of the matrix is to quickly synthesize a large amount of design parameters (hence rapid redesign). Marks should be entered in a box at the intersection of the row/column of interest. A mark indicates dependency.

3. Check/verify DDM

   - The DDM should be checked, as as in many circumstances, multiple performance parameters will be dependent on one design parameter.

4. Decompose matrix to create a ‘banded matrix’

   - The purpose of decomposition is to rearrange the rows so that the shaded ‘dependencies’ form a diagonal band that will exhibit groupings referred to as ‘chunks.’ Decomposition can be done in a program such as Excel, by rearranging rows. Matrix software is available to optimize the decomposition, however; for simple decompositions that CIS deals with, Excel is sufficient.

5. Identify faulty parameters and correct.

   - Performance parameters that do not meet requirements must be corrected. Typically, one or two faulty performance parameters are acceptable to continue with rapid redesign. If more than two faults exist, a new design concept should be reconsidered.

   - If changes are made to parameters in the DDM, neighboring parameters (especially if ‘chunks’ overlap) may also be affected, and the DDM should be rechecked

6. Interpret decomposed DDM to find most efficient order for redesign

   - The order of the shadings should be read left to right, and should follow the diagonal pattern. The ‘chunks’ represent independent groupings and so the DDM does not point to the order that the chunks should be looked at. Faulty parameters can be highlighted on the DDM by highlighting the rows and columns that contain the faulty parameter.

Design Process Example

Figure 2 shows a design process used by an American aerospace corporation. The first step of the process is to decide upon the scale of the task, and to decide upon the level of detail for analysis. The second step is the creation of product specifications. These specifications result from the combination of customer needs, some desired specifications, environmental policies, and regulations (such as aerospace or medical standards). The third step is one of the most creative ones; during conceptual development, much brainstorming is performed, while maintaining a schedule, and paying attention to cost and performance needs. Engineers select several concepts, using a variety of decision making tools. The selected concepts are then developed in detail during step 4, along with cost-performance analysis. In the fifth step, changes are made to details- dimensions, tolerances, and geometry are typical areas subject to modification. During the sixth step, prototypes of the product and its subsystems (which can be tested independently) are created. These prototypes are used to evaluate performance. The seventh step of the process is the validation of the manufacturing processes used to create the product. Depending on where components will be manufactured, testing is broken down by process, and usually requires running hundreds of trials once the actual manufacturing line is completed. Step eight is the completed product and process, where manufactured products are tested and certified under quality standards and delivered to the customer. Step nine includes the necessary maintenance and support to keep the product operating. If the product is no longer used, it must be decommissioned and properly disposed.

A popular way to improve engineering design is through concurrent engineering (National Research Council, 2002). Concurrent engineering is defined as "a systematic approach to the integrated, simultaneous design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements (Winner, Pennell, Bertrand, & Slusarezuk, 1988)." Concurrent engineering encompasses many aspects of a product's lifecycle (National Research Council, 2002):

- Design for assembly
- Availability
- Cost
- Customer Satisfaction
- Maintainability
- Manageability
- Manufacturability
- Operability
- Performance
- Quality
- Risk
- Safety
- Schedule
- Social acceptability

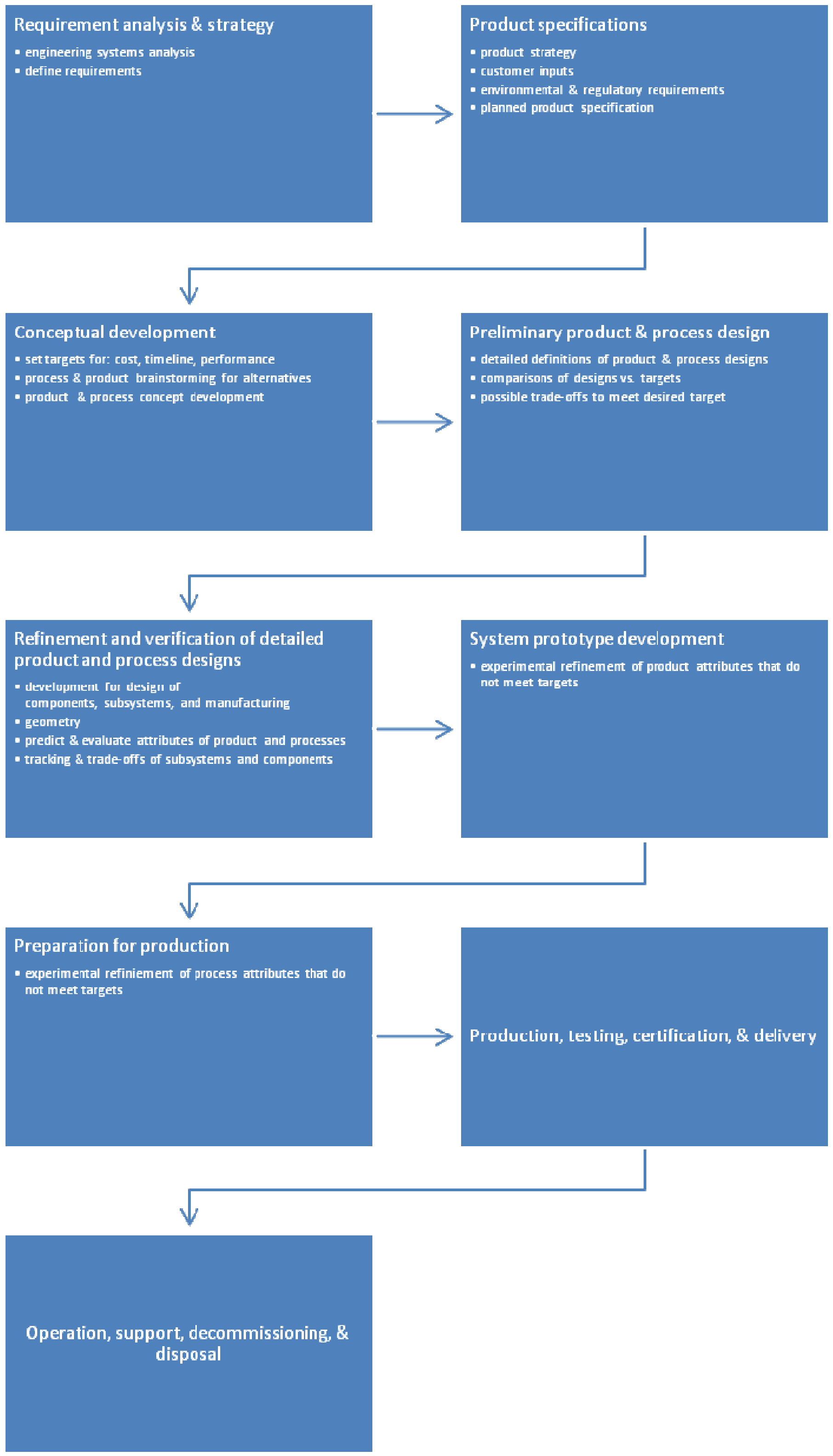


Figure 2: Design and development steps (Committee on Advanced Engineering Environments, 2000)

The Decision Making Process in Engineering Design

Engineering design, like other activities such as business, sports, and medicine, is reliant upon many decisions that will determine the outcome of the designed product. The NRC emphasizes the importance of distinguishing the quality of a decision from the desirability of its consequence. When evaluating a decision, it is important to only judge the situation before the outcome, as a good decision does not always result in a good outcome. When a decision must be made in a situation, this is referred to as decision basis (National Research Council, 2002). Decision basis is made up of three elements:

- Knowledge of the situation
- Options for the decision
- Desired outcome

The use of models is important when considering various options for any engineering decision. Models help represent complex options, and simplify the task for the decision maker. Figure 3 summarizes the relationship of the previously mentioned elements in the decision basis. The frame is the condition surrounding the decision. It is clear that the decision maker is the link that must input the three elements and output the decision. If the three elements are unbalanced, the stool will not support the decision maker, and a bad decision will be certain to result.

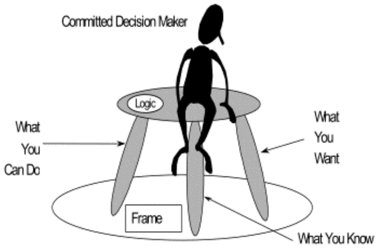


Figure 3: Typical decision (National Research Council, 2002)

The engineering design process cannot be automated, as problems arise that only an individual can deal with. Problems that arise in the engineering design process are three-dimensional; they exhibit uncertainty, complexity, and may be time-dependent (National Research Council, 2002). Conventional analysis tools and computer-based tools help engineers reduce the uncertainty and complexity of a problem, while decreasing lead-time to a manufacturable product. Computer software designed to streamline the modeling process and simulate finished products can be broken down into three types:

- Solid modeling software
- Kinematic software
- Dynamics software

Solid modeling software, typically referred to as computer aided design (CAD), allows the user to create parts in a three dimensional environment, and packages typically allow for assembly of various components, weldments, and fasteners, as well as output to drawing format. The benefits of CAD software is that it allows engineers to make quick changes to final designs, as well as use the solid models for various static and dynamic analyses, as well as serve as an input for computer aided manufacturing (CAM).

Kinematic software is used to visualize motion and physical interferences. Finite element analysis (FEA) packages may be included with either CAD or kinematic software. Dynamics software is similar to kinematic software, except that it included the necessary algorithms to analyze dynamic loadings, accelerations, and stresses while a component is in motion.

The purpose of solid modeling and kinematic software can be summarized as follows (Engineer's Handbook, 2006):

- Simulate mechanisms to help zero in on a workable design.
- View physically-realistic animations to spot hitches and study aesthetics.
- Find interferences among moving parts--and fix them immediately in the same system.
- Verify an entire mechanical system with numerous and even unrelated moving components.
- Plot out motion envelopes for designing housings and ensuring clearances.
- Create animations of assembly sequences to plan for efficient manufacturing.
- Generate accurate load information for improved structural analysis.
- Calculate required specifications for motors, springs, actuators, etc. early in the design process.
- Produce animations for output to video or posting on web sites to show customers and clients how a product will *really* work.

Current Design Process at CIS

CIS currently makes use of a design process that relies heavily on the experience of its engineers. Creativity is dependent on its engineers, and a process for conceptualizing new designs has not been standardized. The process at CIS is as follows (Sosnovsky, Windsor, Yunfei, Qi,, & Xiaobo, 2007):

1. Simple feature requirement (e.g. lock slides when open, manual release to close)
2. Concept (from engineer experience and sketches)
3. Design Calculations (free body diagram and analysis of loads and forces)

4. Design solid model (Pro-E 3D model)
5. Finite element analysis of critical areas (Pro-Mechanica)
6. Prototypes and testing
7. Manufacturing feasibility and cost
8. Final design

In addition, CIS provides its engineers with a guidebook illustrating common existing slide mechanism designs as well as a computer database containing all existing slide components.

Objectives & Methodology

Introduction

The goal of this project is to implement a standardized design process for linear slide mechanisms at Central Industrial Supply to increase design creativity and reduce design time. Central Industrial Supply currently relies on its engineering experience to conceptualize designs, rather than a standardized design process. To achieve this goal, the following objectives were created:

1. Develop a design process focused on the conceptualization of linear slide mechanisms, incorporating the usage of software into the conceptual design stage.
2. Create an understandable design process manual for CIS engineers.
3. Design a rear lock mechanism for an existing slide using the proposed design process manual.
4. Redesign a rear lock mechanism using the proposed design process manual.
5. Create prototypes for both designs, and test to evaluate their functionality, performance, and durability.

It is important to note that previous CIS MQP work was provided to the team and used as starting point for this year's project. The purpose of this year's methodology was to continue with last year's findings and revise it as necessary to be truly useful at CIS. Thanks to the 2007 MQP, the team had a solid framework to build and improve upon.

Developing the Design Process

At the beginning of the project, the design process suggested by previous MQP work was thoroughly discussed and summarized. Once the process was understood, problems were identified that prevented CIS from implementing the suggested design process. The following problems were identified:

1. Design process is not concise: 90 page report
2. Very detailed, but there is no summary or guide to help CIS understand how to make use of all the research
3. Design process is specific to only one component (out of 9)
4. Design process does not make it clear on when and how software should be used

Based on the above four problems and after discussion with CIS, it was determined that a design process manual was necessary to:

1. Concisely instruct an engineer through the design process
2. Apply the standardized design process to all linear slide mechanisms
3. Instruct the engineer on *when* and *how* to use conceptual design software

The design process was developed by adopting the proposed 2007 design process and revising it to satisfy CIS' needs. The revisions were based upon researched conceptual methods, communication with engineers, results from a survey created for CIS design engineers, a comparison of design processes, and the usage of conceptual design software.

Creating the Design Process Manual

In order to implement the developed design process, a design process manual was created. The manual was created with the goals of being easy to use and effective. Existing design process manuals were researched, along with literature documenting effective flow chart creation.

Testing the Design Process Manual

In order to demonstrate the usability of the design process manual, a new rear lock was designed and an existing rear lock was redesigned using the proposed manual. The test also pointed out the areas that needed improvement in the design process manual, which were made in subsequent drafts of the manual. The success of the designed rear lock points to the notion that the manual can guide an engineer to create a mechanism that meets functional and structural requirements while promoting creativity and reducing design lead time. For a more detailed look at the testing procedure used refer to Appendix E.

Prototyping and Evaluation

The new rear lock design was prototyped in order to visualize and confirm its functionality, performance, and durability. Before the rear lock was prototyped, the solid models were modified to reduce to prototype lead time. The use of pins and small machined parts were favored over stamping processes that would require custom tooling. The rear lock was assembled and incorporated into the existing slide mechanism to allow for testing and demonstration.

Another slide lock was prototyped according to the changes suggested by the redesign process. These changes were made on a provided QualSlide slide mechanism. The changes were made on the manufacturing floor, using grinding equipment.

Once prototyped, the slide mechanisms were delivered to the quality control department, to undergo standard CIS testing procedures. A test plan outlining the whole process was presented to the engineers as well. The testing process consists of functional, performance, and durability tests, as shown below:

- 200 operation cycles (functionality)
- 10 push/pull force measurements (performance)
- 2000 operation cycles (durability)

The tests were conducted with each slide, with no loading (only the lock operation was of interest), and the open-close cycles were performed by a quality control department employee. The purpose of the initial 200 cycles is to break-in the mechanism, to obtain consistent operation before the push/pull forces are measured. The push/pull forces define the minimum force required to engage and disengage the rear lock. The final stage of the test consists of 2000 cycles, which demonstrate the product's durability.

The push/pull force measurements for the redesign prototype was conducted slightly differently than the other slides; the chassis member was extended slightly before the intermediary member was extended, as the purpose of the redesign was to reduce pull force under that condition. Details on the redesign concept can be found later in the report.

Evaluations of the prototypes were done using the above mentioned functional, performance, and durability characteristics, as well as a qualitative assessment by CIS' lead design engineer. The qualitative assessment was an open-ended question, probing for feedback on the creativity of the prototypes. Results of the testing are discussed in the Analysis chapter.

Revised Design Process

Problem Identification

The customer initiates the design process by requesting a product that can be either customized from an existing product or a new design. After receiving the order, a categorized list of customer specifications must be developed through communication with the sales engineers and the customer. Next, a problem statement should be made for the slide mechanism. The purpose of writing a problem statement is to establish accuracy and clarity for the scope of the project. The problem statement should specify as much as possible the characteristics, limitations, and applications of the problem.

The next part of problem identification is the creation of a goal statement for the design. In order to do this, functional and structural requirements should be identified. Functional and structural requirements include:

- Dimensions
- Weight
- Movement and locking functions
- Strength
- Push/pull force to operate
- Additional customer specifications- quality standards, material, plating and painting

Background Research

The term 'background research' refers to studying the collection of previously published and unpublished information about slide mechanism, such as determining what work has been conducted in the field and what other designers have created. This step is necessary to ensure that CIS designs are original and purposeful.

In this step, engineers search in the existing design database to check whether any of the existing designs satisfy the functional requirements. If there are existing designs that satisfy the functional requirements, they should be used, provided that a new design is not a customer requirement. If there are existing designs that satisfy most of the functional and structural requirements, they should be considered for redesign. If a completely new mechanism is required, then research for existing patents on slide mechanisms with similar parameters must be conducted to ensure that CIS will not infringe upon existing designs.

At the conclusions of the background research stage, the engineer has a thorough understanding of the problem, design restrictions, and design task.

Redesign

The redesign process is used when there are existing designs that satisfy most of the new functional and structural requirements. The purpose of redesign is to reduce lead time by using an existing design as a starting point.

The first step in redesign is to select the most feasible mechanism for redesign. All of the knowledge of structural and functional requirements comes from the previous background research process, as well as knowledge of existing feasible designs for redesign. In order to select the optimal mechanism for redesign, a series of *design dependency matrices* should be compared. The design dependencies will identify faulty performance and design parameters for each feasible mechanism for redesign. The mechanism with the fewest (or requiring least amount of time to fix faulty parameters) faulty parameters should be chosen for redesign. The design dependency matrix also indicates the order in which the parameters should be redesigned. Refer to the following section for detailed instruction on creating a design dependency matrix.

The next step, after selecting a mechanism for redesign, is to conduct the detailed design process to ensure that the slide mechanism meets the customer's requirements. The order in which changes are made to the mechanism should follow the order recommended by the design dependency matrix. The detail design process determines the shape and size of components, using computer aided design software.

Next, after the detail design is complete, the engineer must check the practicality of the design. To do this, all necessary parameters for functional requirements should be identified, and then the functionality of each component should be identified. With this information, the engineer should eliminate non-functional components for the purpose of *value engineering.* These changes should be made to the solid models using computer aided design software.

Then, the solid models must be checked for reliability and strength using finite element analysis software. If the component performance is not acceptable, then necessary design changes must be made to the solid model. Once the model is acceptable for reliability and strength, the mechanism can be prototyped and tested. At this point the design process is complete, and the mechanism is ready for manufacture.

Design Dependency Matrix

As previously mentioned, the design dependency matrix is a useful tool that will shorten lead times in during the redesign stage, by determining:

- Performance parameter dependency on design parameter
- Optimal order for making changes to parameters during redesign

- Faulty design and performance parameters

The following steps summarize the DDM creation and usage:

1. Create list of design parameters and performance parameters of the component to be redesigned
    - The design and performance parameters can be both qualitative and quantitative, but the design parameters must be independent of each other. The performance parameters should indicate the customer's specifications.

2. Create a matrix, with design parameters as columns, and performance parameters as rows
    - The purpose of the matrix is to quickly synthesize a large amount of design parameters (hence rapid redesign). Marks should be entered in a box at the intersection of the row/column of interest. A mark indicates dependency.

3. Check/verify DDM
    - The DDM should be checked, as in many circumstances, multiple performance parameters will be dependent on one design parameter.

4. Decompose matrix to create a 'banded matrix'
    - The purpose of decomposition is to rearrange the rows so that the shaded 'dependencies' form a diagonal band that will exhibit groupings referred to as 'chunks.' Decomposition should be done in a program such as Microsoft excel.

5. Identify faulty parameters and correct.
    - Performance parameters that do not meet requirements must be corrected. Typically, one or two faulty performance parameters are acceptable to continue with rapid redesign. If more than two faults exist, a new design concept should be reconsidered.
    - If changes are made to parameters in the DDM, neighboring parameters (especially if 'chunks' overlap) may also be affected, and the DDM should be rechecked.
6. Interpret decomposed DDM to find most efficient order for redesign

- The order of the shadings should be read left to right, and should follow the diagonal pattern. The ‘chunks’ represent independent groupings and so the DDM does not point to the order that the chunks should be looked at. Faulty parameters can be highlighted on the DDM by highlighting the rows and columns that contain the faulty parameter.

Workspace Definition

When there are no suitable models for redesign, a new design must be created. Workspace definition is the first step in the new design stage. Workspace is the available design space, and usually has several conditions for its definition. For example, the workspace for a locking element has three types of space: the space which is available to the locking element in any state, the space which is available to the locking element only in the locked state, and the state which is completely unavailable to the locking element. The purpose of workspace definition is to ensure that the physical layout of slide mechanism components is planned, prior to detailed design. Properly defining these physical constraints improves efficiency of the design process, as it ensures that the design remains physically feasible. Before the workspaces are defined however, the types and number of standardized mechanisms needs to be identified. For example, the engineer may determine that a front, staging, and rear lock are needed, based on data from the problem identification step. Once these basic necessary components are identified, a physical workspace for each component can be defined.

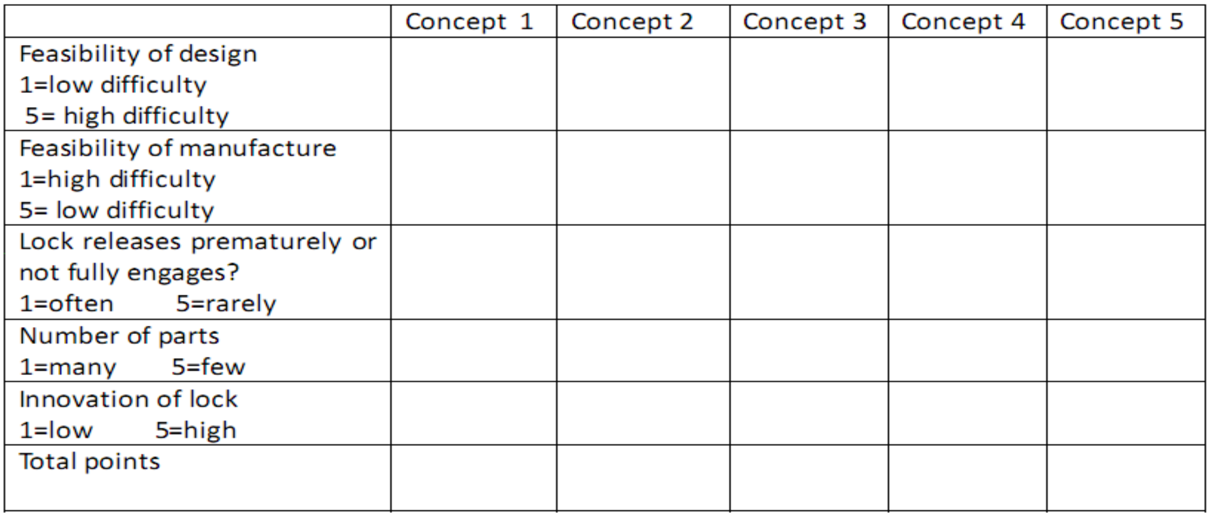
Then, define how many locks should be used in the linear slide. A linear slide can have up to four different locking mechanism, the front locking mechanism, the rear lock, the staging lock and the disconnect mechanism. The front locking mechanism is the mechanism that locks the chassis and intermediary members together when the chassis member is fully extended, and lets the user manually release the lock. The rear lock is the mechanism that locks the intermediary and the cabinet members together when the intermediary member is fully extended out of the cabinet and the chassis is being extended. The staging lock is the mechanism that locks the chassis and intermediary member together when the intermediary member is not fully extended out of the cabinet. On some slide designs there is a disconnect mechanism, which allows the user to completely pull the chassis member out of the intermediary. The composition of the slide lock should be decided based on the customer’s requirement. After defining the locks that may be used, engineers should define the locks’ position along the length of the slide.

New Concept Development

After completion of the workspace definition steps, and it is determined that a new design concept is necessary, engineers must begin the brainstorming stage. If an entire slide mechanism is being created, the mechanism must be considered in components, and each component can then be conceptualized separately. For each component, the combination of sketches and conceptual design software must be used to develop multiple component concepts. The usage of Working Model 2D is recommended, and its specific usage is described in Appendix D (Engineer’s Manual). The purpose of

Working Model 2D is to be able to draw mechanisms, and quickly simulate their motions and responses to applied forces.

After several concepts have been developed, only one concept must be chosen to fully develop into a detailed design. This evaluation can be carried out by use of a decision matrix. An evaluation matrix is a standardized method for evaluating characteristics of each concept. Examples of characteristics would include feasibility of design, feasibility of construction, predicted performance, and predicted durability. An example of an evaluation matrix is shown below.



	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Feasibility of design 1=low difficulty 5= high difficulty					
Feasibility of manufacture 1=high difficulty 5= low difficulty					
Lock releases prematurely or not fully engages? 1=often 5=rarely					
Number of parts 1=many 5=few					
Innovation of lock 1=low 5=high					
Total points					

Figure 4: Evaluation matrix example

As shown above, each characteristic to be evaluated occupies a row in the matrix. Also, each characteristic receives its own scale, such as 1 to 5, or 1 to 3. Higher numbers are more favorable than small numbers. In this way, characteristics can be 'weighted' more heavily than less important characteristics. Once all the concepts are evaluated and marked in the matrix, the sum of the ratings in the columns are summed, and recorded in the bottom row of the matrix. The concept that should be chosen is the column with the greatest number of total points.

Next, engineers must use CAD software to create a detailed design of the chosen concept. This process should be iterated for each component of the concept until all the components of the slide mechanism have been finished. At the conclusion of this step, the engineers will have a set of solid models that will be assembled and tested using finite element analysis (proceeding steps).

Solid Model Assembly and Finite Element Analysis

At this point, the engineer has a set of solid models for the linear slide components. Now, the solid models must be combined to form subassemblies and assemblies. The software recommended for this is Pro/Engineer, as it is a powerful CAD software that is already used at CIS. Much care should be taken to properly reference and mate the solid models, so that components can be edited and removed easily. The assembly must be checked for interferences in the Pro/Engineer. If there are interferences, changes must be made to the components.

After sufficient clearance is confirmed in the assembly, finite element analysis must be conducted on the assembly, using Pro/Mechanica. The assembled slide mechanism must be tested at both the retracted and fully extended positions, to confirm structural stability. Factor of safety (FOS) should be determined while performing the FEA tests. Once the structural characteristics are acceptable, the design can be prototyped, tested, and necessary changes made to the design. At this point, the design process is complete.

Analysis

Design Process

The effectiveness and feasibility of the developed design process was investigated by using the process to create a new rear lock mechanism. Testing the manual allowed the team to identify the key areas within the design process that needed improvements. Revising the developed design process resulted in further improvements. The problems discovered while designing a new rear lock mechanism included:

- New concept development (concept generation with Working Model 2D)
- Concept evaluation matrix (need for more applicable evaluating factors)
- Need for simultaneous design of components, especially with locking and release mechanisms

New Concept Development

During this phase, the designer is instructed to use conceptual design software to visualize new concepts, especially with regard to locking element movement. The usage of software allows visualization of mechanisms with multiple linkages and degrees of freedom. The initial design process did not include a procedural process for the engineers to learn how to use the software in an effective way. Using Working Model 2D during the process involved understanding linkages between various components, viewing their motion and how they relate to each other within the mechanism. Working Model 2D was user-friendly and its effective concept generation allowed for creativity as well as understanding of the interaction between the mechanism components. It also allowed the team members to explain their concepts to each other, with minimal explanation and confusion.

Concept Evaluation Matrix

When creating a new lock it is important to be creative and innovative. One way to ensure the development of a successful mechanism is to develop many concepts, and then choose the best concept by using a concept evaluation matrix. The concept evaluation matrix is a rating scale that assesses each concept on a variety of aspects before the design is modeled in a CAD program. It decides which concepts are the best solutions to the overall problem. The concept evaluation that was used during the test could have been more specific to performance and rear lock design if the CIS design requirements were more specific. For future designs, CIS engineers should define the requirements as specifically as possible to help create a detailed concept evaluation matrix.

Simultaneous Design of Components

A linear slide consists of a variety of locks which have both a locked state and a released state. During conceptual design, a designer must consider multiple components simultaneously to develop a functional design. This was apparent when designing the locking elements, as the releasing elements needed to accompany their locking elements. Unfortunately, the 2007 design process forced the designer to create the locking mechanism before the release mechanism, rather than design the two simultaneously.

Prototype

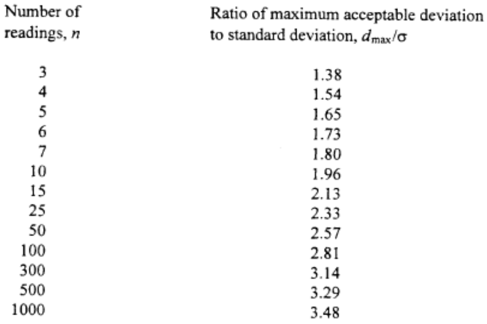
Creation

The new rear lock was prototyped with the assistance of a CIS engineer. The solid models were revised slightly so that the shapes could be machined and attached via a combination of pins and adhesive. Loctite 688, an anaerobic adhesive, was used for joining metal components. The components were machined, ground, and installed on the existing slide mechanism. The placement of the rear lock was relocated, as CIS did not have any unstamped intermediary and cabinet members available at the time, due to production line configuration.

Testing

As outlined by the Prototype Test Plan, which can be found in Appendix F, the testing evaluated the prototype's functionality, performance, and durability. Functionality was confirmed by operating the slide mechanism through 200 consecutive cycles. Performance was measured by taking 10 push/pull force measurements every 200 cycles, and durability demonstrated by operating the slide mechanism for 2000 cycles. Keep in mind that these push/pull forces were measured dynamically, so the force required to engage a static slide mechanism would be much higher than a moving slide mechanism. Also, the material used for creating the prototype rear lock components was different than the material used in the manufacture of the existing rear lock. The prototype material had a higher coefficient of friction, possibly due to the lack of polishing or electroplating. Static friction could have been reduced by plating the components, or by applying a low-friction coating to the components.

When analyzing the push/pull force data collected by the CIS quality control employees, some of the data points were rejected when calculating the mean push/pull forces. 8% of the data was rejected (5 out of 60 points). The data was rejected according to Chauvenet's criterion (Furlong, 2008). Chauvenet's criterion rejects data statistically, based on the amount of data available. An acceptable interval is created for each set of measurements, using the standard deviation and a value determined by the number of data points measured. See table below for Chauvenet's values (Furlong, 2008).



Number of readings, n	Ratio of maximum acceptable deviation to standard deviation, d_{max}/σ
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

Figure 5: Chauvenet's criterion for data rejection (Furlong, 2008)

The value of each measurement was compared to the acceptable range of values: d_{max} is the distance of any given data point to the mean of the data set. In one instance d_{max} was calculated to be 0.984 lbf. This means that any measurement 0.984 lbf beyond the mean should be rejected from the data. The graphs in this analysis section show all data points to illustrate the variation of measurements over the 2000 cycle tests. Mean values are also indicated on the graphs, using the corrected data (Chauvenet's criterion). Variation in measurements can be attributed to unpredictable variations in the testing methods- such as the speed at which the slide locks were operated.

All three lock mechanisms (existing, new, redesigned) passed the functional tests. When examining the push forces required for the three locks, the new rear lock mechanism required the least amount of force. The new rear lock reduced the average push force by 4.4 lbf. No noticeable differences were observed between the redesigned rear lock and the existing rear lock, as the release mechanisms were identical.

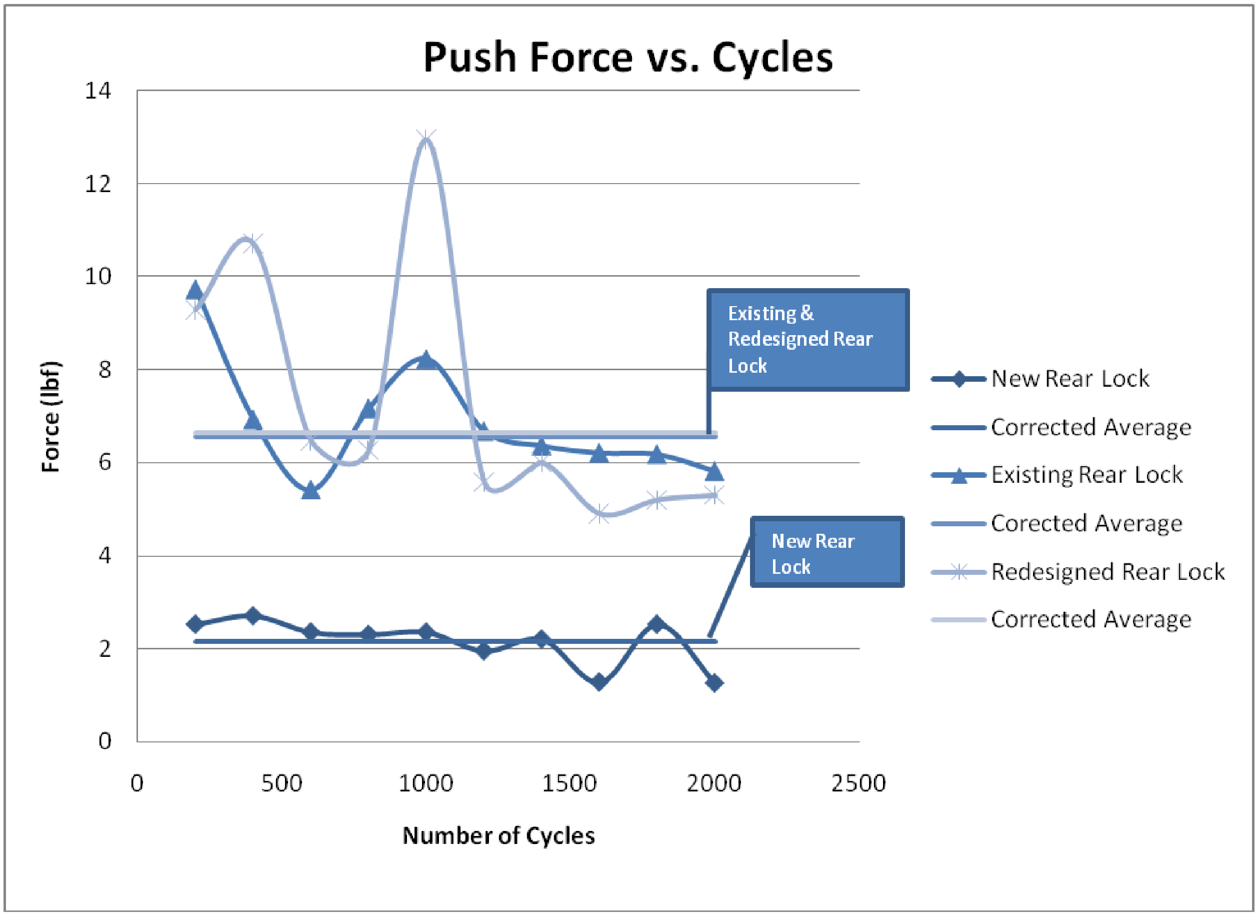


Figure 6: Push Force Results

Pull force characteristics also improved with the new rear lock: average pull force was reduced by 3.65lbf. The redesigned rear lock exhibited higher pull force however, which was unexpected. It was hypothesized that the pull force would decrease after the redesign, as the binding contact area was removed. The higher pull force (0.5 lbf higher than the existing rear lock) could be the result of manufacturing variations. These manufacturing variations exist in the friction between the intermediary and cabinet members, in the ball bearing slide interface. Bend angle variation for the sheet metal used for the sliding surfaces can result in a slide that feels 'tight' and requires more pull force. For future testing, this variation could be avoided by measuring the pull force of the slide mechanism before modifying it to redesign specifications.

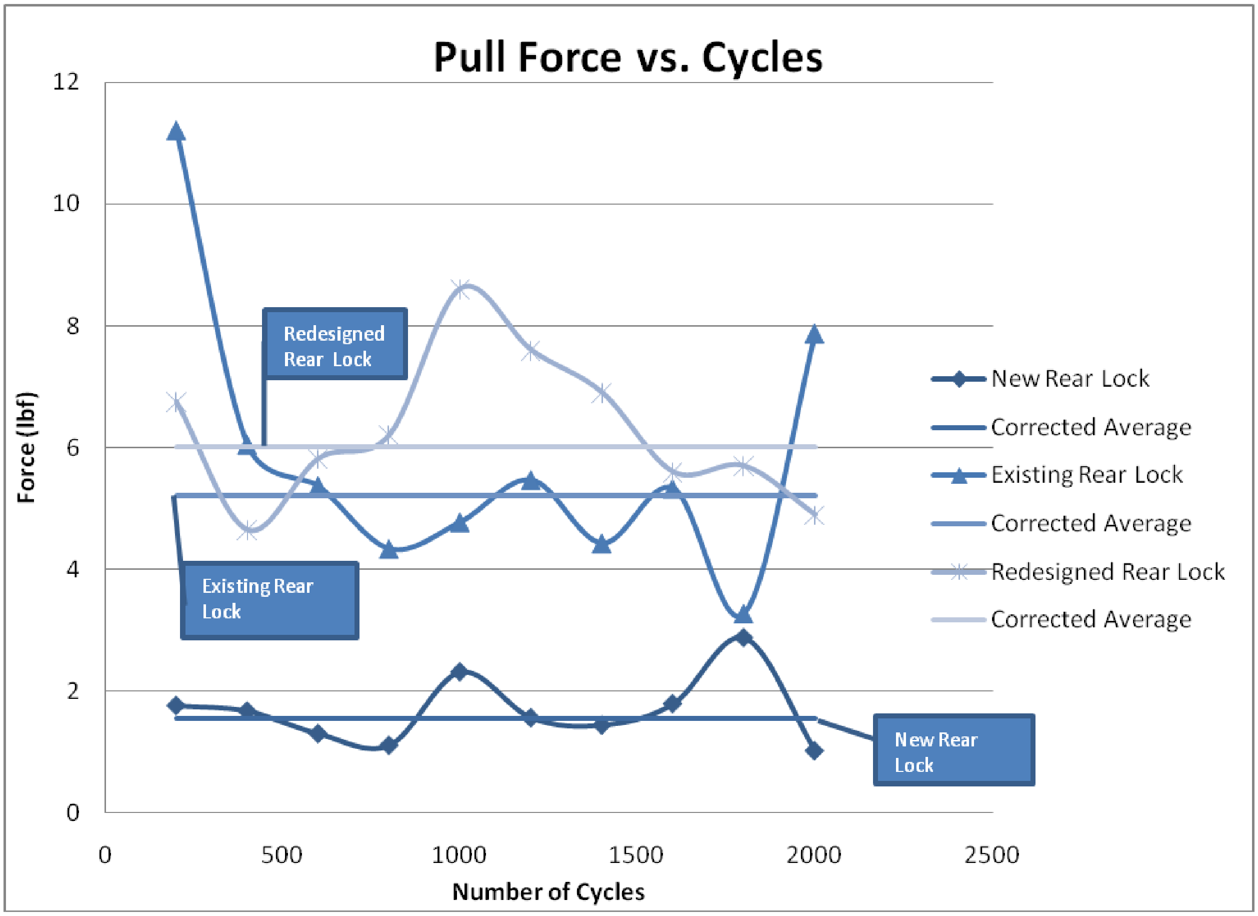


Figure 7: Pull Force Results

Characteristic	**New rear lock**	**Redesigned rear lock**
Fully extends, locks, & retracts	100%	100%
Push force reduction	67%	1%
Pull Force reduction	70%	-15%
Passes CIS 2000 cycle test	100%	100%

Figure 8: Test Results

Conclusions

The design process was found to be an effective and feasible methodology for designing linear slide mechanisms, as a new design and redesign were fully developed using the documented process. The developed ‘Engineer’s Manual’ is an effective tool for CIS design engineers, as it was used to create a new rear lock mechanism that reduced push/pull force by about 68%, while satisfying standardized quality standards at CIS. Furthermore, the usage of conceptual design software, specifically Working Model 2D, is a critical tool in the design process that can be used to enhance creativity and reduce lead time during the design process.

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Appendix A: Mini-focus Group and Survey Plan

A focus group in the business setting is typically a randomly selected group of 8 to 12 customers who are invited to speak in a led discussion with a business leader (Timm, 1994). For the scope of this project, the customers will be the CIS design engineers who will be using the team's deliverables. There are several advantages to a focus group (Timm, 1994).

- The focus group typically brings in outside ideas from the end user of an organization's goods or services. In this situation, the end users are engineers.
- Since the "interviewer" does not ask questions or record answers in a traditional sense, he acts as a discussion leader to direct and focus the group discussion toward the issues being researched.
- As the focus group discussion begins to evolve, it is hoped that a spontaneous interchange of ideas will result with a wide variety of insightful and useful data.

A mini-focus group will be led by one team member with CIS engineers. The form of the focus group will be structured, and the leader will ask a set of questions that are aimed to get the most information as possible during a 20 or 30 minute discussion. The purpose of the discussion, rather than a survey, is to encourage open-thinking about the proposed design manual. The discussion aims to gather ideas about what should be included in the manual. While the team already has a plan for the engineer's manual, feedback from the engineer's themselves is critical, since they are the intended users. Without the discussion, the final engineer's manual could turn out useless.

There are several suggestions from (Timm, 1994) for the discussion leader of a focus group. They can be summarized as follows:

- Be alert mentally for feedback. If questions are not understood by the participants, ask them differently.
- Do not hesitate to ask for clarification in a non-threatening way such as "I'm not clear on what you are saying. Can you help me understand that better?"
- Avoid disagreement, even if one of the participants is saying something inconsistent with previous statements. Instead, use probing questions seek clarification. Disagreement may result in the participant becoming defensive, and will stall progress.
- Remain a nonjudgmental listener at all times.

In addition to the mini-focus group, a survey has been created to answer specific questions that do not need the leadership of a focus group discussion.

Another set of questions is devised into a ten-question survey, for the CIS design engineers in Singapore. The survey is aimed at answering questions pertaining to how software is currently used, the shortcomings of the software, and how the engineers see software being used in the future. Below are some main advantages to the survey being used, as (Timm, 1994) points out:

- They consume fewer resources.
  Surveys are not as labor-intensive and once designed, a questionnaire can gather a large quantity of data without requiring a lot of employee time.
- They are easy to administer.
  Since the questionnaire requires a written response, they only need to be either printed and distributed, or emailed.
- Responses may be kept confidential.
  Data may be more accurate, since most respondents will be frank and honest when their answers are anonymous.
- Data is quantitative and easy to process.
- Answer may be of high quality.
  Since respondents may take time in thinking about the appropriate response, and not be faced with pressures of an in-person interview.
- Management is more likely to be receptive to the questionnaire approach.

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Appendix B: CIS Design Engineer Survey

1. How would you rate your skills with CAD software on a scale from 1 to 10, 10 being the highest?
2. How would you rate your skills with FEA software on a scale from 1 to 10, 10 being the highest?
3. What software do you currently use when developing new concepts for locking mechanisms?
4. When not using software, what mathematical tools do you use to determine forces, applied loads, angles, coupler curves, etc.?
5. What software limitations do you currently face? Be specific.
6. How would you like to see software used in the future at CIS
   a. Do you think conceptual programs such as Working Model 2D would be useful during new concept development for locking mechanisms?
7. Does the current design process encourage creativity?
8. What is the most time consuming part of conceptual design?
9. Do you think a design process manual would be a beneficial tool?
10. What is one thing you would like to see in this type of a manual?

Appendix C: Survey Results

1. How would you rate your skills with CAD (ProE) software on a scale from 1 to 10, 10 being the highest?

A: 8.5
B: 8
C: 7
D: 7
E: 8 for soild and sheetmetal modeling. Beginner for surface modeling.

2. How would you rate your skills with FEA (ProMechanica) software on a scale from 1 to 10, 10 being the highest?

A: 8
B: 6
C: never learn
D: 5
E: 6. We only use Pro-Mechanica for FEA when there is a customer request or for solving critical issues

3. What software do you currently use when developing new concepts for locking mechanisms?

A: proe
B: ProE
C: ProE**.**
D: ProE.
E: ProE. I would think of some design concepts and sketch them out. After that, I would model each part needed for the design concept to build up the virtual mechanism. I would then do simple position simulation of the mechanism at various critical stages.

4. When not using software, what mathematical tools do you use to determine forces, applied loads, angles, coupler curves, etc.?

A: formulas
B: formulas
C: Formula such as Load and deflection measurement.
D: Applied Mechanical & Math's
E: I would do basic engineering calculation such as load, force, spring calculation, etc.

5. What software limitations do you currently face? Be specific.

A: time consume to build 3D model in conceptual phase
B: Mechanism simulation
C: Software which able to simulate movement of a mechanism
D: Time constraint
E: ProE can only model object not interactive at mechanism concept generation.

6.How would you like to see software used in the future at CIS

a. **Do you think conceptual mechanism design programs such as Working Model 2D would be useful during new concept development for locking mechanisms?**

A: might be, depends if it is user friendly.
B: yes, it will be useful for mechanism simulation.
C: Solidworks. Yes. Working Model 2D able to run, refine simulations with pre-defined objects and constraints which will determine more realistic/clear results.
D: It might be, but all are depends on the software user friendly and the designer skills.
E: I strongly believe custom mechanism design software can help in developing mechanism concept.

7.Does the current design process encourage creativity?

A: sometimes
B: sometimes
C: Occasionally. If times permit, it will be good if we are able to have a project (CIS R&D work) mainly to create new mechanism or to improve existing mechanism. This will allow us to involve more creativity works.
D: Yup.
E: Not really as we tend to design based on experience.

8.What is the most time consuming part of conceptual design?

A: locking latch
B: Find the correct concept to the solution
C: The process of translating requirements into a user interface design.
D: Locking System and Time constraint
E: Coming out with preliminary design conceptual that is original in design

9.Do you think a design process manual/guide would be a beneficial tool?

A: definitely
B: depend on the content of the design process guide.
C: To starts off a new design project, there are steps in the design process to follow that will be able help a person to achieve the best results.
D: Definitely yes
E: Definitely, it will guide the engineer to develop design in a systematic way with thorough consideration in most aspects of design.

10.What is one thing you would like to see in this type of a manual/guide?

A: a summary list of existing mechanism conceptual detail as long as we can find or searched from internet
B: competitor product detail photo on some important portion.
C: Problem solving for example, conceptualizing and documenting design solutions.
D: A detailed of the design constraints of tooling, material properties, and mechanism of mechanical movement.
E: Design concept innovation, useful engineering calculation models would be 2 vital features.

Appendix E: Testing Procedure for the Engineer's Manual

The following test plan outlines our strategy to assure that the evaluation of the Engineer's Manual created will cohere to the requirements of the design engineers. The design process manual consists of a concise step by step process to create linear slide mechanisms at Central Industrial Supply. The creation of this manual is to serve as a standardized guide for design engineers to work in a more efficient manner while continuing to keep their creative and innovative characteristics. In this test, five students will act as design engineers, and will go through the entire manual step by step to create a completely new linear slide mechanism. The test will identify the extent to which the:

- functional requirements are met
- structural requirements are met
- design process promotes creativity
- design process promotes manufacturability

Methodology

The main feature to be tested within the Engineer's Manual consists of a flow chart procedure with descriptions of each step within the process. To prove the effectiveness of these steps and understand whether they pass or fail CIS criteria, the following testing procedure will be followed:

1) Receive functional and structural requirements from CIS
2) Use drafted design process to create a creative linear slide design including all components (these components will be split up amongst the team, to simulate the CIS engineering environment with multiple engineers working on a single project):
    a) Cabinet member, Intermediary member, Chassis member
    b) Front lock, Rear lock, Staging lock
    c) Release Mechanisms
    d) Housing
    e) Disconnect mechanism
    f) Self closing mechanism
3) Prototyping
    a) After sufficient finite element analysis on the finished slide, final design will be given to Chong Beng and the CIS prototyping team will create the physical model of the slide.
4) Grading and analysis
    a) The finished model will be graded using an established rubric.
    b) The team will analyze the problems that occur into within the process manual. These problems will be recorded throughout the design process.

Required Resources

The following software will be used:

Sam 5.1

Working Model

ProEngineer

ProMechanica

Testing Schedule

Approval:

Before beginning this test, the approval of Dennis and Chong Beng is required. Approval should occur by July 9, 2008.

July 10-18

-Creating a linear slide mechanism using design process manual

July 21-25

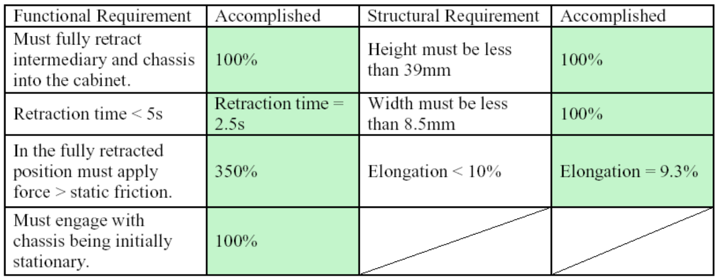
-Creation of the prototype physical model

-Grading and analysis

Grading Rubric

1. Grade performance based on functional and structural requirements

The same format of grading will be used as last year's case study



Functional Requirement	Accomplished	Structural Requirement	Accomplished
Must fully retract intermediary and chassis into the cabinet.	100%	Height must be less than 39mm	100%
Retraction time < 5s	Retraction time = 2.5s	Width must be less than 8.5mm	100%
In the fully retracted position must apply force > static friction.	350%	Elongation < 10%	Elongation = 9.3%
Must engage with chassis being initially stationary.	100%		

2007 Grading Rubric

2. Grade Creativity:

The final design must be original with innovative use of new concepts and redesigns. This is essential to understand any limitations that may occur within the process. This will be a qualitative grade given by Chong Beng.

3. Grade Manufacturability:

The design must be realistic to manufacture with CIS' resources. We will understand the manufacturability of our final design once we communicate with the prototype engineers

Test Deliverables

After the test, the team will include a performance based analysis of the Engineer's Manual in the final report. The grading rubric and scores will be included within the report's appendix. At the conclusion of the test the following will be available:

1.) A prototype of the designed linear slide mechanism.

2.) Analysis of the Engineer’s Manual and recommendations for its use.

Appendix F: Testing Procedure for the Prototype

The following test plan outlines our strategy to fully evaluate the quality of the newly prototyped rear locking mechanism. This rear locking mechanism was designed using the Engineer's Manual as a guide. The Engineer's Manual was created for Central Industrial Supply to serve as a standardized guide for design engineers to work in a more efficient manner while continuing to keep their creative and innovative characteristics. In this test a series of force and duty cycle testing will be performed on the physical prototype. This test will identify the functionality, performance, and durability of the rear lock. The results of this test will indirectly confirm the workability of the Engineer's Manual as well as identify problems within the process.

Methodology

To prevent any bias throughout this test, CIS testing engineers will conduct previously used standardized testing procedures to test the new rear lock design while addressing the following:

5) Functionality
    - Slide will be opened and closed to check proper engagement and disengagement of the lock. Rear lock must be functional to proceed with testing.
6) Performance
    - Rear lock engagement and disengagement force will be measured using a force meter. The push and pull force will be measured on one slide with no load.
7) Durability
    - The set of slides will be mounted on a server rack and the slides will be opened and closed (one cycle) 2000 times. A predetermined arbitrary load will be exerted on the set of slides, as decided by CIS testing engineer.
8) Grading
    - The finished model will be graded using an established rubric. (below)
9) Analysis
    - The team will analyze the problems that occur into within the process manual. These problems will be recorded throughout the design process.

Testing Schedule

Approval:
Before beginning this test, the approval of Dennis Koh Meng Kee and Goh Chong Beng is required. Approval should occur by July 22, 2008.

July 18-22
-Creation of the prototype physical model
July 22-23
    -Testing procedure
    -Grading functional and structural characteristics

Grading Rubric

4. Grade based on previously mentioned parameters

Table 1: Grading Rubric

Parameter	Accomplished
Functionality	Pass/Fail
Min Pull Force	# lbf
Min Push Force	# lbf
Cycles completed	# of Cycles

5. Grade Creativity:

The final design must be original with innovative use of new concepts and redesigns. This is essential to understand any limitations that may occur within the process. This will be a qualitative grade given by Chong Beng.

Test Deliverables

A summary including the following:

1) Completed grading rubric
2) Comments from CIS testing engineers

Appendix G: Engineer’s Manual Testing Summary

Problem Identification

Customer Specifications

- Remain part of QualSlide line
- New rear lock
    - Fully locks intermediate and cabinet members
    - Pull force to engage rear lock: less than current lock

Problem Statement

Customer needs a rear lock for an existing QualSlide mechanism that is unique from current CIS designs.

Functional Requirements

- Rear lock releases when chassis member is retracted into intermediary member.
- Rear lock must not interfere with the full movement of the slide- chassis and intermediary must fully retract into cabinet member.
- Rear lock must engage and release reliably and smoothly.
- Must adhere to standards.
- Durability- corrosion resistance. Should be same as other slide components (plated).

Structural Requirements

- Must fit within preset members of QualSlide US6, 979, 067 (chassis, intermediary, cabinet)
- Must be manufacturable into preset linear slide members with minimal impact to stamping procedure
- Geometric constraints for workspace: fit into existing lock

Goal Statement

Create a unique and innovative rear lock for an existing linear slide.

Background Research

Patent Research

Patents were researched using keyword searches that included: *server rack slide lock*, *server rear lock*, *server front lock*, *slide lock*, and *server rack slide*. Patents over 20 years old (from date of submission) were not included in research, as US patents expire after 20 years. Patents found include server rack slide applications very similar to those at CIS. The most relevant patents resulted by searching through competitors' patents. The competitors searched include King Slide and Accuride.

Research of Existing CIS Designs

We did not go into detail looking for existing designs that we could use for redesign, as the problem statement was already very specific- to create a *new* rear lock. The purpose of creating a new design was to become familiar with the usage of Working Model.

Workspace Definition

The available workspace was limited because of the fact that the rear lock was required to fit into an already existing slide. The workspace was determined by measuring (in ProE) non-interference spaces between the three members of the slide. Defining these dimensions gave us a good idea of the magnitude of the components to be designed. The figure below shows a solid model created to illustrate the workspace defined.

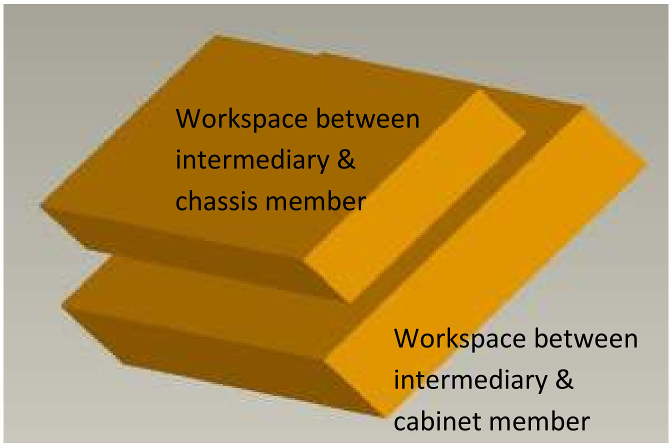


Figure 9: Defined workspace

New Concept Development

Brainstorming

After defining the allowable space in which the rear lock could be placed we began brainstorming lock concepts. During this step in the flowchart we kept in mind the functional features of the existing mechanism and sketched various lock ideas. Each team member created one lock concept and sketched it out on paper. This allowed us to come up with 5 lock concepts in a short period of time.

Locking & Release Mechanism Concepts

The concepts were drawn in Working Model to visualize the motion of each component in two dimensions. Working Model allowed us to view each concept in its released state, moving state, and locked state before deciding upon which idea was the best. Also working model allowed us to identify the components of the locking mechanisms and how they relate to each other. Using the conceptual software we were able to recognize the use of springs, chassis, intermediary, cabinet and the linkages that relate them to each other in each of its three states of motion.

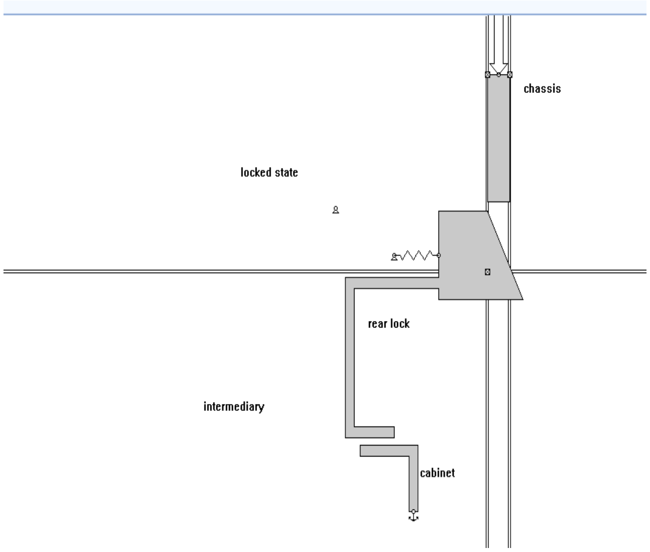


Figure 10: Locked state

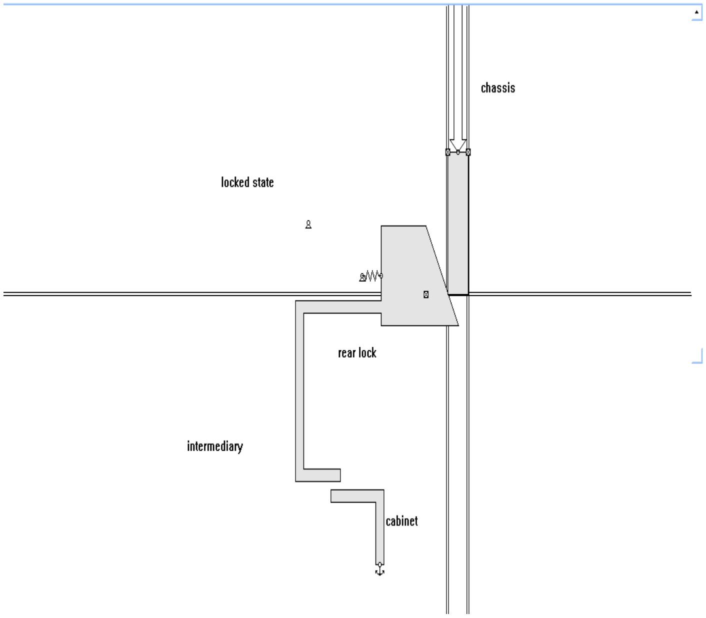


Figure 11: Moving state

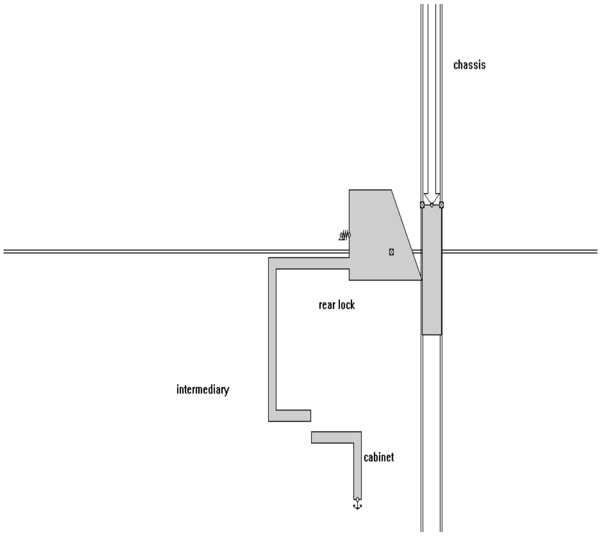


Figure 12: Released state

Concept Evaluation

After visualizing all of the concepts using Working Model, each team member explained his/her concept and with the use of the evaluation matrix we decided on which idea would continue to detailed design. The evaluation matrix used rating scales on a variety of issues concerning feasibility, innovation, and complexity. Each team member filled out the ratings and we totaled the scores of each concept to decide the winning design.

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Feasibility of construction 1=high difficulty to construct 5= low difficulty to construct	2.6	2.6	4.4	3.8	4.4
Number of parts 1=many 5=few	3.2	2.8	4.2	4	4.2
Innovation of lock 1=low 5=high	4.6	3.6	4.4	4	2.6
Feasibility of design 1=low feasability 5=very feasible	3.2	2.6	4.6	4.2	4
Likeliness to function without failure 1=low 5=high	3.8	2.6	4.2	3.8	3.6
Does lock fully engage and not unlock prematurely? 1=no 2=yes	2	2	2	2	2
Total points	19.4	18.8	23.8	21.8	20.8

Figure 13: Decision matrix used

Detail Design

After the concept was selected and modeled in Working Model, two team members developed the concept into a set of solid models. First, a list of necessary components was created, and the components were divided among the two members to design. The decided components were:

1. Slider w/ 2 pins
2. Return spring
3. Lock detent on cabinet member
4. Slot in intermediary member

Initial dimensions were agreed upon by experience, and necessary conditions to make a functioning lock. An assembly was created with the initial solid models and several issues came about as result:

1. Interferences of intermediary and slider
2. Placement of lock detent on cabinet member
3. Size and position of slots, pins, and springs
4. Necessary rounds on parts

After the assembly was created, the two team members worked together to make changes to the components and were able to immediately look at the assembly for interferences and feasibility. Few structural changes were made to the cabinet member, to accommodate a quick prototyping period. Focus was spent on the slider mechanism. The spring from the supplied slide was reused as well, to decrease prototyping time. If the rear lock does not meet performance specifications due to an inadequate spring, another standardized spring can be installed. Spring force calculations were avoided, as the focus of this test was to create a new working concept, rather than create *detailed* component specifications.

It is important to note that components were detailed simultaneously, and that it would have been very specific to create components individually, without consideration of behaviors with neighboring components. FEA analysis was not performed, as instruction of CIS.

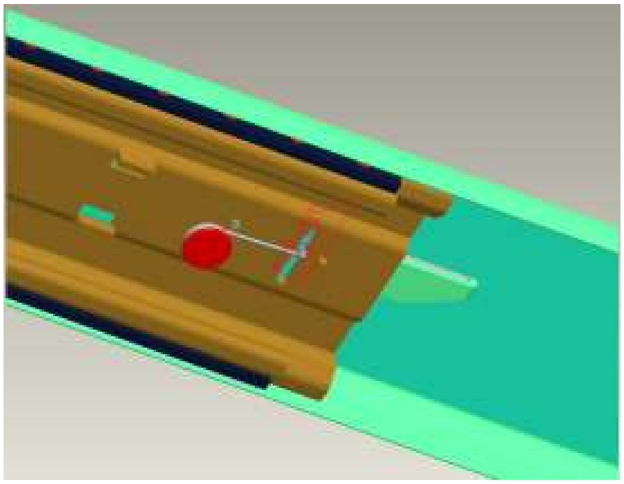


Figure 14: ProE assembly of new rear lock mechanism

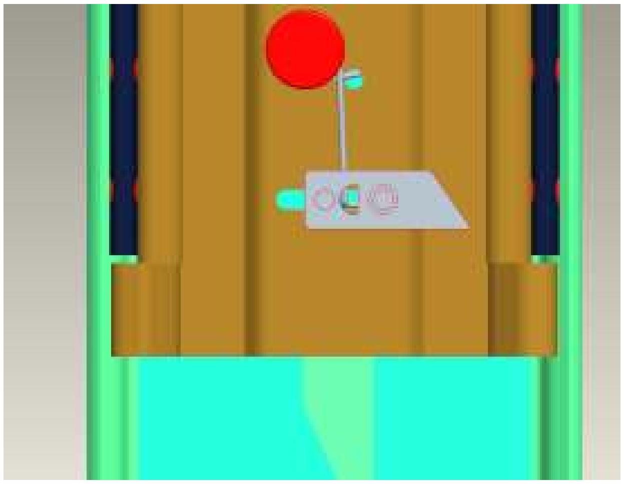


Figure 15: View of release mechanism

Appendix H: Rear Lock Redesign Procedure

Note: This redesign will be included in the final report, in addition to the already agreed upon deliverables.

Resources needed from CIS are:

1. linear force meter (small scale) for measuring pull force
2. Sheet metal cutters or grinding bit to remove about a 1cm square from the intermediary member

The team noticed that the current rear lock binds during certain circumstances. The binding is the result of the locking element contacting the intermediary member, adding a significant amount of resistance to the pull force required to fully engage the rear lock.

Note that this only occurs when the chassis member extends at least 1.5 cm before the intermediary fully extends. Since there is no staging lock in the design, the chassis and intermediary members may separate at any point while the slide mechanism is being extended. The rear lock was investigated, and the housing for the lock element was found responsible for the excessive binding. The housing consists of a series of cutouts (stamped) that allow for free movement of the locking element along its coupler curve. The locking element has three degrees of freedom- horizontal, vertical, and rotational. The rotation of the locking element is restricted by this housing, intentionally.

The team determined that the faulty design parameter was the shape of the housing, given the type of locking element. To reduce the binding affect, the team suggested that housing cutout be lengthened by about 8mm. The team will measure the pull force of the existing slide through a series of linear force measurements. Next the team will grind out the lock housing on the existing slide to the dimensions of those proposed. A new set of pull force measurements will be taken, and compared to the pull force of the original design. The goal is to significantly reduce the pull force experienced when engaging the rear lock when the intermediary has begun to extend before the intermediary has fully extended. If this improvement is deemed worthy of implementation at CIS, the team will prepare suggestions for steps to implement this manufacturing change with minimal impact to the current production.

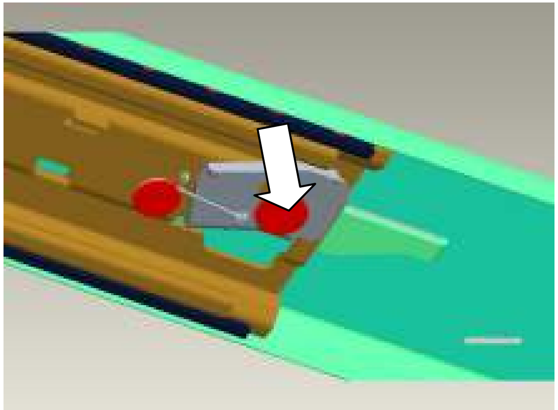


Figure 16: Lock element movement

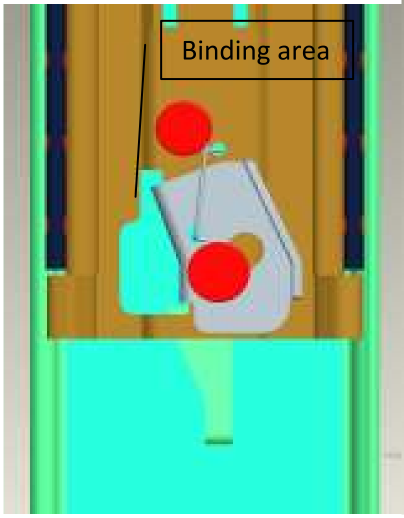


Figure 17: Existing rear lock

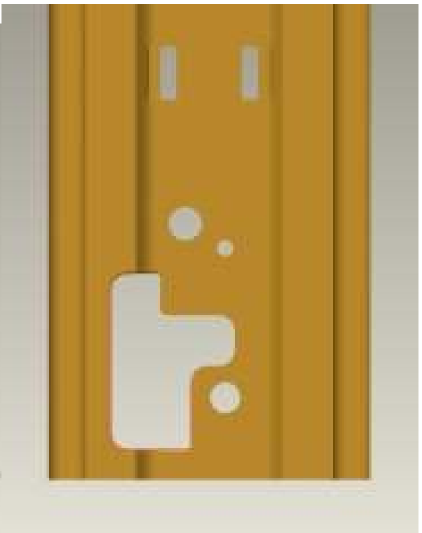


Figure 18: Housing area expanded to reduce binding

REAR LOCK	Lock Length	Lock Height	Lock Thickness	Number of Features of the Locking Element	Type of Locking Element	Manufacturing Tolerances	Staging lock used?	Dimensions of Housing in comparison to enclosed elements	Type of Housing	Number of Features of the Housing for the Locking Element	Number of Features in the Housing
Lock Manufacturability	▨	▨	▨	▨	▨	🟦			▨	▨	▨
Lock Geometric Constraints	▨	▨	▨			🟦					
Lock reliability	▨	▨		▨	▨	🟦		🟦			
Pull force to engage lock		🟪	🟦	▨	▨	🟦		🟦			
Push force to disengage lock		🟦	🟦			🟦					
Lock Scalability				🟦	▨	🟦			▨	🟦	
Chassis always extends AFTER intermediary member					🟦	🟧	🟧				
Tendency of binding/excessive friction					🟧	🟧		🟧	🟧		

Figure 19: Design Dependency Matrix for Redesign

A design dependency matrix was used to analyze rear lock design and performance parameters. Highlighted boxes in orange indicate the faulty parameters- those that need to be redesigned to satisfy the required functional requirements- to significantly reduce the pull force to engage the rear lock. Several possible solutions to reduce the pull force were devised:

1. Incorporate the use of a staging lock

The binding only occurs when the chassis member begins to extend before the intermediate member locks in the extended state. The use of a staging lock would ensure that the chassis member extends only after the intermediary locks in its extended state, which would avoid the binding conditions.

2. Modify the housing area to eliminate binding

Changing the dimensions of the area stamped out of the intermediary would eliminate the contact areas that are responsible for the binding. This would only address the binding issue, and would not change the likeliness of the chassis member to extend before the intermediary member.

3. Modify the locking element to eliminate binding

Changing the shape of the locking element would reduce the magnitude of the binding in the contact areas of the locking element and housing.

Solution 1 was rejected for the increased cost of manufacturing and the amount of design work needed to incorporate it into an existing product. Solution 3 was rejected as a significant amount of design work would be needed to modify the locking element, which would result in the manufacture of new locking elements (increased cost, and machine downtime to implement). Solution 2 was selected, for its simplicity. Relatively little redesign would be necessary, and the changes would have negligible effects on the manufacturing process. The necessary changes to the design process would be machining a new die punch for the locking element housing in the intermediary member.

Appendix I: CIS Linear Slide Mechanisms

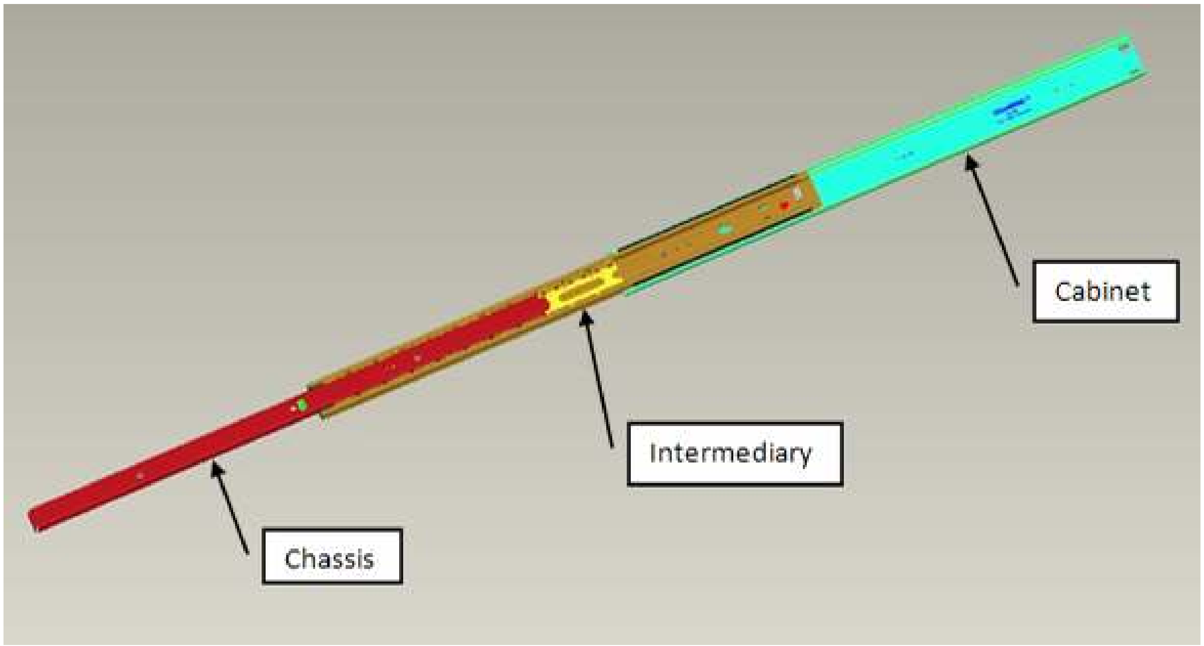


Figure 20: CIS QualSlide

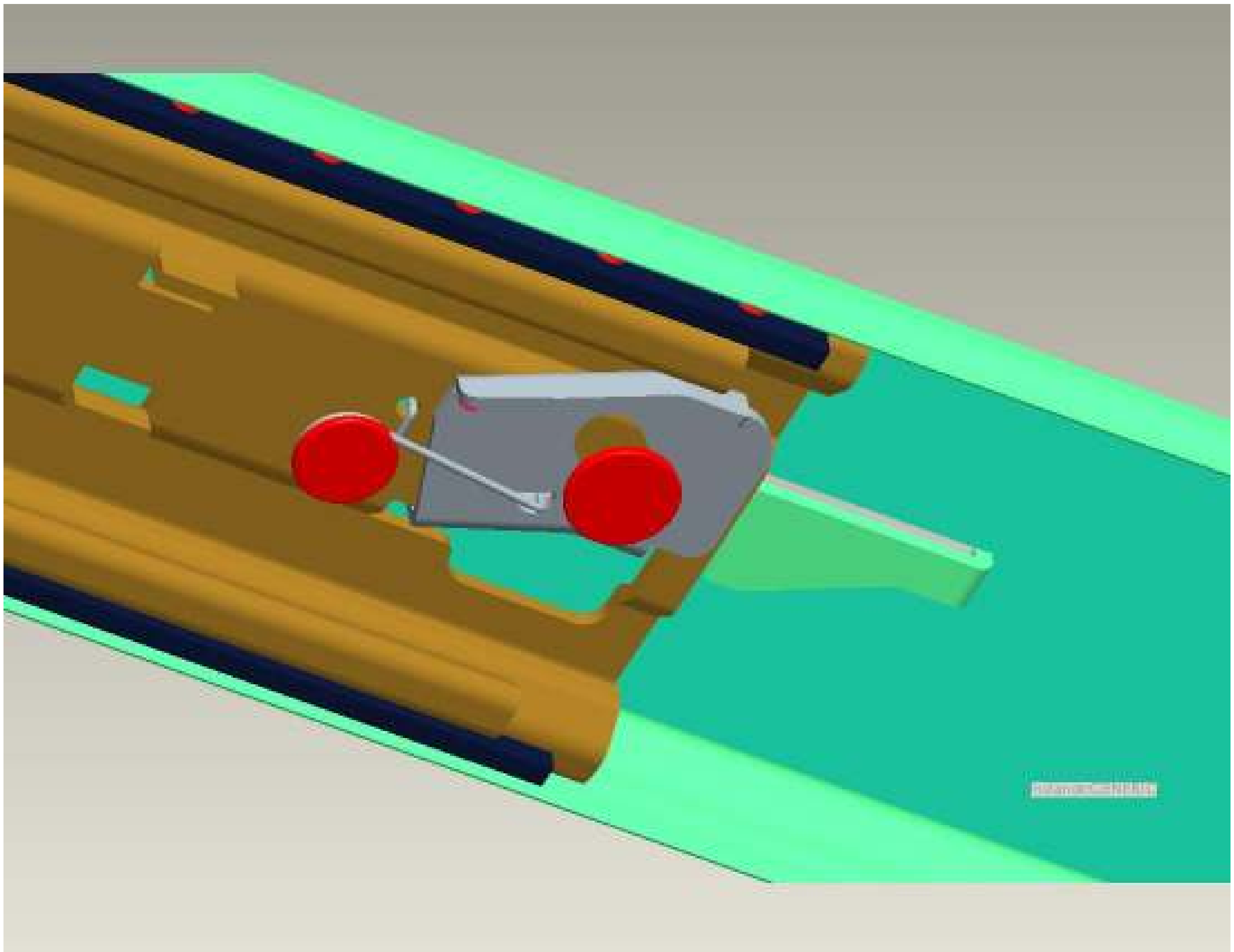


Figure 21: Example of a CIS locking mechanism