Box Folding Machine Design by Using Product Design Method
Functional Based Model

Yuxing Wang and Robert B. Stone*
Oregon State University, Corvallis, OR 97331, America

*Corresponding author e-mail: wangyux1121@foxmail.com

Abstract. In order to meet the growing demand for products, scientists have been developing product design methods. Based on the existing product design methods and the Oregon State University's Modern Product Design, this report talks about the improved product design method and uses this method to design one new case. The example case is box folding machine. It consists of a feeding system, a transport system, a folding system, and an exporting system. The core part folding system consists of a two-step folding system. By folding twice, the finished box is wrapped and self-locking. Through the final estimation, the folding speed of the box folding assembly line is five times that of manual folding. As a result, the box folding assembly line can meet the needs of fast folding.

Keyword: Customer Needs, Concepts, Functional Model

1. Introduction of Product Design Method

1.1. Literature Review

With the continuous improvement of people's living standards, people's demand for new products is getting higher and higher. To satisfy the needs of each of various types of requirements, numerous scientists have devoted different opinions and every effort to solve the problem of product design [1]. Why do people value product design so much? As Otto said, the design of new products is like a battleground, and designers are the first-line combat soldiers who lead and execute the war [2]. Whoever controls this field firstly takes the lead in the market. Besides, according to G. Ulman, product design methods are important because people's demand for new products is continuous. People have been always pursuing higher quality and more cost-effective products [3]. Many researchers in product design area have been trying to figure out how to design an excellent product. As a result, a large variety of types of design processes and methods have been created. However, there is no unified standard or conclusion here. There are four main design approaches [1].

A Systematic Approach, which is made by Pahl and Beitz, has four phases: Task clarification, conceptual design, embodiment, and detail design [4]. The first step of this method is to identify
requirements, and second step develops reasonable solutions for each need. Next step is embodiment design, and during this step, solutions transform to the technical product. For the final step, the product will be improved to satisfy all the requirements, and all the details will be considered during the last stage. Axiomatic design requires a scientific approach that can find the best model [1]. The feature of this method changes the design method from creativity and imagination to scientific laws and rules [5].

Altshuller proposes that creativity may obey the scientific steps, and he advocates design with the branches of the problem or not entire issues. This method, called Theory of Inventive Problem Solving (TRIZ) [6].

In What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services, the correct input of the design is vital because wrong information can make the final products fail. Thus, Ulwick proposes the designer not only consider customer needs, customers’ jobs, outcomes, also constraints should be thought as well [1][7].

Based on above four product design methods and the modern product design methodology of Oregon State University's Modern Product Design, this report talks about the product design methods, and uses this method to design an example case: box folding machine. In this report, the design process includes three phases, clarify problem, develop concepts, and embody design. This process starts with what to design, and it ends with the product that can satisfy customer needs.

1.1.1 Problem Clarification

1.1.1.1 Mission statement

The mission statement is a brief description of a new product, which describes in the audit report mainly discuss the evolution from a vision statement to a mission statement. The vision statement typically defines the overview and overall intent of the organization. However, the vision statement lacks details on how to fulfill the primary intention of the new product. The revised version of a vision statement evolved into a mission statement, which serves as a goal that the organization can visualize and challenge itself to meet. The idea captures the development of a new product for the customer and industry in the future.

1.1.1.2 Customer needs

Customer need is a voice from the customer, and it goes through the entire process of product design [8]. In other words, customer needs are customer wants, and the customer expects. Therefore, whether it can meet all customer needs is also a way to judge whether the final product is qualified. For gathering customer needs, questionnaires and interviews are two useful methods.

1.1.1.3 Functional modeling

Functional modeling plays a vital role during the product design process, which represent an independent form blueprint of a product, and which can tell designers, which function needs to be achieved [9]. The central realization is the function of converting customer needs into products. The functional model can help answer some design questions with a focus “on what has to be achieved by a new concept or redesign and not how it is to be achieved” [1][2].

For creating a functional model, initially, the process description should be made to identify the high-level user and device functions which describe the complete product life cycle. In general, there are three phases of process description: Preparation, Execution, and Conclusion, which represent from purchase to disposal of.

After making the process description, the life cycle of the product is clear. Next step is to create functional modeling. The functional model is abstract in the process of product design. When more details need to be considered as accommodating human-based operations and environmental interactions, the
functional model is not good enough. Therefore, the process modeling methodology is made to solve this problem\textsuperscript{[1]}. Similar to the steps of creating a functional model, the process model begins with creating a black box. This black box illustrates the transformations of energies, materials, and signal. Then, the black box model will be decomposed into the event line with each event having a detail configuration model showing the flow of processes in each event.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{black_box.png}
\caption{Example of Black Box}
\end{figure}

\textbf{1.1.2 Conceptual design}
This process mainly has two steps. The first step called concept generation, and the second step called concept selection. Concept generation is a process that shows the abstract description convert to product idea\textsuperscript{[2]}. In general, this process should be finished by a team because different people have different perspectives; in this way, it is easy to get more concepts.

After enough concepts generated, the second step is selecting concepts, which is a critical point in the process of product design. The method used to reduce concepts by making the Pugh chart. A Pugh chart is a simple design tool for comparing design ideas against your design criteria early in the design process. The left column lists evaluation criteria and selects one concept as a datum for comparing with all the other concepts\textsuperscript{[10]}. According to the total score, the best concept can be found.

\textbf{1.1.3 Embodiment design}
After the concept design, a concept has been logically selected from numerous concepts, so next step is embodiment design. Embodiment design has more specific parameters and layout of the product\textsuperscript{[2]}. At this stage, the designer needs to determine the overall layout design, shape, and materials. The final design needs to analyze the advantages and disadvantages to optimize, and the design focus shifts to more details such as production process, product size and so on\textsuperscript{[11]}.

\section{Case study: Box Folding Machine}

\subsection{Problem Clarification}

\subsubsection{Mission statement}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Product description & Help people folding paperboard \\
\hline
Goal & Making box, faster folding \\
\hline
Primary market & Who use paper box for packing, transporting... \\
\hline
\end{tabular}
\caption{Box folding machine}
\end{table}
2.1.2 Customer needs
The customer is Sun Sugar Farm. There are some information and needs gathering from the talking with the owner of this farm. She designed a paper box for packing her produce. However, folding this paperboard by hand is time-consuming. Thus, she would like to have an automating assembly line to faster fold those boxes.

Customer needs from the interview:
A. Could be used on small and large scale farms, in the field, or inside at the packinghouse assembly line.
B. Could handle the different sizes from the Low Profile Pint to the new two-pound container.
C. Could handle the different materials from lighter SBS to the more massive micro flute and possible grass fiber version.
D. Automation must be used for fast folding.

2.1.3 Functional modeling
After analysis of customer needs, the next step is to solve how to meet all of them. Based on the methodology provided by Nagel, the functional model should be used. Also, the functional model can enhance creativity and emphasis on what must be accomplished.

**Figure 2.** Process description for Assembly line

First step is to build process description, and it analyzes the entire life cycle of the product through three phases. The process description for assembly line is shown in Fig 2, also because the folding is the main problem that needs to be solved, the system boundary will include importing paperboard, folding, and exporting paper box.

In order to identify overall function and input/output flows, next step is to create the black box model.
Figure 3. Black box of Assembly Line

For the black box of assembly line, the input flows have material flow, energy flow and signal flow. Hand is needed to input the paperboard, and electricity supports energy for the assemble working. Because this is an automatic assemble line, the control signal is indispensable input. As the electricity is input, there must be energy transfer. As the result, heat and noise are parts of outputs. The good automatic assemble line needs to show the working situation by visual signal, so visual signal is output.

Using the Zen method which involved engineers to imagine being one of this input to understand and explain the product flow. Fig 4 show the complete functional model for the Assembly line individually.

Figure 4. Functional model for Assembly line

After analyzing customer need and focus on the interaction of products, the events can be generated by main customer need. Consider of the customer needs of assembly line, three events can be defined: importing, folding, output. Automation level of the machine has been improved to accelerate the folding speed, thus importing, folding and output are processes that can be improved. The process model of assembly line is shown in Fig 5.
2.2 Conceptual Design

2.2.1 Box folding assembly line
As the functional model shows, the box folding assembly line has three parts: importing, folding, and exporting.

2.2.1.1 Importing part
The first concept uses suction cups to lift the paperboard from the storage and to place the paperboard to specified position.

Second concept comes from printer feeding part. It uses the difference of friction between paper and paper and between paper and roller. The roller has larger friction, so the roller can grab the only one sheet of paper and feed it into working area.

2.2.1.2 Folding part
A. Box folding
This concept comes from robotic by using the robotic arm and control system to imitate the real hand to fold. It’s like folding a box by hand, one step at a time and often with complex mechanical mechanisms and advanced control systems.

B. Cartons forming
The key part for this concept is to fold box by transporting the paperboard into mold to finish folding process. It’s basically a machine equipped with an automatic arm, and once the carton is formed by means of a mold, box will be transported along a conveyor.

2.2.1.3 Exporting part
A slope can be a simple exporting part, which can transport processed products to a specific direction.

2.3 Embodiment Design
2.3.1 Box folding assembly line

2.3.1.1 Layout

The box folding assembly line consist of importing part, folding part, and exporting part. Because of the particularity of the paperboard, only one-time fold cannot finish it. Thus, the secondary folding system is designed. In addition, the paperboard needs to be transported to the folding part, so a conveyor is designed for transporting paperboard. The layout of box folding assembly line is showing in Fig 6, and the two times folding part is the core of the entire assembly line.

![Image of Box Folding Assembly Line](image)

**Figure 6.** Layout and overall rendering

2.3.1.2 Importing

The main task of the feeding system is to feed the paperboard one by one to the folding part. In addition, considering that the box folding assembly line cannot be overly dependent on human participation, so the feeding system must have a certain function of storing paperboard. A box that holds a hundred sheets of paper is designed to store paperboard, which reduces the number of times people add paper. At the bottom of the box, there is a gap that allows only one piece of paperboard to pass, so that the sheets are transported one by one. A conveyor belt is designed to transport the sheets to the folding section.

2.3.1.3 Folding

At first, the paperboard is transported to the mold, then the air cylinder pushes the pressure head to press the paperboard into the mold, and the paperboard passes through the three steps inside the mold in order to erect the outer edges of the paper. The first-time folding is completed.
Figure 7. Folding part with folding mold

Then, it is second time folding. The pressure head continues to press down on the paperboard until it reaches the second folding system, and then the pressure head returns to original position preparing for next time press. The second folding system mainly folds the unfolded edge back into the interior of the carton by the rotation of the two folding sheets, and due to the design of the paperboard, the excess portion of the edge enters the vent, which is at the bottom of the carton to achieve a self-locking state. The self-locking carton is folded, and the folded carton is very stable and will not be easily deformed.

Figure 8. Positions of some parts

2.3.1.4 Exporting

Exporting part is not a necessary part, so here using a simple mechanics to export the folded boxes.

3. Conclusion and Future Work

The carton forming machine is a relatively mature and common machine. This Box folding machine is designed primarily to meet the needs of the sun sugar farm. The unique place is that the first-time folding is Multi-level folding, and the second folding is required to complete the folding process. The entire project was perfectly completed and met expectations, meeting all customer needs. However, since the simulation prototype was not produced, it was impossible to accurately calculate how much the folding speed was increased. However, it can be obtained by collecting data on a carton forming machine with the
same working principle, the folding speed is 1500 trays/hour (30trays/min) (Econoseal Econoform and Econolock Tray Formers, n.p.). People folded a box by hand for about 10 seconds, after practiced many times. By using the assembly line, the folding speed is almost 5 times that of the pure hand folding speed.

\[
\text{Ratio} = \frac{30 \text{trays/min}}{1\text{tray/10s}} = 5
\]

For future work, the carton forming machine will become more efficient and smarter. The carton forming machine in this report has been equipped with a detection system, but the detection system has certain defects. For example, after detecting the overlap of the sheets, it may not be repaired immediately. Therefore, in the future, a structure can be designed that can detect problems and it can fix problems.

References

[1] Nagel, R. L. (2010, June 10). A Design Framework for Identifying Automation Opportunities. Mechanical Engineering.
[2] K.otto, K. (2001). Product Design: Techniques in Reverse Engineering, Systematic Design, and New Product Development. New York: Prentice-Hall.
[3] G.Ullman, D. (2010). The mechanical design process. New York: McGraw-Hill. Incline Rating. (n.d.). Retrieved from Spinlife: https://www.spinlife.com/spinlifeuniversity/Scooters/Incline_Rating.cfm
[4] Pahl, G. W. (2007). A Systematic Approach, Springer Verlag. Engineering Design. Principle of swivel chair. (2017). Retrieved from shushi100: http://www.shushi100.com/article/xitong/article-121503.html
[5] Suh, (1990). The Principles of Design. New York, NY, Oxford University Press, Inc.
[6] Altshuller, G. (2005). 40 Principles (Extended Edition): TRIZ Keys to Technical Innovation. Technical Innovation Center, Inc. Econoseal Econofrom and Econolock Tray Formers. (n.d.). Retrieved from Propac: https://www.propac.com/packaging-equipment/carton-tray-forming/econoseal-cartoners/tray-formers/econoform-and-econolock/
[7] Ulwick, A. W. (2005). what Customers Want: Using Outcome-Driven Innovation. New York, McGraw-Hill.
[8] Abbie Griffin, J. R. (1993). The voice of the customer. Marketing Science.
[9] Robert B.Stone. (1999). Development of a functional basis for design. ASME Design Engineering Technical Conferences.
[10] Pugh, S. (1996). Creating Innovative Products Using Total Design: The Living Legacy of Stuart Pugh. Boston: Addison-Wesley Longman.
[11] Pahl, G. (1970, January 01). Embodiment Design.