Development of Conceptual Design Support System for Mechanisms

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved:

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CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Erfan Ruzalfian Ag Besar

ABSTRACT

Conceptual design of mechanisms was primary based on the designer. In order to get good design, designer has to design a concept that reach its criteria as well as acceptable cost. The reason behind this research was that experienced designers create complex mechanisms, in part, by creating abstract representations of simpler building blocks by combining various mechanisms. Every machine has their own mechanism which consists of functions and for every sub-function have their own conceptual design. In order to make designer easier in their designing of a machine, creating a database that can help designer to choose the most compatible and relevant with the machine. Designing a machine or product need a collaboration of many expertise from different disciplines. Other than that, designing manually will need a lot of time during concept evaluation. Based on a systematic investigation of hundreds of existing mechanisms and machines, firstly identified the set of functions and sub-functions for mechanism design that have in a machine or known as functional decomposition. After that concept generation will be done where the software will automatically generate a morphology chart of conceptual design base on the functions for mechanism design that already been identified in a machine early on. The designer can manually remove any conceptual designs that are not compatible or irrelevant with the design during the morphology chart. The software will then continue with concept combination to make a synthesis to generate a few concepts variant and lastly concept evaluation where all the concept variants will be automatically evaluate and rank. At the end of the process, the designer should get a design of machine with most compatible conceptual design. The limitation of this thesis is it only limited to only mechanisms.

ACKNOWLEDGEMENTS

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Next, I would like to thank the FYP committee for their support and knowledge to assist the students. Thank you to all the lecturers and master students that have knowledge in my project from UTP who has provided efficient guidance and help throughout the course of the project.

Finally, I would like to apologize if any party was inadvertently excluded from being mentioned above and I would like to thank all the parties that were involved in making this project a success. Thank you.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Mechanisms are devices to change an input to any desire set of output either in force or movement of a machine [1]. Examples of mechanisms are gear, pulley belt, chains, crank, cam follower, as well as screw mechanism. Each of these mechanisms has their own functions. This function is where it determines the output of a specific mechanism. For a spur gear, it is consists of two gear that attach with each other that have different size and have different movement. When the input is one of the gear that are moving right side, then the output will be the other one gear that are moving left side. There are several more functions in a mechanism such as convert, connect, change, and support.

Conceptual design is a preliminary drawing that shows the idea of the designer after a master plan had been done [2]. It makes the designer to explore new ideas that can be make from the master plan. The designer makes a conceptual design by relating to functions of a mechanism. It point out a difference from design in general by not necessarily being actually functional but as illustrating a design that may show an idea that may potentially be functional. To have the most innovative products, designers not only need to know the useful concepts but also need to recognize other concepts that better. The best designer will use creative thinking methods and design process that help in the synthesis of new concepts.

Nowadays, designers want to find an automated conceptual design of mechanisms so that they easier to generate several alternative concept by inserting functions and concept design by the user. My research is basically the same only that it is partially automated. Once the function for every sub-function that have in mechanism have been chosen, a set of different concepts will be automatically shown based on the functions. Then a morphology chart which consist of the functions and concepts. Here the user can manually cancel out any concept that irrelevant with the design. Thus, synthesis will conduct and a few of concept variant where the concept of design will be evaluate and rank.

1.2 PROBLEM STATEMENT

In mechanisms of machines, there have a lot of functional basis and conceptual design that can be used by designer to create a machine. In order to create a machine, we need to know which functions and concept design will be use. Based on the functions of the machine that design, a few innovations may be appear during the conceptual design.

In this project, the main problem is designer need to have lots of experience and knowledge to design a product. If not the chosen concept might not be the best. This is because without automated, designer needs to do it manually and may lack of knowledge to design the product. Second it is time consuming. As we all know automated is more time saving than doing it manually especially during the concept evaluation.

Last but not least to design a machine or product, it requires collaboration of expertise from different disciplines. Designer that want to design a product that not expertise in their field will face a problem. Thus, by using automated this problem can be solved.

1.3 OBJECTIVES

The objective of this project is:

- To enhance a conceptual design support system for mechanisms.

1.4 SCOPE OF THE STUDY

The scope that I will be studying in my project is type set of functions that have in mechanisms of design. There have a lot of functions in mechanical design such as; branch, channel, connect, control magnitude, convert, provision, signal, and support, but for my project it only limited to mechanisms.

Other than that, the concept of each function also will be in my scope for example worm gear and rank pinion is in convert function, shaft is to connect rotational energy, and cam drive to regulate speed. Every function has their concept and all of this concept will be input into the software.

Lastly is how the software of support system in mechanisms works. The designer need to create a functional decomposition first before start using the software. This is to ensure the designer easier to input what function and sub-function need in their design. After that input all the function and sub-function to create a morphology chart that consist of set of concepts. Lastly concept evaluation where the designer will get their final choice for their design.

1.5 OUTLINE OF THESIS

Chapter 1 **:** Introduction of my thesis, background, objectives, scope of studies, and problem statement.

Chapter 2 **:** Literature review on a few of articles that related with my thesis.

Chapter 3 **:** Methodology where the steps of my project as well as the steps of using the software to get the final result.

Chapter 4 **:** Results and recommendation of my project. A few of case study had been done to prove my objective is achieved.

CHAPTER 2
LITERATURE REVIEW

2.1 Functional of Mechanisms

Functions of mechanisms also known as functional block is a systematic design that provides a way to describe an entire machine or system in a general way. A machine can be modeled as a single component entity that transform input of energy, material, and signal into desired output [3]. For example spur gear where the function is change direction; the input will be rotational motion to the right while the output will be rotational motion as well but to the opposite side. Pinion and rack function also to convert direction; the input will be rotational motion while the output will be linear motion.

There are several types of functions that can relate with mechanisms which are [4]:

I. Transport
II. Transmit
III. Rotate
IV. Allow DOF (Degree of Freedom)
V. Couple
VI. Change

For every of this functions of mechanisms have their own concept for example on the first function which is transport. This function can be related with movement that have lift or move something. The concepts for this function are cam mechanism, four bar linkage, crank and piston, and gear mechanism [5]. All of this concept can lift or move at the output of a mechanism.

2.1.1 Transmit

This function can be related with conduct or convey. The concept of this function is roller chain and belt [5]. This can be seen on a bicycle where it uses roller chain to transmitting mechanical power from one gear to another gear. As for belting mechanism, one of the examples is hydroelectric system where it conveys the mechanical power of turbine to the generator.

2.1.2 Rotate

This function can be related with spin or turn, anything that related with changing to opposite direction. The concept for this function is spur gear [5]. This spur gear basically consists of two gears that attach with each other; one is the input while the other one is output. When one of the gears is turning right side, the output which is the other gear will be turning to the left.

2.1.3 Allow DOF (Degree of Freedom)

This function can be related with constrain or unlock. The concept for this function is planetary gear train and cam mechanisms [6]. This type of gear consists of two different size of gear that are attach with a bar on respective center. The large gear is fixed so the DOF only have one. When the arm is pull, the mechanism has a definite motion.

2.1.4 Couple

This function can be related with assemble, attach or join. Any mechanisms that can join to other are consist of this function. The concept of this function are four bar linkage, universal joint, Cardan joint, Hardy-Spicer joint, and Hooke’s joint [6]. All of these concepts attach or join from one mechanism to the other mechanism.

2.1.5 Regulate

This function can be related with control, limit, or allowable movement. This function is for any device that need the output remain stationary for a period of time while the input keeps turning. The concept for this function is cam mechanisms and Geneva drive. Geneva drive is a mechanism that moves a continuous rotation into an intermittent rotary motion. It is an intermittent gear where the drive wheel has a pin that moves into a slot of the driven wheel made it to move by one step. Figure 1.1 is an example of Geneva drive [6].

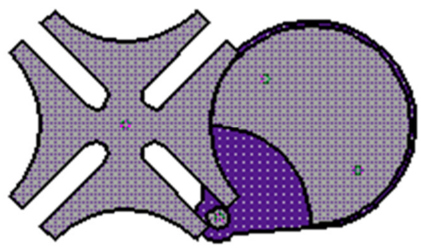


Figure 1 Geneva drive [6]

2.1.6 Change

This function can be related with amplify, decrease, increase, or adjust. Any mechanisms that change the input into another output that increasing force or decreasing force are consists in this function. The concept for this function is slider-crank, crank and piston, cam mechanisms, rack and pinion, spur gear, bevel gear, and quick return mechanism [6]. All of these concepts change the motion of the input whether rotary to linear, translational to rotary, or rotary to translational. For spur gear it can change the speed of the output due to its different size of gears. Bevel gears can change the angle of the output as well as the speed depends on the number of teeth of the gear. As for quick return mechanism, it converts rotary motion into reciprocating motion. When the disc rotates the slide will move forward and backward [6].

2.2 Automated Conceptual Design of Mechanisms

Automated conceptual design is a tool to help a designer to design a device or machine automatically [7]. All the user need to do is just define the functions of a desire device and input the functions into the computer-aided conceptual design system. After a designer inputs a desired function in the form of input, the designer also may input some performance requirements on the desired solution, computer-aided conceptual design systems can then begin automated conceptual design of mechanisms until receive the final result of the design.

Mechanism systems can be classified as single input and single output systems (SISO), single input and multiple output systems (SIMO), and multiple input and multiple output systems (MIMO) [8]. For my research that only limited to mechanisms, only SISO will be using in the conceptual design. Mechanisms like slider crank, cam mechanism, spur gear, roller chain, and others concepts are mainly only have single input and single output system. The automated conceptual design of SISO mechanisms using morphological matrix is consists of the following three steps [9]:

I. Functional synthesis based on device with a result of other possible functional chains to get a desired function for the device.
II. Concept of each functions synthesis based on the solution list of all sub-functions in the functional chains that had been generated in step 1. From this synthesis a morphology chart will be generate to result in combinations of concepts design.
III. Ranked concept variant will be generated and concept evaluation will be carried out resulting of some desirable solutions design.

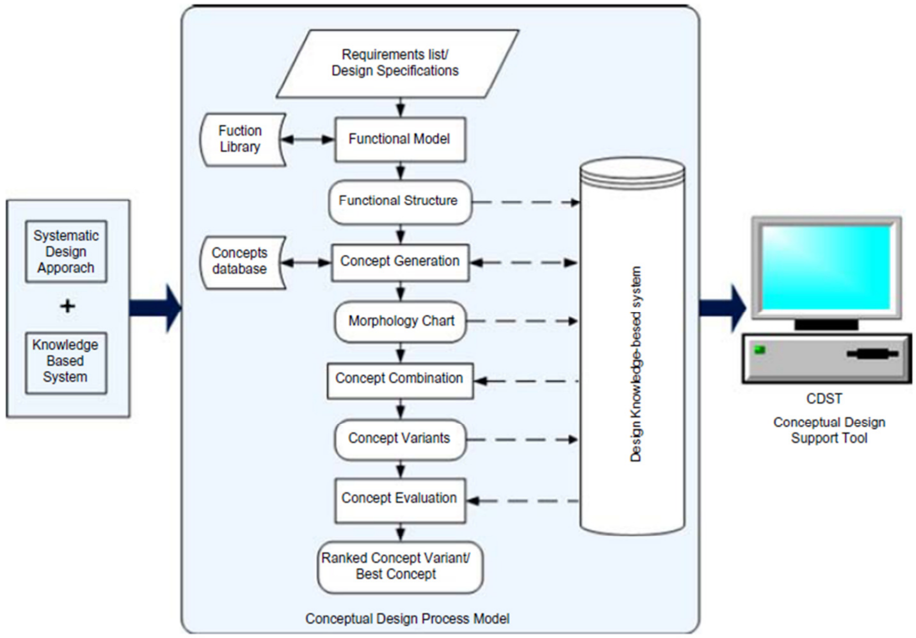


Figure 2 Flowchart of the Functional Synthesis Process [10]

Figure 1.2 shows the flowchart of how the process carried out in functional synthesis using automated conceptual design. Firstly the user needs to know the requirement and specification of the desire design. After that the user need to know the sub-functions of mechanisms that essential to the device, then the will need to choose all the sub-functions from the function library and input them. The computerized conceptual design will then automatically generate a concept based on the input of sub-functions that been input by the user. The computerized conceptual design uses a systematic design approach and knowledge based system that had been program in the software to come out with morphology chart of concepts. For automated conceptual design, it will automatically generate the until final concept design but for my research it will be partially automated conceptual design where the user need to remove any irrelevant concept to the desired design in the morphology chart. After synthesis process of the morphology chart, a few of concept variant will be generate and the user once more need to input desired criteria manually during the concept evaluation so that ranked concept variants can be finalized.

2.3 Automated Conceptual Design of Mechanisms Using Improved Morphological Chart

The objective of this automated conceptual design is by developing a comprehensive and extensible methodology for automated conceptual design of mechanisms utilizing a design prototype synthesis methodology [8].

I. A motional vector pair based functional representation model.

- *Type.* A motion can be classified as rotation (R), translation (T), and helical motion.
- *Orientation.* Can be define as X, Y, and Z with the Cartesian coordinate, while rotation and helical can be define with axis.
- *Direction.* Can be define as ‘1’ or ‘-1’ if rotation. For helical can be define as ‘0’.

II. Motion function matrix and its integration with mechanism prototype knowledge based (MPKB).

- *Motional function matrix.* The function delivered by a mechanism prototype in a particular situation can be qualitatively represented with a pair of input and output motional vectors. Because each variable of the motional vector can merely have very few values such as R, T, 0, 1, etc.
- *The integration of motional function matrix (MFM) with MPKB.* In the design catalogues of mechanism prototypes, the orientation transformation relations of prototype functions are described with words, such as **parallel** or **perpendicular** [8].

As a result, a design catalogue model is proposed to provide extensive support for conceptual design activities such as synthesis, evaluation, and verification. Not only can it yield as many combination solutions as possible solutions, but can automatically filter out infeasible combination solutions with the aid of a systematic performance constraint verification approach. It could often lead to the loss of optimal solutions due to the nature of heuristic search. Other than that, Due to the space limitation, the present study only focuses on the automated synthesis method of single input to single output (SISO) system [8].

2.4 Automated Conceptual Design of Multiple Input and Multiple Output Mechanical Transmission System

Presenting a systematic approach to automated conceptual design of multiple input and multiple output mechanical transmission system, based on the functional decomposition strategy. There are several methods which are [9]:

I. Transmission functional representations.

- This is to describe the transmission function such as performance, dynamic properties, and operating characteristic so that the mechanical transmission function can be expressed through change in motion features. There are 4 important variables that are selected to represent motions in a qualitative way which are type, orientation, direction, and reciprocator factor.

II. Automated conceptual design of MIMO (many input to many output) mechanical transmission system.

- After a designer inputs a desired function in the form of input and output motional vectors and some performance requirements on the desired solution, computer-aided conceptual design systems can then begin automated conceptual design of mechanisms.

By using these methods MIMO systems can be transformed into solving the problem of SISO, SIMO, MISO solutions, therefore they describe the problem separately. Due to the space limitation, the present study only focuses on the automated synthesis method of SISO systems, which has laid a solid foundation for our future exploration in how to evolve a SISO combinatorial mechanism solution into SIMO/MIMO with the branching strategies.

2.5 A Framework for Function-Based Conceptual Design Support System

To describe the framework of conceptual design support tool (CDST) developed to assist designers during conceptual design process. First it need know the conceptual design process of a model then the model will be constructing by using modeling module, concept generation module, concept combination module as well as concept evaluation module [10].

I. Conceptual design process model.

- The conceptual design process model is developed by investigating manual conceptual design process following a systematic design approach.
- Concept generation process can be automated if the necessary knowledge is acquired and stored in the computer system.
- Tasks like concept combinations process and representing the generated concept on morphology chart are time consuming which need computer support.

II. Model construction.

- *Functional modeling module.* It is a process where it analyzes the requirement list or design specification to come up with the overall function of the design problem.
- *Concept generation module.* The goal is to generate many concepts in the design process by making use of existing design knowledge in the alternative concept database.
- *Concept combination module.* This is where the morphology chart as an input and gives the combine concept variants as an output.
- *Concept evaluation module.* It takes the output of the combination phase and gives ranked concept variant as an output. It includes Pugh's evaluation method, weighted decision matrix, and analytical hierarchy process.

The CDST present assists designers to perform conceptual design process more efficiently than solely manual design by handling some of the repetitive tasks and providing available concepts in the database. It helps the designer by only taking the designer input. Currently, the alternative concepts database consists of few general mechanical designs. The database can be enhanced by adding more concepts through the knowledge acquisition module provided [10].

2.6 Reconciling and Evolving Previous Efforts

Reconcile and integrate two independent research efforts into a significantly evolved functional basis. These efforts were from the National Institute of Standards and Technology (NIST) and two U.S. universities.

Method [11]

I. Reconciliation of the NIST taxonomy and the functional basis.

In order to meet those goals, the authors agreed to take a critical look at both vocabularies and to reconcile and integrate the differences.

General approach. The intent of the integrated functional basis is that the set of terms at a given level should provide complete coverage of all concepts within that category. During reconciliation, the following categorization algorithm is employed:

- The new term might be a subset of the existing term it overlaps with, and would therefore be bumped down to the next lower level.
- The new term might be a superset of the existing term it overlaps with, in which case the new term might replace the existing term and the existing term would be bumped down to the next lower level.
- The new term might be similar enough to an existing term that it might be categorized as a comparable term (synonym) rather than entering the basis as a new item.

Specific approach. This is to reconciling two functional vocabularies by using 3 steps which are *review, union and intersection*, and *reconciliation*.

- *Review*. The latest versions of the functional basis (Stone and Wood, 2000) and the NIST function and flow taxonomies (Szykman et al., 1999a) are reviewed and definitions for each of the function and flow terms are formulated.

- *Union and Intersection*. The union of the two vocabularies is generated, creating a combined list of terms. Those terms that fall in the intersection of the two sets form a core set of terms that are common to both. This process is carried out at each level of function and flow.

- *Reconciliation*. The comparison is carried out with respect to product examples which is the function term's sustainability based on whether or not it describes an operation that a product carries out a flow.

From the methods of reconcile and integrate two independent research into an evolved functional basis, the reconciled functional basis, resulting from the comparison and combination of the two vocabularies, is shown in Tables 1.

Class (Primary)	*Secondary*	*Tertiary*	*Correspondents*
Material	Human		Hand, foot, head
	Gas		Homogeneous
	Liquid		Incompressible, compressible, homogeneous,
	Solid	Object	Rigid-body, elastic-body, widget
		Particulate	
		Composite	
	Plasma		
	Mixture	Gas-gas	
		Liquid-liquid	
		Solid-solid	Aggregate
		Solid-Liquid	
		Liquid-Gas	
		Solid-Gas	
		Solid-Liquid-Gas	
		Colloidal	Aerosol
Signal	Status	Auditory	Tone, word
		Olfactory	
		Tactile	Temperature, pressure, roughness
		Taste	
		Visual	Position, displacement
	Control	Analog	Oscillatory
		Discrete	Binary

Figure 3 Functional Basis Reconciled Flow Set [11]

The reconciled function set in Table 2 has been modified from having categories of class, basic and flow restricted (in the original functional basis) to class (primary), secondary, tertiary and correspondents.

Class (Primary)	*Secondary*	*Tertiary*	*Correspondents*
Branch	Separate		Isolate, sever, disjoin
		Divide	Detach, *isolate*, release, sort, split, disconnect, subtract
		Extract	Refine, filter, purify, percolate, strain, *clear*
		Remove	Cut, drill, lathe, polish, sand
	Distribute		Diffuse, dispel, disperse, dissipate, diverge, scatter
Channel	Import		Form entrance, *allow*, input, *capture*
	Export		Dispose, eject, *emit*, empty, *remove*, destroy, eliminate
	Transfer		Carry, deliver
		Transport	Advance, lift, move
		Transmit	Conduct, convey
	Guide		Direct, shift, steer, straighten, switch
		Translate	Move, relocate
		Rotate	Spin, turn
		Allow DOF	*Constrain*, unfasten, unlock
Connect	Couple		Associate, connect
		Join	Assemble, fasten
		Link	Attach
	Mix		Add, blend, coalesce, combine, pack
Control Magnitude	Actuate		Enable, initiate, start, turn-on
	Regulate		Control, equalize, limit, maintain
		Increase	*Allow*, open
		Decrease	Close, delay, interrupt
	Change		Adjust, modulate, *clear*, demodulate, invert, normalize, rectify, reset, scale, vary, modify
		Increment	Amplify, enhance, magnify, multiply
		Decrement	Attenuate, dampen, reduce
		Shape	Compact, compress, crush, pierce, deform, form
		Condition	Prepare, adapt, treat

Figure 4 Functional Basis Reconciled Function Set [11]

2.7 Concept Generation From The Functional Basis of Design

This paper presents a concept generation algorithm that utilizes the Functional Basis and a web-based repository of existing design knowledge to generate and rank viable conceptual design variants. The methods using are as follows [13]:

III. Review of design tools used during concept generation.

- *Functional basis of design*. The functional basis uses function and flow words to form a sub-function description as a ***function*** and a ***flow***. Generation of a black box model, creation of function chains for each input flow, and aggregation of function chains into a functional model are the sequence of steps that lead to the repeatable formation of a functional model in their approach.
- *Design Repository*. This repository, which includes descriptive product information such as functionality, bills of materials, and design structure matrices (DSMs), now contains detailed design knowledge on approximately 50 consumer products.

IV. Concept generation algorithm.

- The purposed of this method is to utilize the functional basis to link component functionality with component compatibility and create, filter, and rank concept variants. The function-component matrix (FCM) and the design structure matrix (DSM) that have in web-based repository of design information will describe the function-component relationship and compatibility of existing product.
- There are 5 steps the algorithm uses the design knowledge contained in the repository. *Generate a conceptual functional model, define function-component relationship using existing design knowledge, compute the set of conceptual variants that solve the function model, define component-component compatibility using existing design knowledge*, and *filter set of conceptual variants using component compatibility knowledge*.

By using these methods the capability to automatically produce viable conceptual design variations based on existing component knowledge. This journal only shows the initial steps taken to generate a matrix-based algorithm for concept generation and early concept evaluation. The specific focus of this research is the combination and formalization of function-based synthesis, constraint management, and state space search to create a comprehensive space of concept variants and search it for feasible design candidates.

2.8 Development of A Functional Basis for Design

Functional basis is a function that consists of several concepts. The objective of this paper is an inductive approach to create a functional basis for use with functional models, focusing primarily on the mechanical and electromechanical domains. The methods are [16]:

I. Generate black box model.

- It is a graphical representation of product function with input or output flows. This relates the designer needs to the functional model. Every designer need to identify one or more input or output flows for the product. These flows will then directly tell the designer what they specifically need.

II. Create function chains for each input flow.

- Develops a chain of sub-functions that operate on the flow by think of each operation on the flow from entrance to exit of the product and express it as a sub-function. There are 2 ways need to view to create function chains which are ***express sub-function in a common functional basis*** and ***order function chains with respect to time***.

III. Aggregate function chains into a functional model.

- This is to aggregate all the function chains into a single model. The result of the derivation is a functional model of a product expressed in the functional basis. With such a functional model, functions may be directly related to designer needs.

Hence the use of the functional basis significantly contributes to the following six product design areas.

I. Product architecture development.
II. Systematic function structure generation.
III. Archival and transmittal of design information.
IV. Comparison of product functionality.
V. Creativity in concept generation.
VI. Product metrics, robustness, and benchmarks.

The scope of this article is limited to the functional modeling portion of conceptual design.

CHAPTER 3
METHODOLOGY

3.1 METHODOLOGY

This section will discuss the proposed project flow in order to complete the project on Development of Conceptual Design Support Tool for Mechanisms. After the title selection process has been completed, preliminary research work on the title are done including consulting the project supervisor. The background information and problem statement of the title given by the supervisor were studied extensively in order to grasp the objective and nature of the project.

After the initial study has been done, extensive literature review is then carried out. This includes retrieving and reviewing journals, technical papers and handbooks related to the topic in order to obtain a clearer and thorough understanding of it. Literature reviews are done according to keywords found in the title itself such as “Conceptual Design” and “Functions for Mechanisms” to get set of functions and concepts.

The next step of the project will be to familiarize with the functionality and usage of the support tool itself and import all the data into the software. This is an important step as this tool will be used extensively in the project. This is then followed by doing a simulation on the software base on with my case study whether my objective of project achieved or not.

A set of concept for every function also must be identified to input it into the software database. It is important as understanding each of the functions before proceeding because it is needed to execute functional decomposition of the product. This decomposition will then be used to create a morphological analysis of the functions or physical properties that the jacket will use. The functions or properties will then be validated first against journals and engineering handbooks to ensure that design generated will be accepted. Last but not least discussion and conclusion of my project as well as final documentation.

Below is the flow chart of my project methodology.

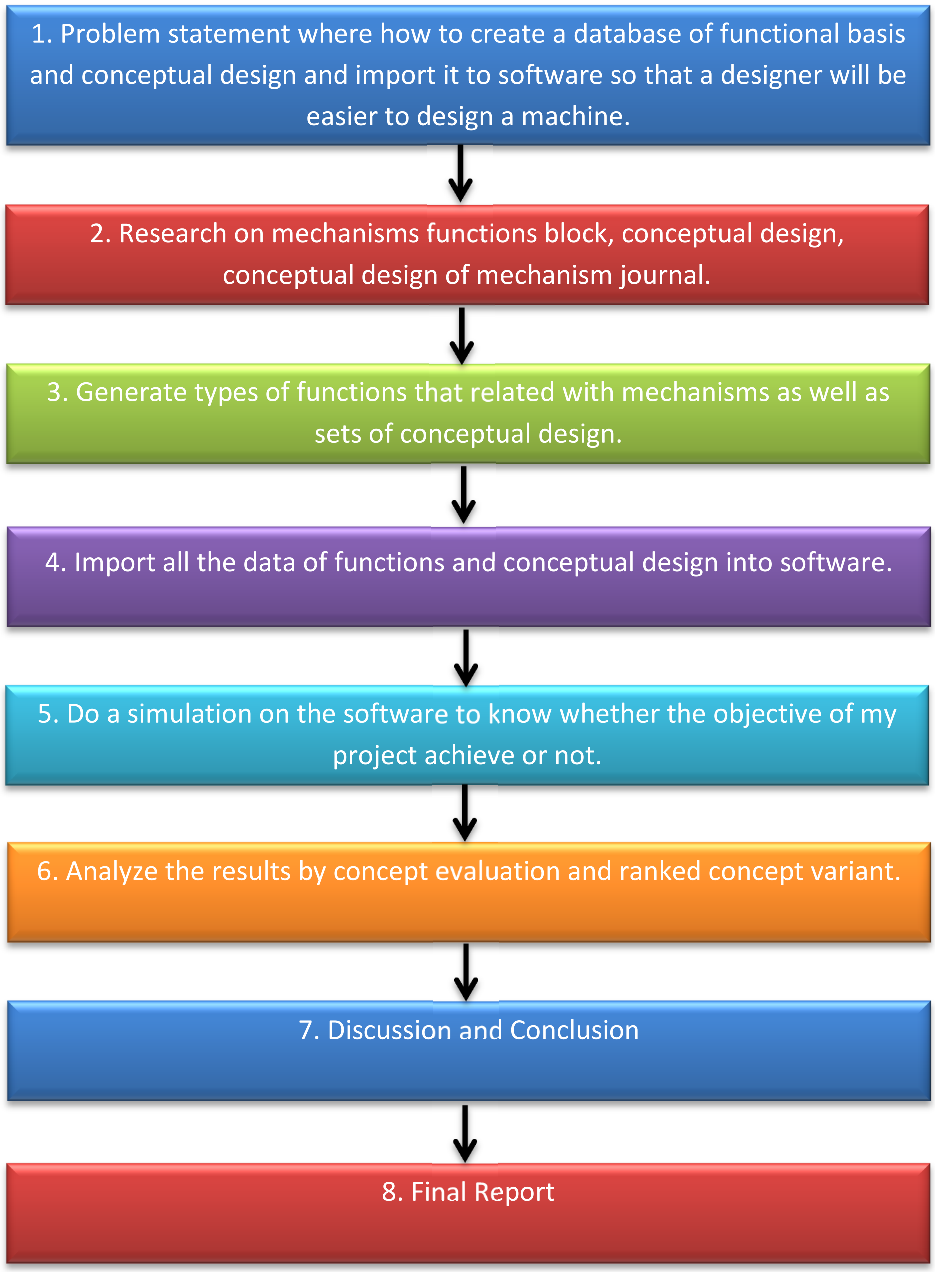
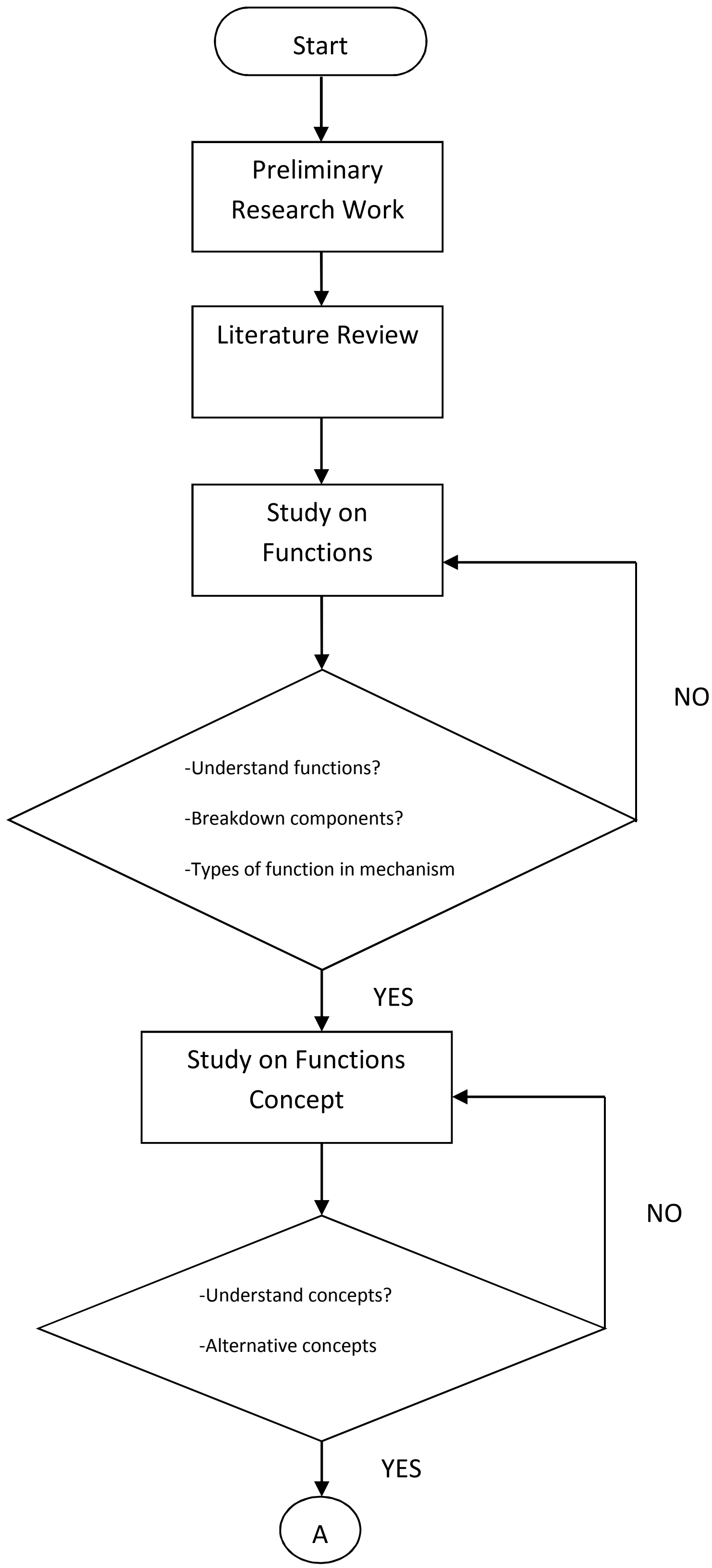


Figure 5 Project Methodology

3.2 Flow Chart



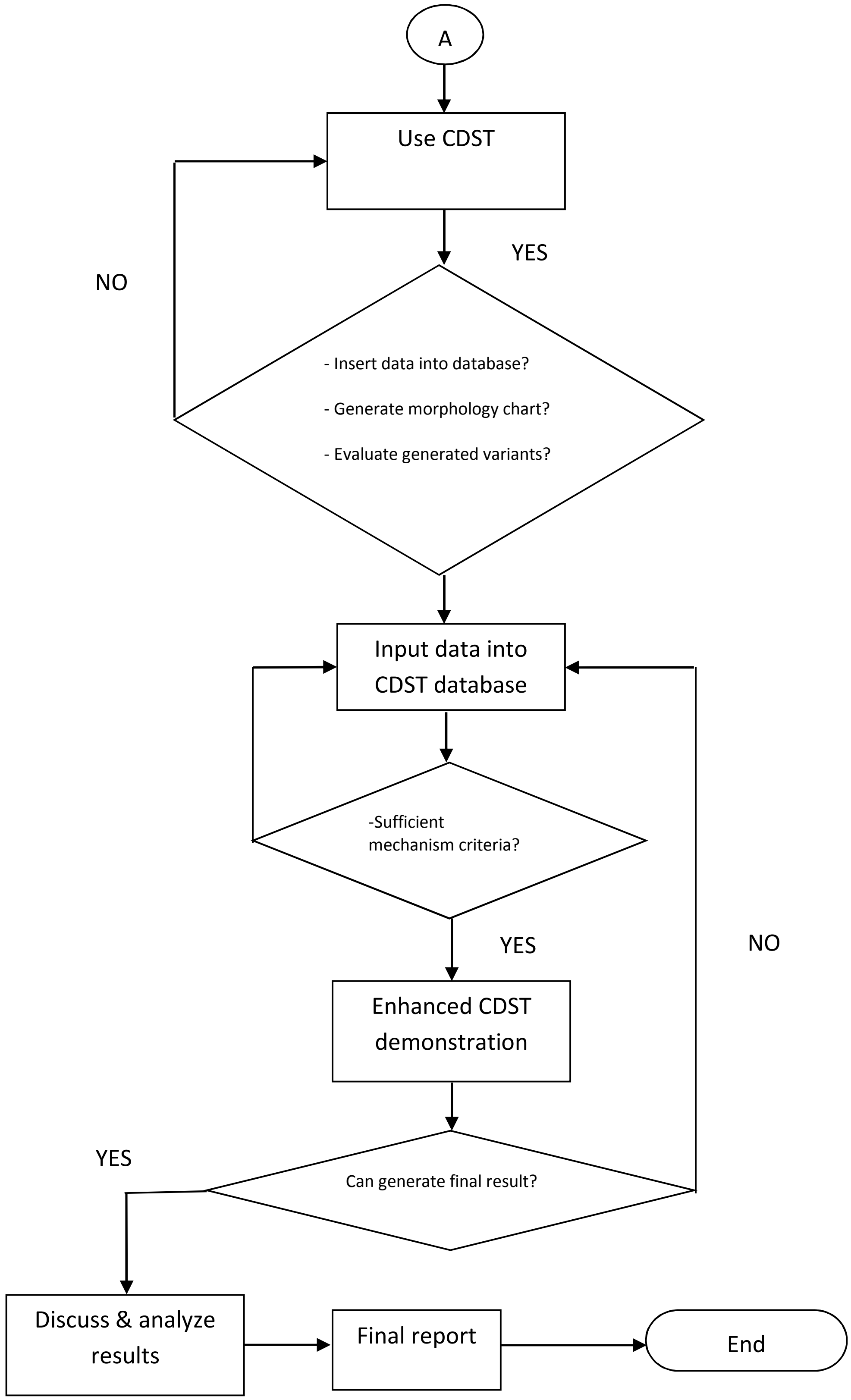


Figure 6 Project Flow Chart

3.3 GANTT CHART

Below are the proposed Gantt charts for this project. The project will be conducted in two semesters as per requirement of the course.

3.3.1 FYP 1

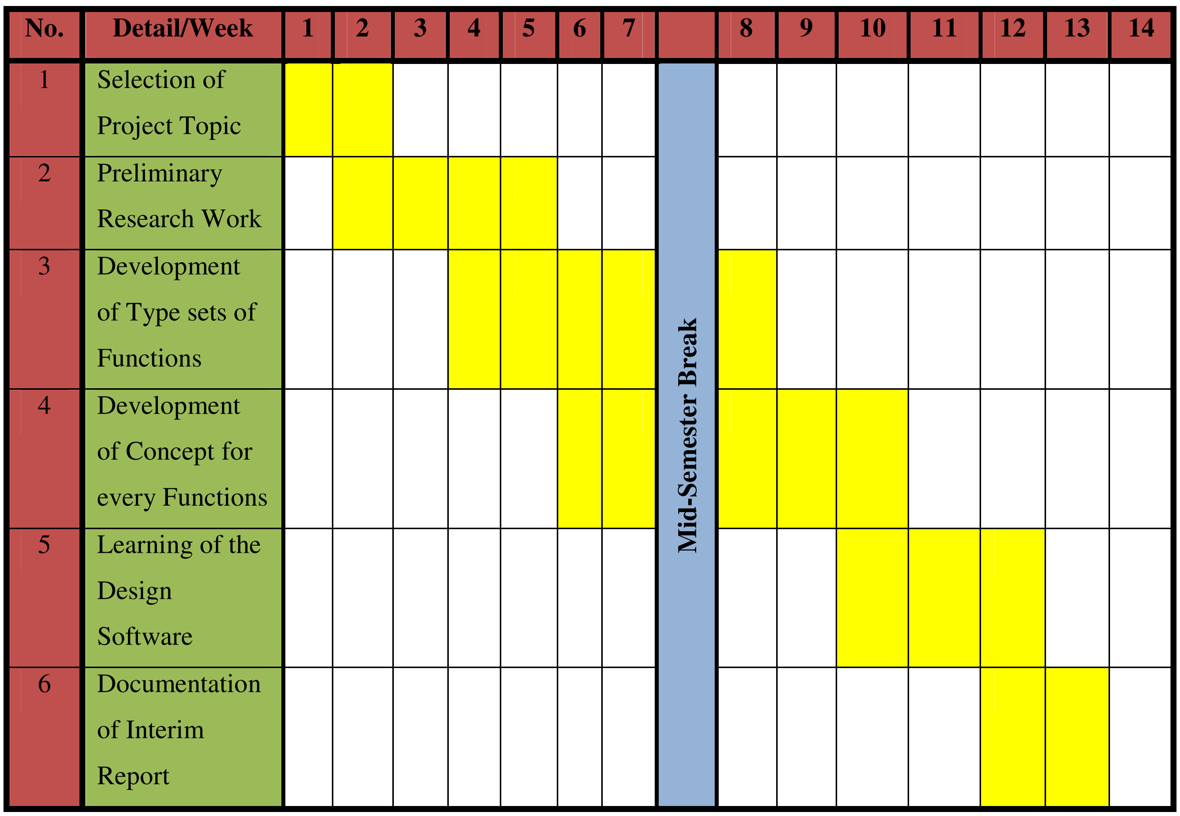


Figure 7 Proposed Gant Chart for FYP 1

3.3.2 FYP 2

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Continuation of Project Progress								Mid-Semester Break							
2	CDST Familiarization															
3	Simulation of Program and Analysis															
4	Modifications and Troubleshooting of the Software															
5	Case study 1 and 2															
6	Documentation of Dissertation Draft Report															
7	Documentation of Dissertation Report (Soft Bound)															
8	Documentation of Technical Paper															
9	Final Presentation															
10	Documentation of Dissertation Report (Hard Bound)															

Figure 8 Proposed Gant Chart for FYP 2

Project Development

CHAPTER 4
RESULTS

4.1 Functions

Hence the results I get for functions that only related to mechanism consists of eleven functions which are transport, transmit, rotate, translate, allow DOF (Degree of Freedom), link, join, increase, decrease, increment, and decrement. From these eleven functions I separate them into class so that the root of the functions can be determined.

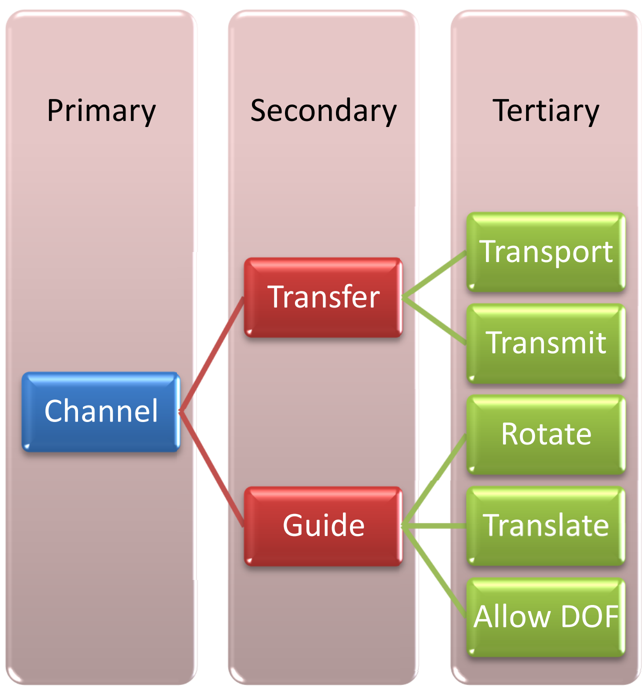


Figure 9 Channel Functions

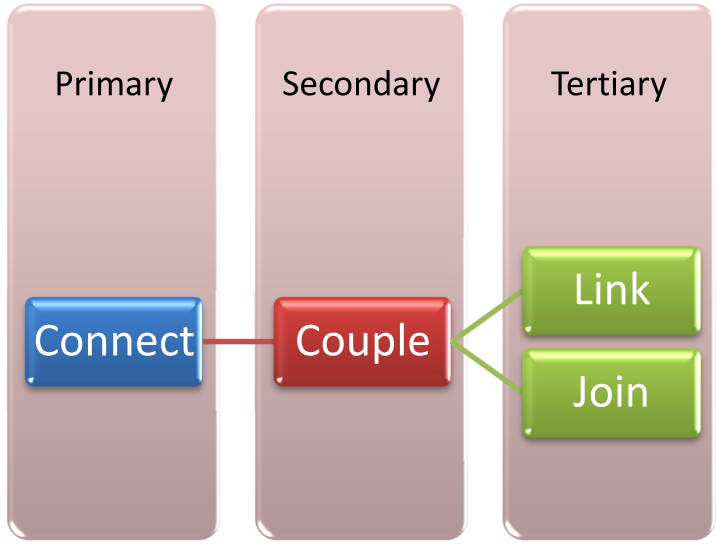


Figure 10 Connect Functions

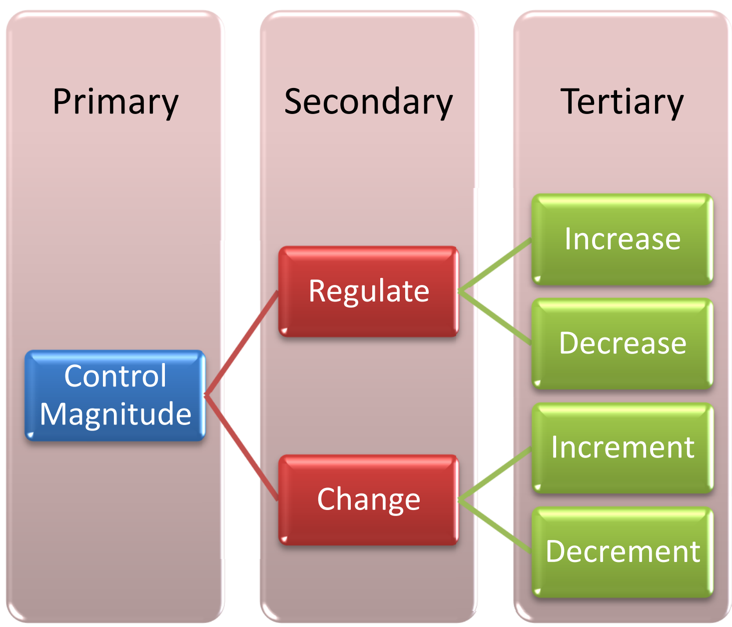


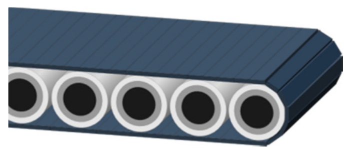
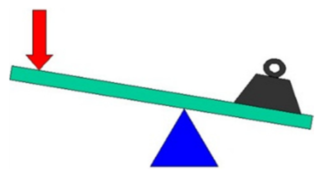
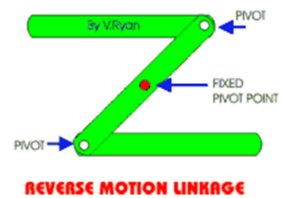
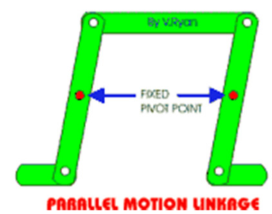
Figure 11 Control Magnitude Functions

4.2 Concepts

As for the concept, I have found several concepts for each of the functions. These concepts are important in designing during morphology chart stage. After we input the sub-functions of the design, a morphology chart will come out and show a few of concepts of each sub-function that we had input in the software. From the chart we can neglect irrelevant concept and choose the most suitable for our design. There are a few concepts that I had already done for their concept which are:

I. Transmit
II. Rotate
III. Join
IV. Increase

For each of the concept, the designer can choose which concept that they want to use for their design for each sub-functions. Below are the morphology chart based on the concept that I already get.

Sub-functions	Option 1	Option 2	Option 3	Option 4
Transmit	 Roller chain (Mechanical Power, INC., 2012)	 Conveyor belt *(A&S Conveyor Belt CO. ltd.,2013)*	-	-
Rotate	 Spur gear (Oliver & Boyd, 1993)	 Lever *(Dirac Delta Consultants LTD diracdelta.co.uk, 2009)*	 Reverse motion linkage *(Daina Taimina, 1999)*	 Parallel motion linkage *(Daina Taimina, 1999)*

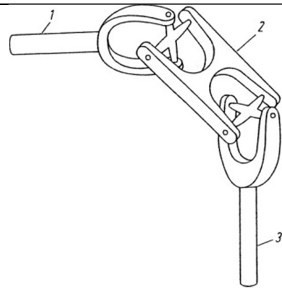
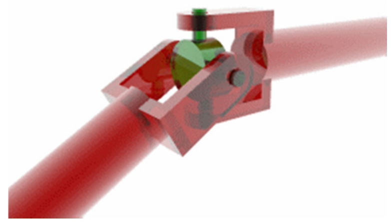
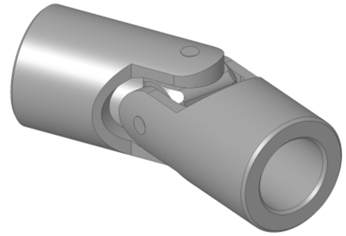
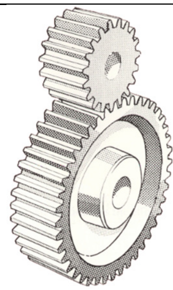
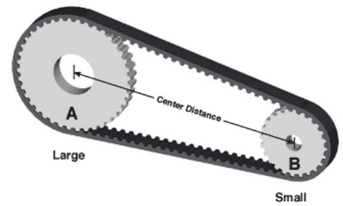
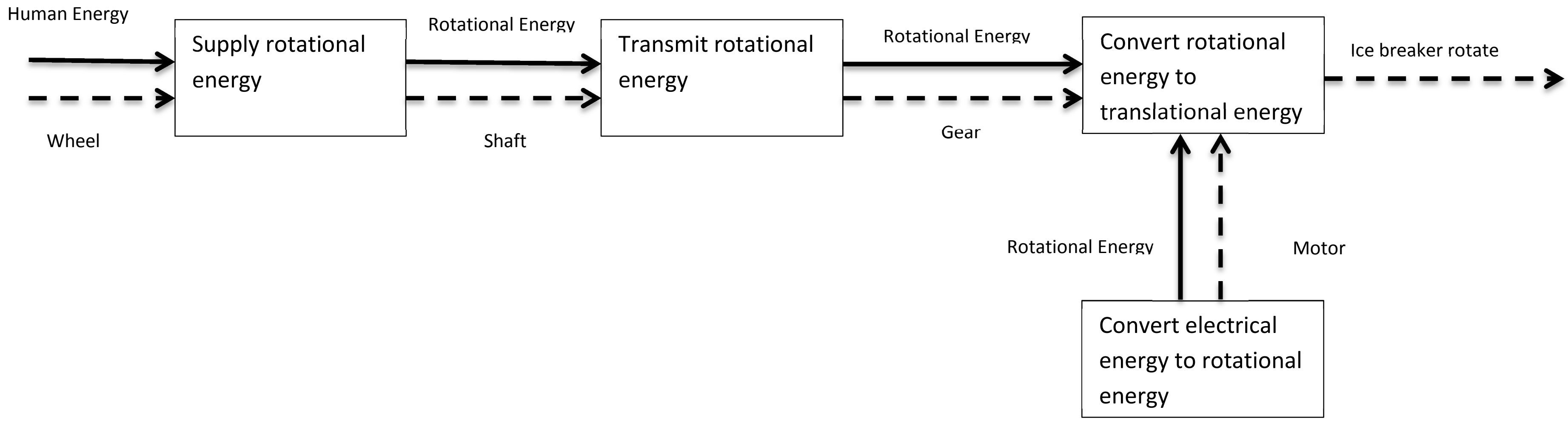
Join	 Universal joint (Mills & Alan, 2010)	 Hooke's joint (Mills & Alan, 2010)	 Cardan joint (Silberwolf, 2007)	 Hardy-Spicer joint (Silberwolf, 2007)
Increase	 Spur gear (Oliver & Boyd, 1993)	 Bevel gear (Emerson Power Transmission Corp., 2008)	 Conveyor belt *(A&S Conveyor Belt CO. ltd.,2013)*	-

Figure 12 Example Morphology Chart based on Functions

4.3 Functional Decomposition

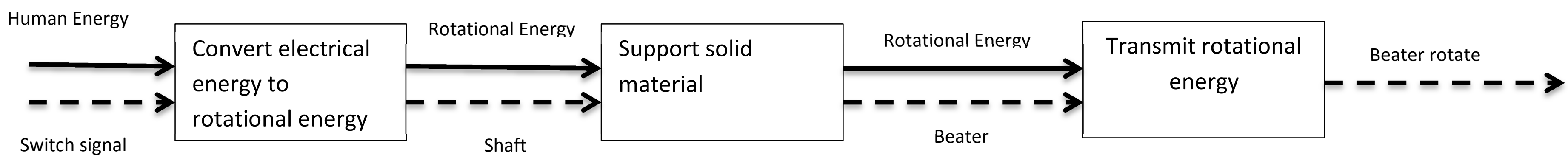
Case Study 1

<u>ABC Machine</u>



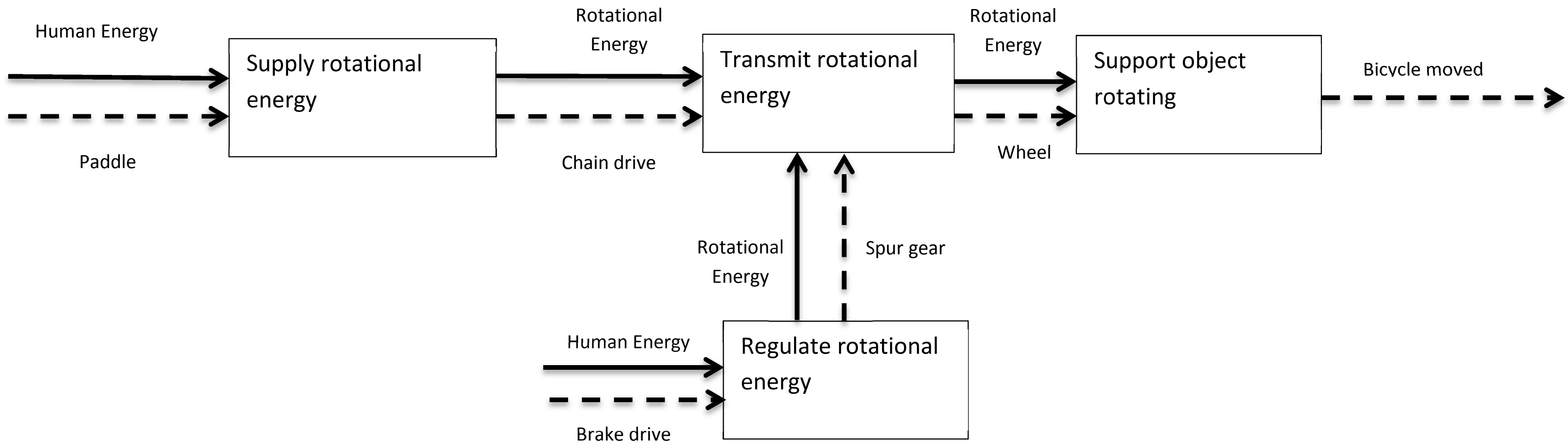
Case Study 2

<u>Egg Beater</u>



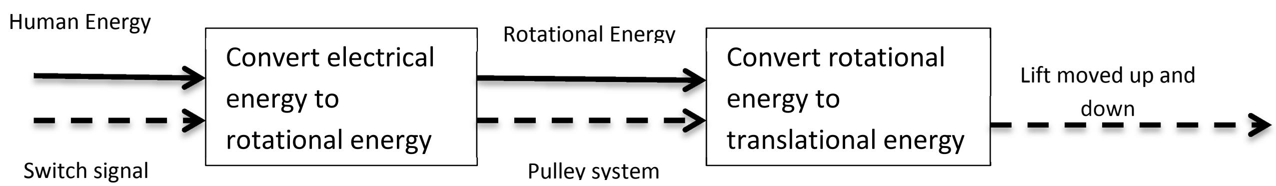
Case Study 3

Bicycle



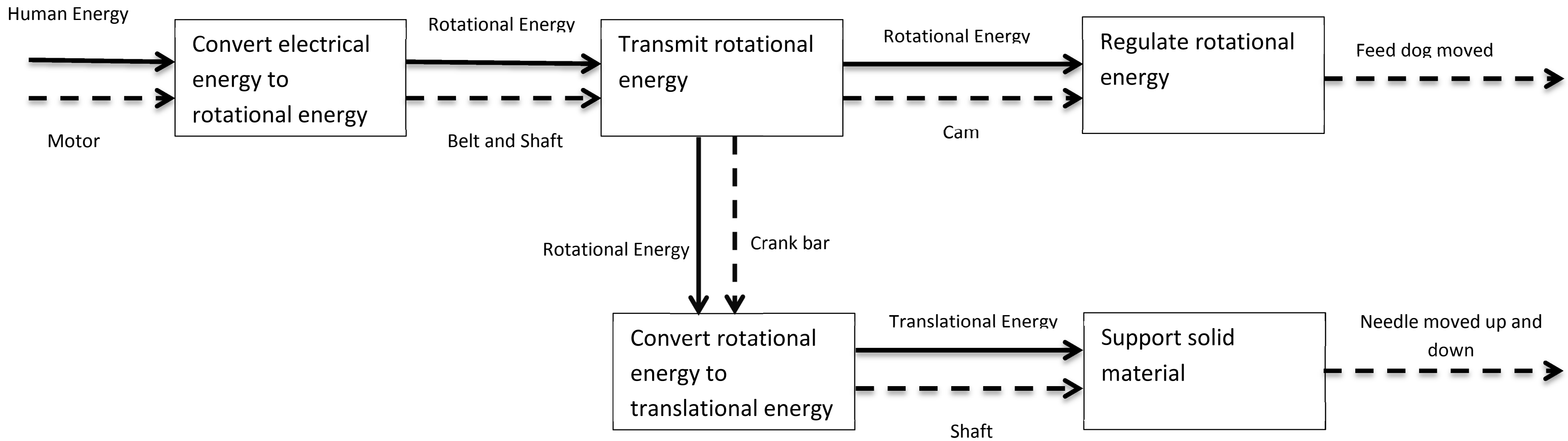
Case Study 4

Lift



Case Study 5

<u>Sewing Machine</u>



4.4 Case Study 1

4.5

I will be taking an example of how I simulate one of my case studies to get final result by using Conceptual Design Support Tool (CDST). For this I have chosen case study one which is ***ABC Machine*** as my initial testing. There are a few steps to do along using this method which are:

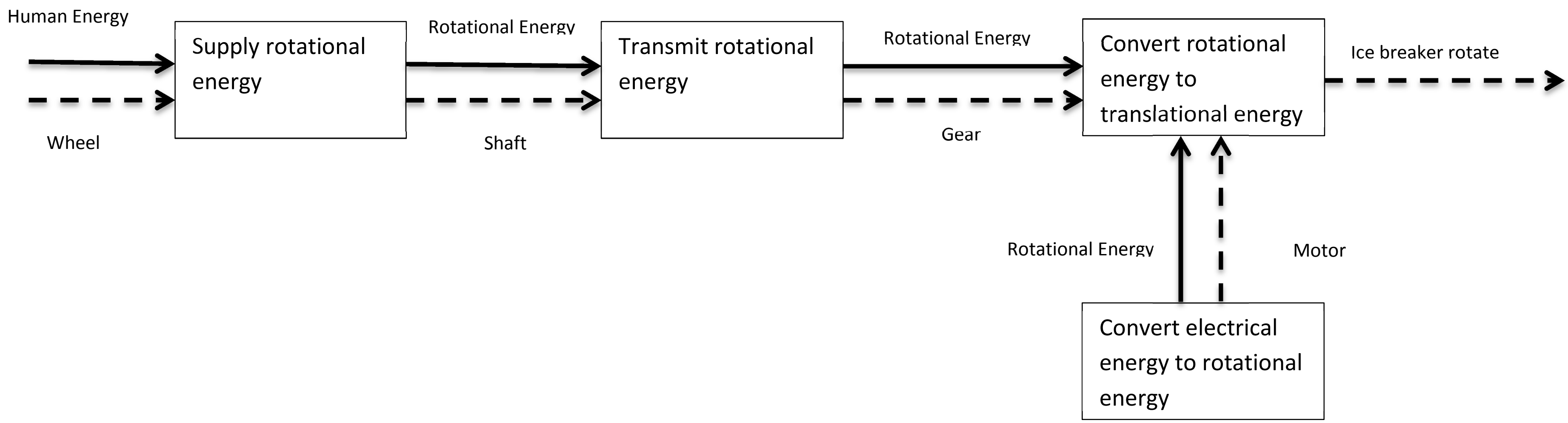
I. Functional decomposition
II. Concept generation
III. Concept combination
IV. Concept evaluation

<u>ABC Machine</u>

Figure 13 ABC Machine (YT Tading Sdn. Bhd.)

1. *Functional Decomposition*

Firstly before start input the functions and sub-functions of an ABC machine, a complete design of functional decomposition for ABC machine is needed. This is to ensure all the functions of the design did not left out during start input into the software. This stage also to ensure the design progress move along more systematically. Below is the functional decomposition that I had done for ABC machine before starting the software.



Functional Decomposition of ABC Machine

2. *Concept Generation*

Once all the sub-functions are added to working memory, the concept generation is initiated by using the “Go” button. If some of the generated concepts have side effects, the system will suggest to the user for possible consideration of the side effects as new requirement. After all the functions and sub-functions had been input as shown in Figure 4.1, the system will automatically create a morphology chart.

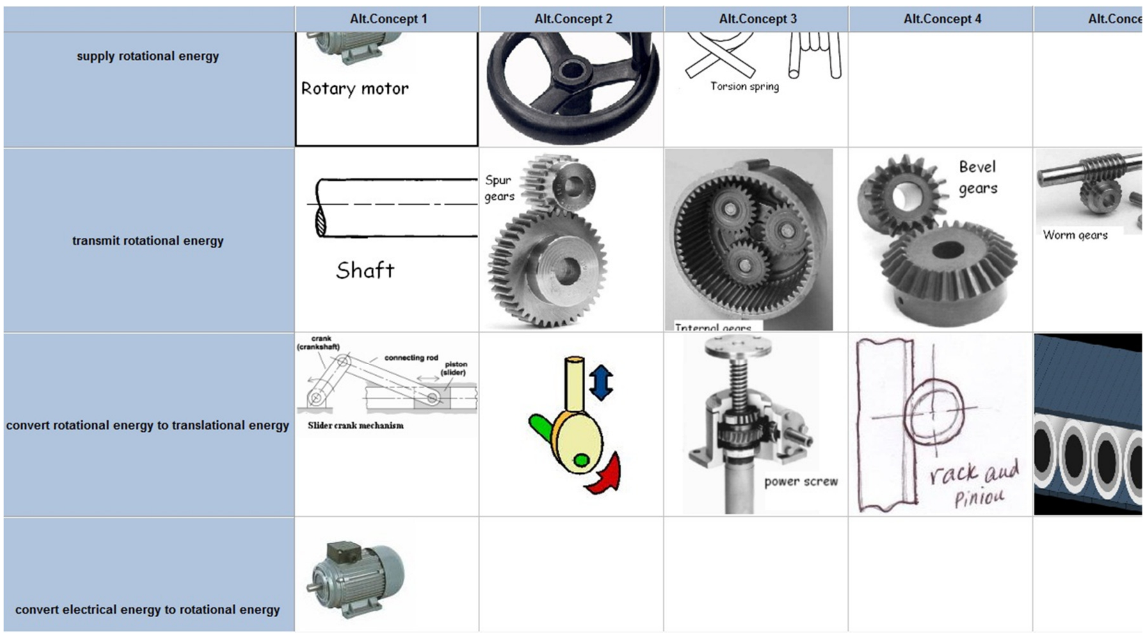


Figure 14 Morphology chart

During this morphology chart stage, the user can reject infeasible concepts. This helps to reduce the combinatorial explosion later in the concept combination process.

3. *Concept Combination*

I use the options to create all theoretically possible concepts variants. From the current morphology chart, the concept combination process results in 140 theoretically possible concept variants. Some of the concept variants can be rejected on the morphology chart. Based on the designer requirement and feasibility of the concepts to be used for easy mobility and cheap concepts, a few concepts are removed from the morphology chart to short out the design options.

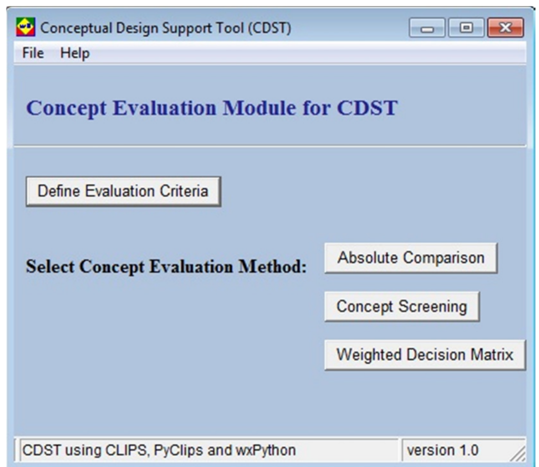


Figure 15 List of Concept Evaluation

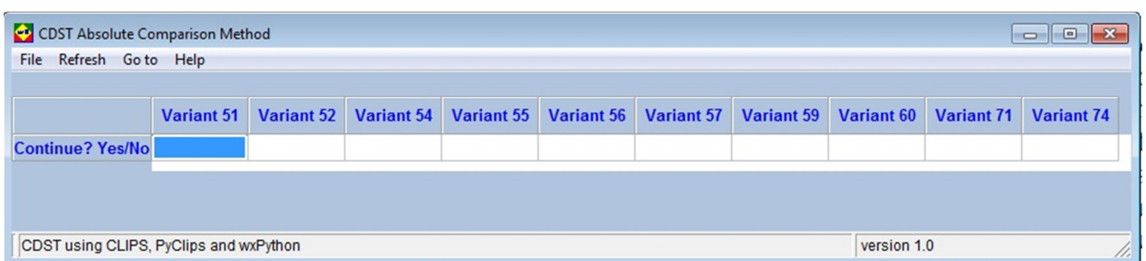
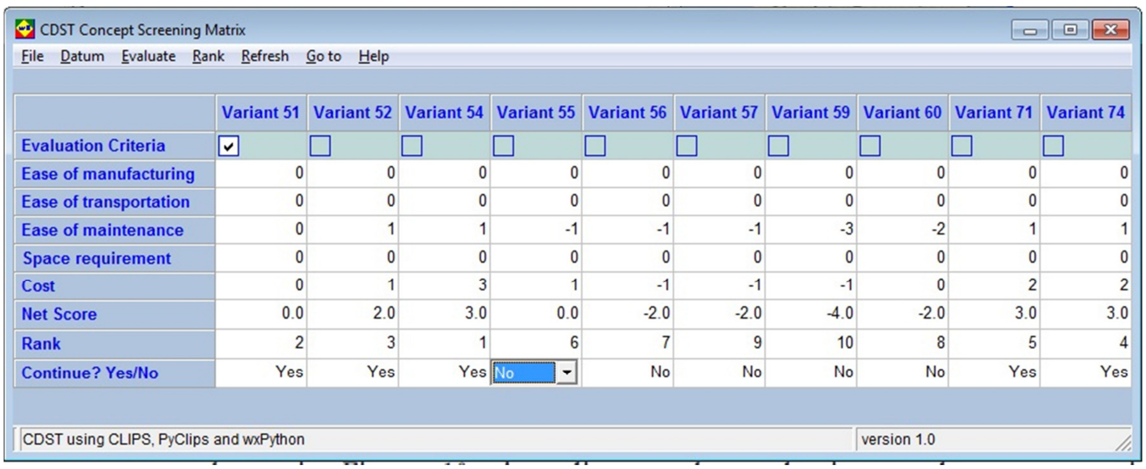


Figure 16 Absolute Comparison

4. *Concept Evaluation*

Once the concept variants are created, concept evaluation will be carried out to determine the best result for designing an ABC machine. There are two steps to determine the final result which are ***Concept Screening*** and ***Weight Decision Matrix***. After each evaluation process infeasible concept variants can be eliminated or combined and the remaining concept variants proceed to the next evaluation process. For brevity only the final weighted decision matrix is shown in Figure 4.4.



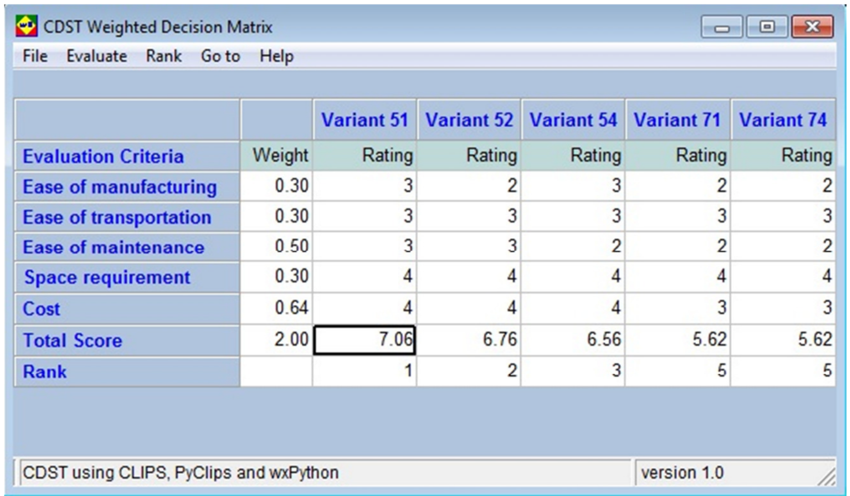
CDST Concept Screening Matrix

File Datum Evaluate Rank Refresh Go to Help

	Variant 51	Variant 52	Variant 54	Variant 55	Variant 56	Variant 57	Variant 59	Variant 60	Variant 71	Variant 74
Evaluation Criteria	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ease of manufacturing	0	0	0	0	0	0	0	0	0	0
Ease of transportation	0	0	0	0	0	0	0	0	0	0
Ease of maintenance	0	1	1	-1	-1	-1	-3	-2	1	1
Space requirement	0	0	0	0	0	0	0	0	0	0
Cost	0	1	3	1	-1	-1	-1	0	2	2
Net Score	0.0	2.0	3.0	0.0	-2.0	-2.0	-4.0	-2.0	3.0	3.0
Rank	2	3	1	6	7	9	10	8	5	4
Continue? Yes/No	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes

CDST using CLIPS, PyClips and wxPython | version 1.0

Figure 17 Concept Screening Matrix



		Variant 51	Variant 52	Variant 54	Variant 71	Variant 74
Evaluation Criteria	Weight	Rating	Rating	Rating	Rating	Rating
Ease of manufacturing	0.30	3	2	3	2	2
Ease of transportation	0.30	3	3	3	3	3
Ease of maintenance	0.50	3	3	2	2	2
Space requirement	0.30	4	4	4	4	4
Cost	0.64	4	4	4	3	3
Total Score	2.00	7.06	6.76	6.56	5.62	5.62
Rank		1	2	3	5	5

Figure 18 Weight Decision Matrix

After each evaluation process infeasible concept variants can be eliminated or combined and the remaining concept variants proceed to the next evaluation process. For brevity only the final weighted decision matrix is shown in Figure 4.5. According to the evaluation result concept variant number 51 which are (motor) + (shaft) + (bevel gear) + (hand wheel) is selected for further development.

Supporting Case and Validation

The automated Conceptual Design Support Tool (CDST) is flexible enough to get the best final result that follow the functional decomposition of a design. In the case of Shean Juinn Chiou and Sridhar Kota [2], the earliest method is just the same where we had to decompose the functions and sub-function of the design that we need. Second part of it that what make our method in designing differ which is the method that they propose is by using first level representation which captures the type of motion of the design as follows: (a) *the types of motion*, and (b) *type of spatial relationship between the input and the output* (Motion Transformation Matrices). On the second level representations is operation constraint vector (OCV) where it captures the constraint of the design.

As for the method that I used was: (a) *concept generation*, where the functions and sub-functions based on the functional decomposition were input into the CDST and automatically created the morphology chart, (b) *concept combination*, where the list of variant were sort out leave it only the possible concept need for the design, and lastly (c) *concept evaluation*, where we had to evaluate the weight of each variant design and the CDST will automatically rank out the best result for the design. The components of the selected concept variant are found in existing ABC machine ensuring that the validity and practicality of the selected concept variant.

4.5 Case Study 2

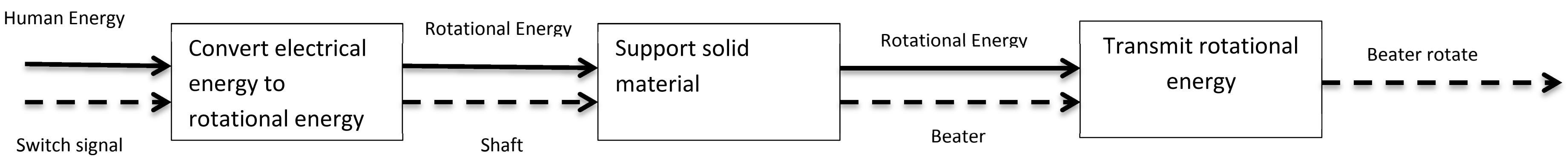
Egg Beater

Figure 19 Egg Beater (YT Trading Sdn. Bhd.)

Egg beater had three main sub-functions for it to work. The first one is the motor inside the machine where it will convert the electricity into rotating movement. When the user switch on the power button, the motor inside will automatically move in rotational movement. Second sub-function is where the machine will had a connector to transmit the rotational energy from the motor. Lastly the beater where it will receive the rotational energy from second sub-function and this rotational energy will then manage to beat the egg inside the bowl.

1. *Functional Decomposition*

<u>Egg Beater</u>



Functional Decomposition of Egg Beater

2. *Concept Generation*

Morphology chart of egg beater will create after inputting all the sub-functions in the software. Unrelated concept that had in the morphology chart can remove during this part.

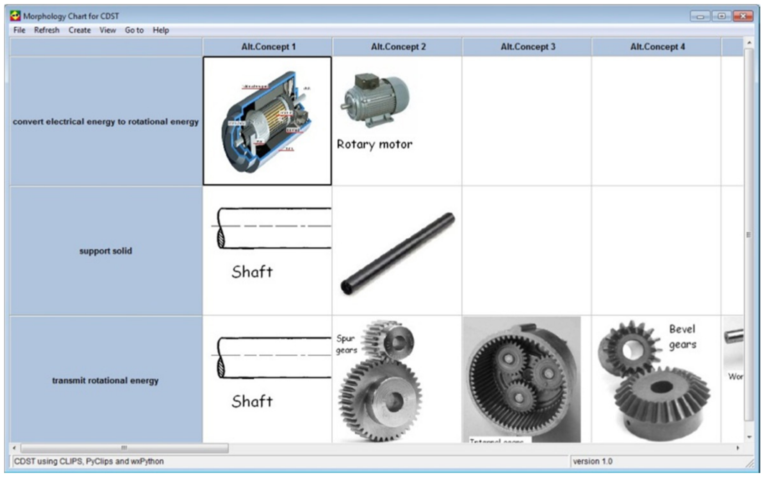


Figure 20 Morphology Chart for Egg Beater

3. *Concept Combination*

After finish removing all unrelated concept from the morphology chart, concept combination is where all concept will be combined with various kind of variant. Below is the figure of concept combination.

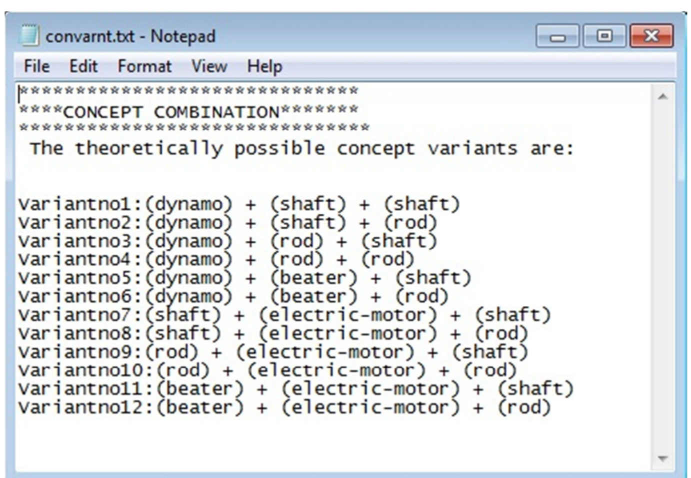
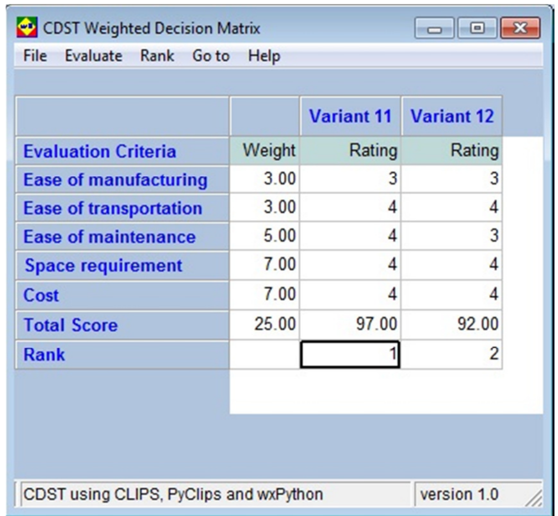


Figure 21 Concept Combination of Egg Beater

4. *Concept Evaluation*

This is the final part of conceptual design where the designer will get the best design base on the rank calculated. We can see that variant 11 (beater + electric motor + shaft) is the best concept design for egg beater.



		Variant 11	Variant 12
Evaluation Criteria	Weight	Rating	Rating
Ease of manufacturing	3.00	3	3
Ease of transportation	3.00	4	4
Ease of maintenance	5.00	4	3
Space requirement	7.00	4	4
Cost	7.00	4	4
Total Score	25.00	97.00	92.00
Rank		1	2

Figure 22 Weight Decision Matrix for Egg Beater

Validation

The method that I used was: (a) *concept generation*, where the functions and sub-functions based on the functional decomposition were input into the CDST and automatically created the morphology chart, (b) *concept combination*, where the list of variant were sort out leave it only the possible concept need for the design, and lastly (c) *concept evaluation*, where we had to evaluate the weight of each variant design and the CDST will automatically rank out the best result for the design. The components of the selected concept variant are found in existing egg beater ensuring that the validity and practicality of the selected concept variant.

4.6 Case Study 3

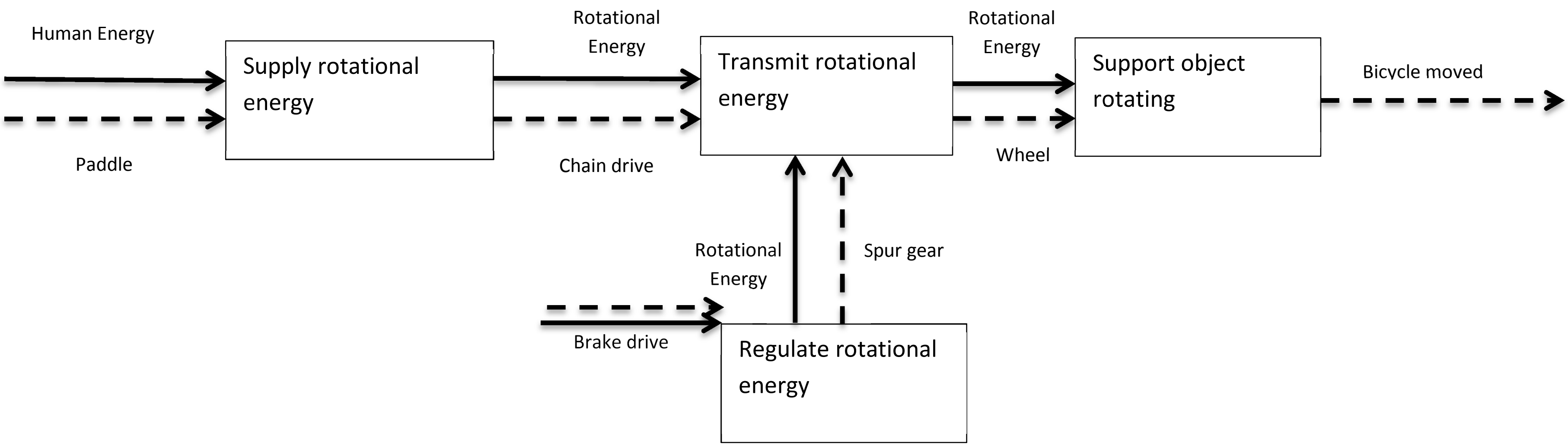
Bicycle

Figure 23 Bicycle (Bernard Dery, 2005-2011)

Bicycle had 4 main sub-functions for it to works. The first sub-function is the paddle where rotational movement from the user will supply to the paddle. Second part is where a mechanism will transmit the rotational energy from the paddle. Third is where the support objects to support the bicycle to move, last but not least mechanism that function to regulate the speed of the bike. This is essential for the user where they can change their speed anytime their want.

1. *Functional Decomposition*

Bicycle



Functional Decomposition of Bicycle

2. *Concept Generation*

Morphology chart of bicycle will create after inputting all the sub-functions in the software. Unrelated concept that had in the morphology chart can remove during this part.

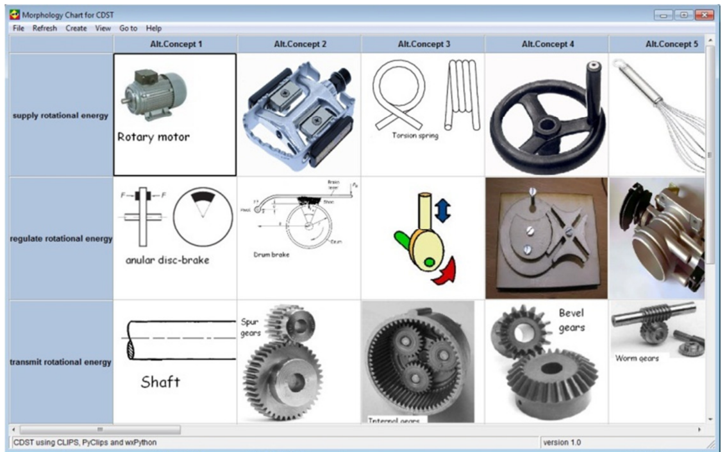
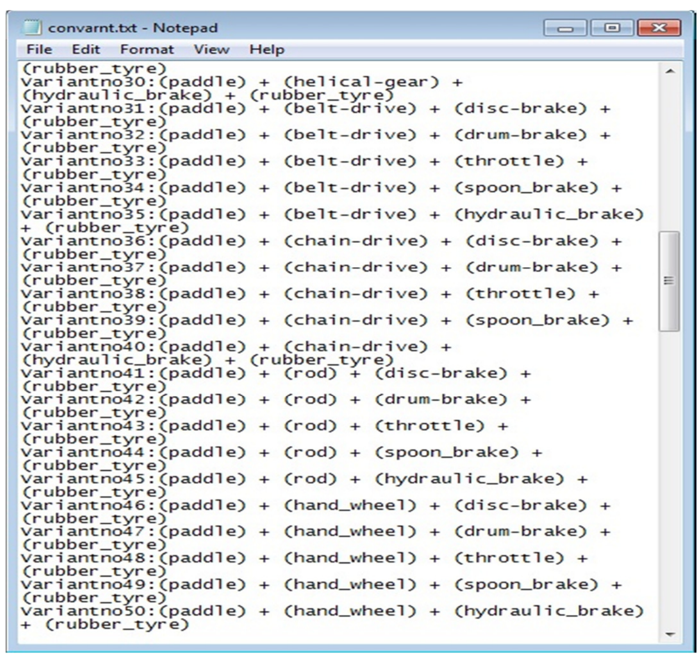


Figure 24 Morphology Chart for Bicycle

3. *Concept Combination*

After finish removing all unrelated concept from the morphology chart, concept combination is where all concept will be combined with various kind of variant. Below is the figure of concept combination.

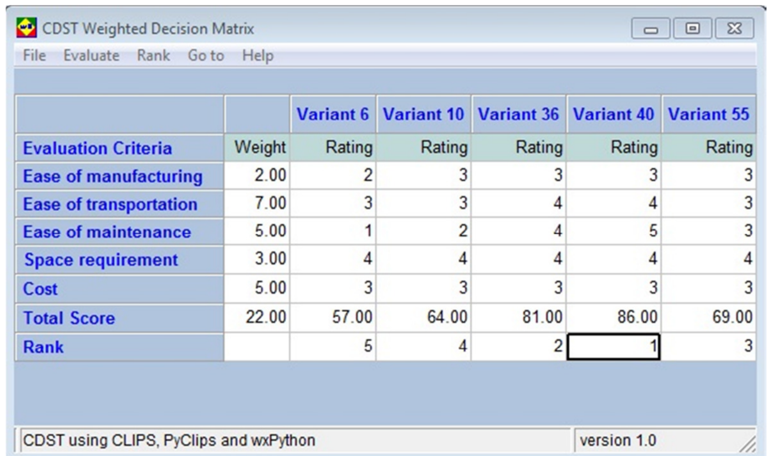



```
(rubber_tyre)
variantno30:(paddle) + (helical-gear) +
(hydraulic_brake) + (rubber_tyre)
variantno31:(paddle) + (belt-drive) + (disc-brake) +
(rubber_tyre)
variantno32:(paddle) + (belt-drive) + (drum-brake) +
(rubber_tyre)
variantno33:(paddle) + (belt-drive) + (throttle) +
(rubber_tyre)
variantno34:(paddle) + (belt-drive) + (spoon_brake) +
(rubber_tyre)
variantno35:(paddle) + (belt-drive) + (hydraulic_brake)
+ (rubber_tyre)
variantno36:(paddle) + (chain-drive) + (disc-brake) +
(rubber_tyre)
variantno37:(paddle) + (chain-drive) + (drum-brake) +
(rubber_tyre)
variantno38:(paddle) + (chain-drive) + (throttle) +
(rubber_tyre)
variantno39:(paddle) + (chain-drive) + (spoon_brake) +
(rubber_tyre)
variantno40:(paddle) + (chain-drive) +
(hydraulic_brake) + (rubber_tyre)
variantno41:(paddle) + (rod) + (disc-brake) +
(rubber_tyre)
variantno42:(paddle) + (rod) + (drum-brake) +
(rubber_tyre)
variantno43:(paddle) + (rod) + (throttle) +
(rubber_tyre)
variantno44:(paddle) + (rod) + (spoon_brake) +
(rubber_tyre)
variantno45:(paddle) + (rod) + (hydraulic_brake) +
(rubber_tyre)
variantno46:(paddle) + (hand_wheel) + (disc-brake) +
(rubber_tyre)
variantno47:(paddle) + (hand_wheel) + (drum-brake) +
(rubber_tyre)
variantno48:(paddle) + (hand_wheel) + (throttle) +
(rubber_tyre)
variantno49:(paddle) + (hand_wheel) + (spoon_brake) +
(rubber_tyre)
variantno50:(paddle) + (hand_wheel) + (hydraulic_brake)
+ (rubber_tyre)
```

Figure 25 Concept Combination for Bicycle

4. *Concept Evaluation*

This is the final part of conceptual design where the designer will get the best design base on the rank calculated. We can see that variant 40 (paddle + chain drive + hydraulic brake + rubber tire) is the best concept design for bicycle.



		Variant 6	Variant 10	Variant 36	Variant 40	Variant 55
Evaluation Criteria	Weight	Rating	Rating	Rating	Rating	Rating
Ease of manufacturing	2.00	2	3	3	3	3
Ease of transportation	7.00	3	3	4	4	3
Ease of maintenance	5.00	1	2	4	5	3
Space requirement	3.00	4	4	4	4	4
Cost	5.00	3	3	3	3	3
Total Score	22.00	57.00	64.00	81.00	86.00	69.00
Rank		5	4	2	1	3

Figure 26 Weight Decision Matrix for Bicycle

Validation

The method that I used was: (a) *concept generation*, where the functions and sub-functions based on the functional decomposition were input into the CDST and automatically created the morphology chart, (b) *concept combination*, where the list of variant were sort out leave it only the possible concept need for the design, and lastly (c) *concept evaluation*, where we had to evaluate the weight of each variant design and the CDST will automatically rank out the best result for the design. Based on '*Engineering Design'* (Dieter Schmidt) [4], the components of the selected concept variant are found in existing bicycle ensuring that the validity and practicality of the selected concept variant.

4.7 Case Study 4

Lift

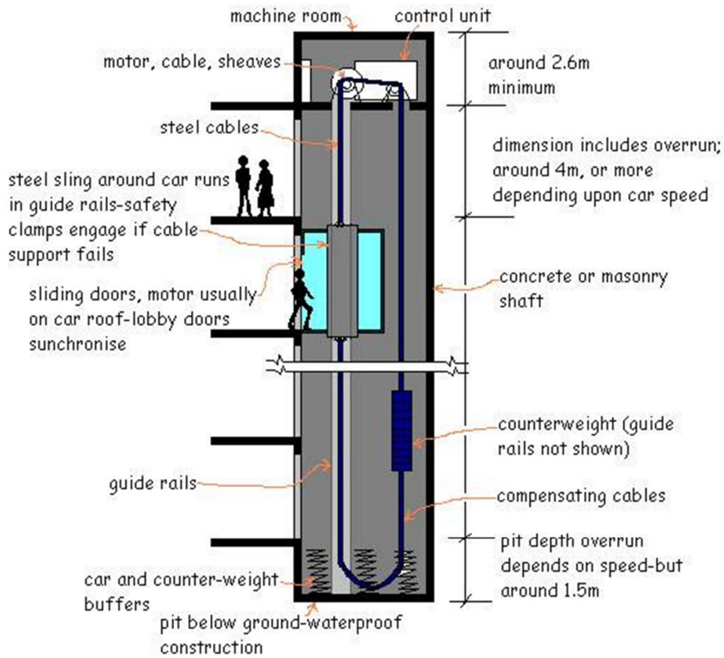
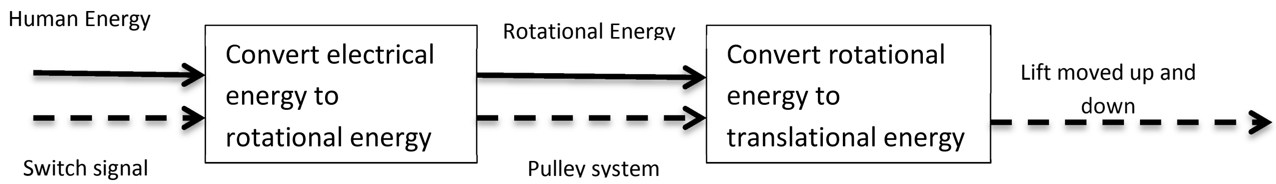


Figure 27 Lift Mechanism (Bernard Dery, 2005-2011)

Lift only has two main sub-functions which are a motor to convert electricity to rotational energy and a mechanism that can convert the rotational energy from the motor into translational energy. This made the lift move upwards and downwards depending on the user of the lift.

1. *Functional Decomposition*

Lift



Functional Decomposition of Lift

2. *Functional Generation*

Morphology chart of lift will create after inputting all the sub-functions in the software. Unrelated concept that had in the morphology chart can remove during this part.

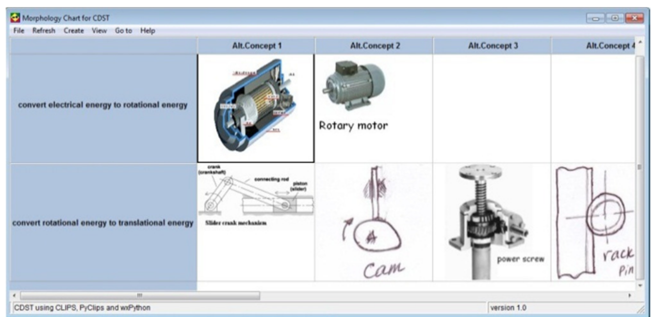
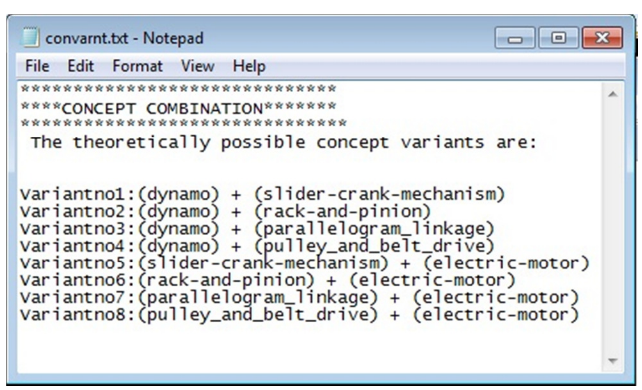


Figure 28 Functional Generation of Lift

3. *Functional Combination*

After finish removing all unrelated concept from the morphology chart, concept combination is where all concept will be combined with various kind of variant. Below is the figure of concept combination.

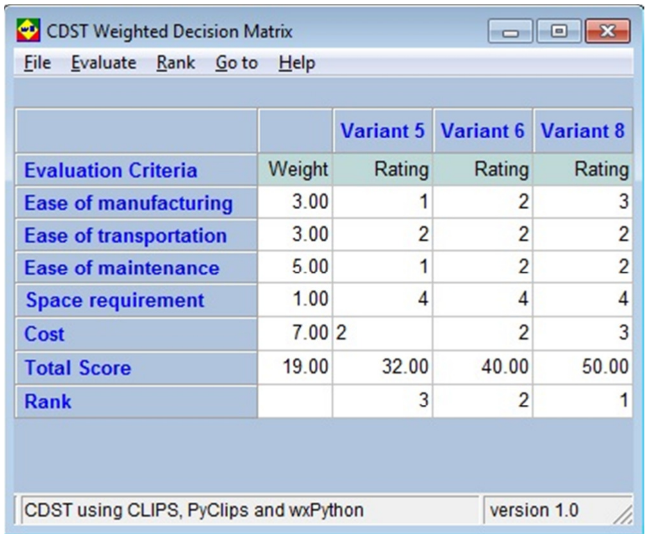

```
convarnt.txt - Notepad
File Edit Format View Help
********************************
****CONCEPT COMBINATION*******
*********************************
 The theoretically possible concept variants are:

variantno1:(dynamo) + (slider-crank-mechanism)
variantno2:(dynamo) + (rack-and-pinion)
variantno3:(dynamo) + (parallelogram_linkage)
variantno4:(dynamo) + (pulley_and_belt_drive)
variantno5:(slider-crank-mechanism) + (electric-motor)
variantno6:(rack-and-pinion) + (electric-motor)
variantno7:(parallelogram_linkage) + (electric-motor)
variantno8:(pulley_and_belt_drive) + (electric-motor)
```

Figure 29 Functional Combination of Lift

4. *Functional Decomposition*

This is the final part of conceptual design where the designer will get the best design base on the rank calculated. We can see that variant 40 (paddle + chain drive + hydraulic brake + rubber tire) is the best concept design for bicycle.



		Variant 5	Variant 6	Variant 8
Evaluation Criteria	Weight	Rating	Rating	Rating
Ease of manufacturing	3.00	1	2	3
Ease of transportation	3.00	2	2	2
Ease of maintenance	5.00	1	2	2
Space requirement	1.00	4	4	4
Cost	7.00	2	2	3
Total Score	19.00	32.00	40.00	50.00
Rank		3	2	1

Figure 30 Weight Decision Matrix of Lift

Validation

The method that I used was: (a) *concept generation*, where the functions and sub-functions based on the functional decomposition were input into the CDST and automatically created the morphology chart, (b) *concept combination*, where the list of variant were sort out leave it only the possible concept need for the design, and lastly (c) *concept evaluation*, where we had to evaluate the weight of each variant design and the CDST will automatically rank out the best result for the design. The components of the selected concept variant are found in existing lift ensuring that the validity and practicality of the selected concept variant.

4.8 Case Study 5

Sewing Machine

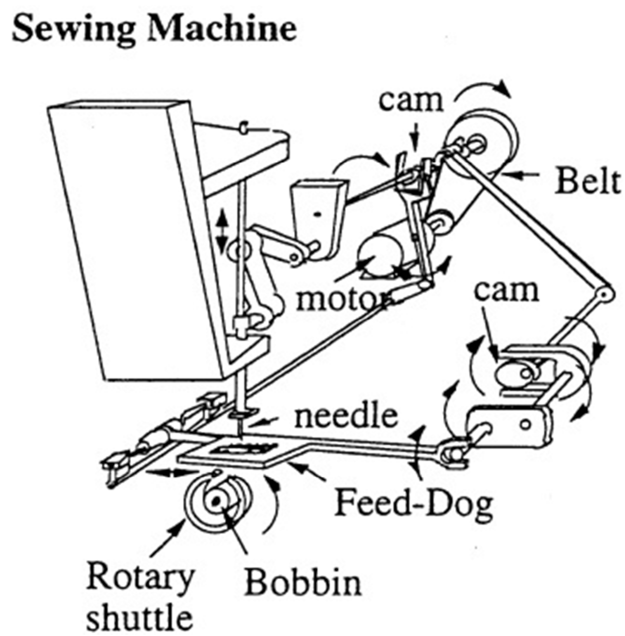
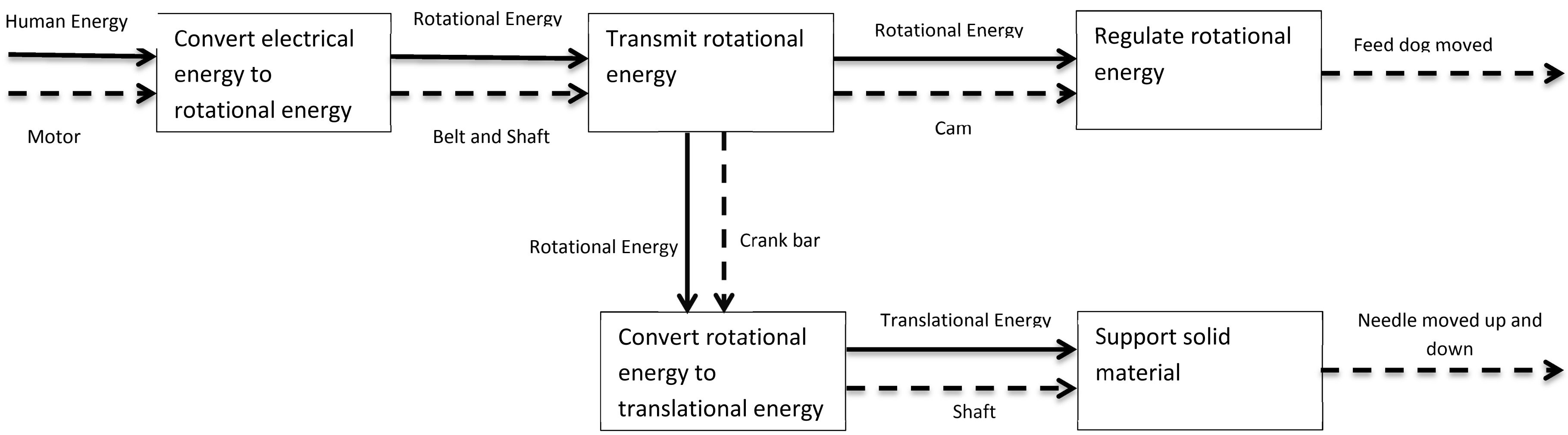


Figure 31 Sewing Machine (Shean Juinn Chiou, Sridhar Kota)

Sewing machine has 5 main sub-functions for it to works. The first one is a motor to convert electricity into rotational movement. Second is a mechanism to help transmit the rotational energy from the motor. This can be using either belt or shaft to transmit the rotational energy. Third sub-function is to regulate the speed of the sewing machine feed dog to guide the cloth moving upwards and downwards. As for the fourth sub-functions, mechanism that can convert rotational energy in translational energy will be needed. This is because translational movement is needed to move the needle and last but not least a mechanism that function to support solid material.

1. *Functional Decomposition*

Sewing Machine



Functional Decomposition of Sewing Machine

2. *Functional Generation*

Morphology chart of lift will create after inputting all the sub-functions in the software. Unrelated concept that had in the morphology chart can remove during this part.

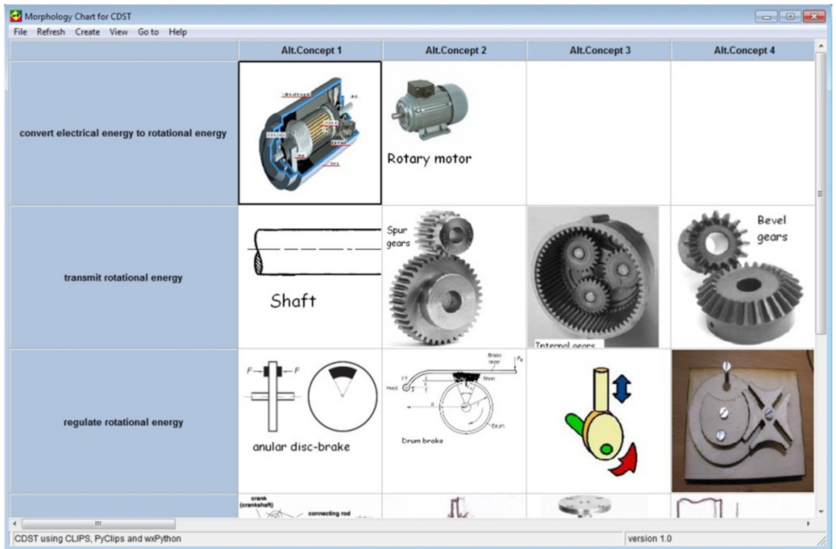
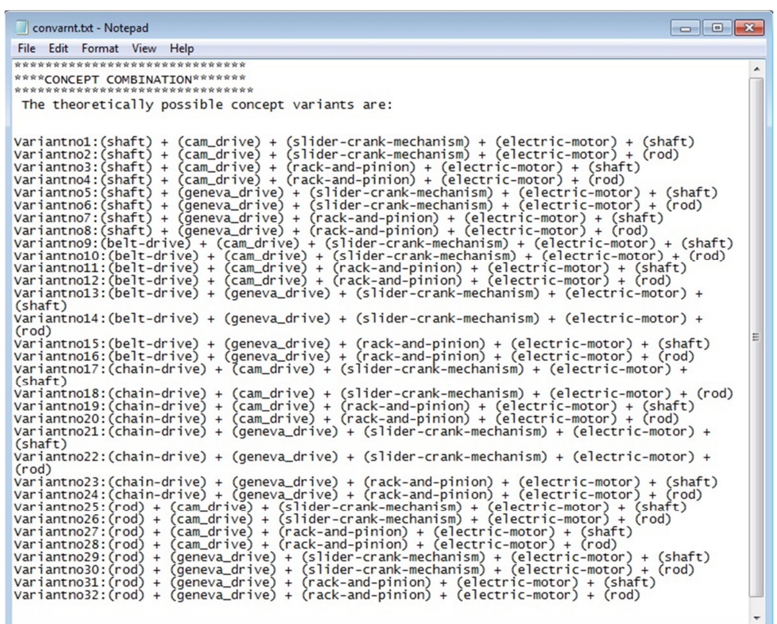


Figure 32 Morphology Chart for Sewing Machine

3. *Functional Combination*

After finish removing all unrelated concept from the morphology chart, concept combination is where all concept will be combined with various kind of variant. Below is the figure of concept combination.


convarnt.txt - Notepad

File Edit Format View Help

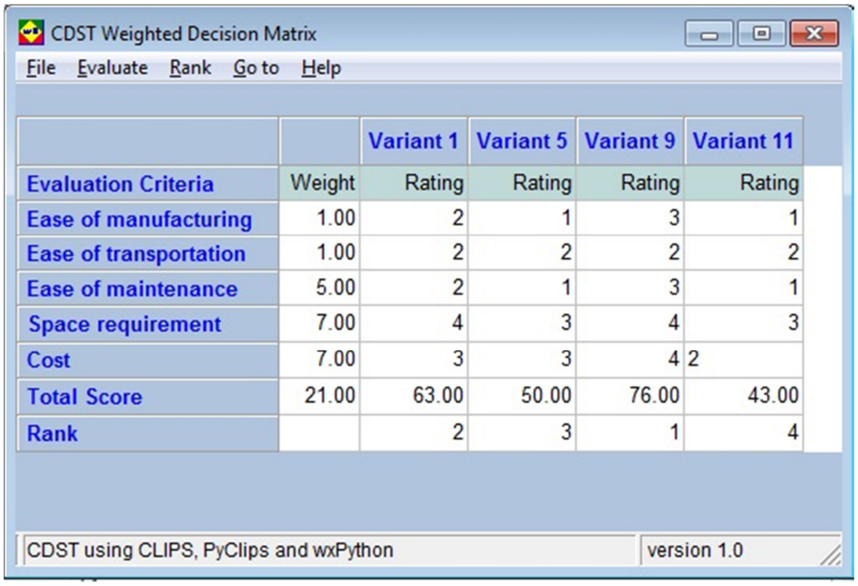
```
*****************************
****CONCEPT COMBINATION*******
******************************
 The theoretically possible concept variants are:

Variantno1:(shaft) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (shaft)
Variantno2:(shaft) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno3:(shaft) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno4:(shaft) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno5:(shaft) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) + (shaft)
Variantno6:(shaft) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno7:(shaft) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno8:(shaft) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno9:(belt-drive) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (shaft)
Variantno10:(belt-drive) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno11:(belt-drive) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno12:(belt-drive) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno13:(belt-drive) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) +
(shaft)
Variantno14:(belt-drive) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) +
(rod)
Variantno15:(belt-drive) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno16:(belt-drive) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno17:(chain-drive) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) +
(shaft)
Variantno18:(chain-drive) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno19:(chain-drive) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno20:(chain-drive) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno21:(chain-drive) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) +
(shaft)
Variantno22:(chain-drive) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) +
(rod)
Variantno23:(chain-drive) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno24:(chain-drive) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno25:(rod) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (shaft)
Variantno26:(rod) + (cam_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno27:(rod) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno28:(rod) + (cam_drive) + (rack-and-pinion) + (electric-motor) + (rod)
Variantno29:(rod) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) + (shaft)
Variantno30:(rod) + (geneva_drive) + (slider-crank-mechanism) + (electric-motor) + (rod)
Variantno31:(rod) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (shaft)
Variantno32:(rod) + (geneva_drive) + (rack-and-pinion) + (electric-motor) + (rod)
```

Figure 33 Functional Combination of Sewing Machine

4. Functional Evaluation

This is the final part of conceptual design where the designer will get the best design base on the rank calculated. We can see that variant 9 (belt drive + cam drive + slider crank mechanism + electric motor + shaft) is the best concept design for sewing machine.



		Variant 1	Variant 5	Variant 9	Variant 11
Evaluation Criteria	Weight	Rating	Rating	Rating	Rating
Ease of manufacturing	1.00	2	1	3	1
Ease of transportation	1.00	2	2	2	2
Ease of maintenance	5.00	2	1	3	1
Space requirement	7.00	4	3	4	3
Cost	7.00	3	3	4	2
Total Score	21.00	63.00	50.00	76.00	43.00
Rank		2	3	1	4

Figure 34 Weight Decision Matrix of Sewing Machine

Validation

The method that I used was: (a) *concept generation*, where the functions and sub-functions based on the functional decomposition were input into the CDST and automatically created the morphology chart, (b) *concept combination*, where the list of variant were sort out leave it only the possible concept need for the design, and lastly (c) *concept evaluation*, where we had to evaluate the weight of each variant design and the CDST will automatically rank out the best result for the design. Based on '*Automated Conceptual* Design' (Shean Juinn Chiou) [2], the components of the selected concept variant are found in existing sewing machine ensuring that the validity and practicality of the selected concept variant.

CONCLUSION & RECOMMENDATION

In conclusion, my project presented in this paper by using conceptual design support tools (CDST) assists designers to perform conceptual design process more efficiently than manual design by handling some of the repetitive tasks and providing available concepts in the database. It supports the designer through the conceptual process by the designer's decision as input and providing the results as an output. It generates alternative concepts for a given set of sub-functions in the functional structure and display on the morphology chart.

In this paper i had demonstrate by using CDST to design a product without doing a lot of repetitive tasks and still manage to get valid final result. Hence, more time will be saved where designer would not need to spend most of their time during concept evaluation as state on problem statement.

In future works I hope the partial automated CDST can upgrade to fully automated software. This will ensure the software will be easier and comfortable to the user where the user would not need to weight the concepts for concept evaluation.

Last but not least to enhance more the CDST software on the functions not only limited to mechanisms but for all functions such as signal and support. This will lead the software to more completion of automatically CDST software. The software also should be enhance so user can edit the 'newly added concepts' in the software. This make editing added concepts easier without reinstall back and redo all the new concepts.

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Appendix : Function Definitions

1) **Branch**. To cause a flow (material, energy, signal) to no longer be joined or mixed.
   a) **Separate**. To isolate a flow (material, energy, signal) into distinct components. The separated components are distinct from the flow before separation, as well as each other. Example: A glass prism *separates* light into different wavelength components to produce a rainbow.
      i) **Divide**. To separate a flow. Example: A vending machine divides the solid form of coins into appropriate denominations.
      ii) **Extract**. To draw, or forcibly pull out, a flow. Example: A vacuum cleaner *extracts* debris from the imported mixture and exports clean air to the environment.
      iii) **Remove**. To take away a part of a flow from its prefixed place. Example: A sander *removes* small pieces of the wood surface to smooth the wood.
   b) **Distribute**. To cause a flow (material, energy, signal) to break up. The individual bits are similar to each other and the undistributed flow. Example: An atomizer *distributes* (or sprays) hair-styling liquids over the head to hold the hair in the desired style.
2) **Channel**. To cause a flow (material, energy, signal) to move from one location to another location.
   a) **Import**. To bring in a flow (material, energy, signal) from outside the system boundary. Example: A physical opening at the top of a blender pitcher *imports* a solid (food) into the system. Also, a handle on the blender pitcher imports a human hand.
   b) **Export**. To send a flow (material, energy, signal) outside the system boundary. Example: Pouring blended food out of a standard blender pitcher *exports* liquid from the system. The opening at the top of the blender is a solution to the export sub-function.
   c) **Transfer**. To shift, or convey, a flow (material, energy, signal) from one place to another.
      i) **Transport**. To move a material from one place to another. Example: A coffee maker *transports* liquid (water) from its reservoir through its heating chamber and then to the filter basket.
      ii)**Transmit**. To move an energy from one place to another. Example: In a hand held power sander, the housing of the sander *transmits* human force to the object being sanded.
   d) **Guide**. To direct the course of a flow (material, energy, signal) along a specific path. Example: A domestic HVAC system *guides* gas (air) around the house to the correct locations via a set of ducts.
      i) **Translate**. To fix the movement of a flow by a device into one linear direction. Example: In an assembly line, a conveyor belt *translates* partially completed products from one assembly station to another.
      ii) **Rotate**. To fix the movement of a flow by a device around one axis. Example: A computer disk drive *rotates* the magnetic disks around an axis so that the head can read data.

iii) **Allow degree of freedom (DOF)**. To control the movement of a flow by a force external to the device into one or more directions. Example: To provide easy trunk access and close appropriately, trunk lids need to move along a specific degree of freedom. A four bar linkage *allows a rotational DOF* for the trunk lid.

3) **Connect**. To bring two or more flows (material, energy, signal) together.

a) **Couple**. To join or bring together flows (material, energy, signal) such that the members are still distinguishable from each other. Example: A standard pencil couples an eraser and a writing shaft. The coupling is performed using a metal sleeve that is crimped to the eraser and the shaft.

i) **Join**. To couple flows together in a predetermined manner. Example: A ratchet *joins* a socket on its square shaft interface.

ii) **Link**. To couple flows together by means of an intermediary flow. Example: A turnbuckle *links* two ends of a steering cable together.

b) **Mix**. To combine two flows (material, energy, signal) into a single, uniform homogeneous mass. Example: A shaker *mixes* a paint base and its dyes to form a homogeneous liquid.

4) **Control Magnitude**. To alter or govern the size or amplitude of a flow (material, energy, signal).

a) **Actuate**. To commence the flow of energy, signal, or material in response to an imported control signal. Example: A circuit switch *actuates* the flow of electrical energy and turns on a light bulb.

b) **Regulate**. To adjust the flow of energy, signal, or material in response to a control signal, such as a characteristic of a flow. Example: Turning the valves *regulates* the flow rate of the liquid flowing from a faucet.

i) **Increase**. To enlarge a flow in response to a control signal. Example: Opening the valve of a faucet further *increases* the flow of water.

ii) **Decrease**. To reduce a flow in response to a control signal. Example: Closing the value further *decreases* the flow of propane to the gas grill.

c) **Change**. To adjust the flow of energy, signal, or material in a predetermined and fixed manner. Example: In a hand held drill, a variable resistor *changes* the electrical energy flow to the motor thus changing the speed the drill turns.

i) **Increment**. To enlarge a flow in a predetermined and fixed manner. Example: A magnifying glass *increments* he visual signal (i.e. the print) from a paper document.

ii) **Decrement**. To reduce a flow in a predetermined and fixed manner. Example: The gear train of a power screwdriver *decrements* the flow of rotational energy.

iii) **Shape**. To mold or form a flow. Example: In the auto industry, large presses *shape* sheet metal into contoured surfaces that become fenders, hoods and trunks.

iv) **Condition**. To render a flow appropriate for the desired use. Example: To prevent damage to electrical equipment, a surge protector *conditions* electrical energy by excluding spikes and noise (usually through capacitors) from the energy path.

d) **Stop**. To cease, or prevent, the transfer of a flow (material, energy, signal). Example: A reflective coating on a window *stops* the transmission of UV radiation through a window.
   i) **Prevent**. To keep a flow from happening. Example: A submerged gate on a dam wall *prevents* water from flowing to the other side.
   ii) **Inhibit**. To significantly restrain a flow, though a portion of the flow continues to be transferred. Example: The structures of space vehicles *inhibits* the flow of radiation to protect crew and cargo.

5) **Convert**. To change from one form of a flow (material, energy, signal) to another. For completeness, any type of flow conversion is valid. In practice, conversions such as convert electricity to torque will be more common than convert solid to optical energy. Example: An electrical motor *converts* electricity to rotational energy.
6) **Provision**. To accumulate or provide a material or energy flow.
   a) **Store**. To accumulate a flow. Example: A DC electrical battery *stores* the energy in a flashlight.
      i) **Contain**. To keep a flow within limits. Example: A vacuum bag *contains* debris vacuumed from a house.
      ii) **Collect**. To bring a flow together into one place. Example: Solar panels *collect* ultraviolet sun rays to power small mechanisms.
   b) **Supply**. To provide a flow from storage. Example: In a flashlight, the battery *supplies* energy to the bulb.
7) **Signal**. To provide information on a material, energy or signal flow as an output signal flow. The information providing flow passes through the function unchanged.
   a) **Sense**. To perceive, or become aware, of a flow. Example: An audiocassette machine *senses* if the end of the tape has been reached.
      i) **Detect**. To discover information about a flow. Example: A gauge on the top of a gas cylinder *detects* proper pressure ranges.
      ii) **Measure**. To determine the magnitude of a flow. Example: An analog thermostat *measures* temperature through a bimetallic strip.
   b) **Indicate**. To make something known to the user about a flow. Example: A small window in the water container of a coffee maker *indicates* the level of water in the machine.
      i) **Track**. To observe and record data from a flow. Example: By *tracking* the performance of batteries, the low efficiency point can be determined.
      ii) **Display**. To reveal something about a flow to the mind or eye. Example: The x-y-z-coordinate display on a vertical milling machine *displays* the precise location of the cutting tool.
   c) **Process**. To submit information to a particular treatment or method having a set number of operations or steps. Example: A computer *processes* a login request signal before allowing a user access to its facilities.

8) **Support**. To firmly fix a material into a defined location, or secure an energy or signal into a specific course.
   a) **Stabilize**. To prevent a flow from changing course or location. Example: On a typical canister vacuum, the center of gravity is placed at a low elevation to *stabilize* the vacuum when it is pulled by the hose.
   b) **Secure**. To firmly fix a flow path. Example: On a bicycling glove, a Velcro strap *secures* the human hand in the correct place.
   c) **Position**. To place a flow (material, energy, signal) into a specific location or orientation. Example: The coin slot on a soda machine *positions* the coin to begin the coin evaluation and transportation procedure.