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REQUIREMENTS FOR ADAPTIVE DESIGN A CASE STUDY

by

S. Sivaloganathan

Abstract

It was intended to investigate the requirements for adaptive design, and the approach, Systematic or Conventional, suitable for an adaptive design problem. In this context systematic approach can be defined as the design process using a transparent design model and appropriate design methods while the conventional approach can be defined as the method starting with a solution and using models and trial and error to improve it with no predefined path. A team of students who had education and training on Systematic approach to design was engaged on the development of an adaptive design of an industrial wheelbarrow. A striking observation was made in that all the groups defined very similar paths using almost the same design tools at different stages of the design. The new industrial wheelbarrow was fabricated and tested for the intended use. The design was proved to be sound requiring only minor modifications. From this work it appears to be safe to conclude that a flexible systematic approach to adaptive design is very effective and hence the knowledge of various design methods or tools is a fundamental requirements for adaptive design. This paper describes the study and the work carried out by a representative group in the development of the industrial wheelbarrow to transport steel balls.

1.0 Introduction

Systematic design approaches are characterized by the use of a transparent design model with definite starting and finishing points and the intermediate stages. There are several design models proposed by design researchers and Evbuomwan et al [1] give a comprehensive survey of them. Design methods are essentially tools and techniques to enhance the systematic design process. Jones [2] described 36 such methods, which could be used at the different stages of the design processes described by the various design models. Conventional approach on the other hand starts with a solution to the problem in the design brief, which is subjected to a series of 'Synthesis, Analysis and Evaluation' cycles until an acceptable solution is found. This may involve the making and testing of physical models. Design models and methods are taught as part of the development program for engineering designers. In an earlier paper [3] the effectiveness of systematic / conventional approach in **new product design** has been investigated. In this paper the effectiveness of systematic / conventional design approach in **adaptive design** problems is investigated. In this context it can be said that in adaptive design one keeps to known and established solution principles and adapts the embodiment to meet the changed requirements [4].

2.0 Background and Statement of the Problem

Six groups of students (five persons in each group) were employed in this adaptive conceptual and embodiment design exercise and observations were made. They were taught with the application of the design model underlying the Design Function Deployment system [5] and the design methods Quality Function Deployment [6], Function Analysis [7], Function Means Tree [8], Morphological Analysis [9], Decision Matrix [10] and Pugh's concept evolution matrix [11]. They were also taught that the design model and the design methods have to be blended together to make the actual design process sequence.

The students were requested to act as a group of young engineers in the research and development section of a cement factory to design a new wheelbarrow to transport steel balls, which they use in the cement mills as grinding media. The company would make only six numbers of them and therefore the use of standard parts was encouraged. They were requested to look at a gar-

Eng. (Dr.) S. Silvaloganathan, BSc MSc, PhD, CEng, FIMech, FIE (Sri Lanka)
Senior Lecturer in Design at Brunel University, England.

den wheelbarrow and use the exercise as an adaptive design problem.

All groups at some stage in the design process have done the following:

a) Analysis of the garden wheel barrow

b) Requirement analysis of the garden wheel barrow and the requirements for the industrial wheel barrow

c) Generation of Conceptual Designs

d) Concept selection and evolution

E) Generation of detailed designs

They have used the Design Methods appropriate to the different stages. The Design Methods used include (a) Stage 1 of Quality Function Deployment (b) Function Analysis, (c) Function Means Tree (d) Morphological Chart (e) Decision Matrix and (f) Pugh's Concept Evolution Matrix. They all used the brain writing pool [12], which is an implementation of the brainstorming technique, at different stages. All the groups had their design process planned at the beginning with the use of the appropriate design methods.

3.0 Work of a Typical Group

An analysis of the produced documents revealed that almost all the groups have followed similar steps to generate the concepts and embodiment. The variation was often in the sequence they followed. Thus studying any one group's work was sufficient to understand the thought processes and the encountered difficulties. This section describes the work carried out by a representative group. They did not use the design model explicitly as advocated by any design system. Instead they defined their own procedure or path to develop the design.The group started the project with a thorough Function Analysis(or a Function Means Tree analysis) to study the existing Garden wheelbarrow. From this they identified customer requirements and their associated design requirements. From the outcomes of these, concepts were generated for subsystems. New conceptual designs for the industrial wheelbarrow, using these subsystems, were then generated .From these the best concept was selected using the Decision Matrix. The selected best concept was then used as the datum for the Pugh's concept evolution process, which led to the development of the optimum concept.Once the concept was finalized the embodiment was developed. Finally the detailed design was established and solid models were built. The design was then sent for manufacturing and testing. Figure 1 shows the process flow chart and the outcomes at all stages of the design process. The following subsections explain each activity shown in the Flow Chart.

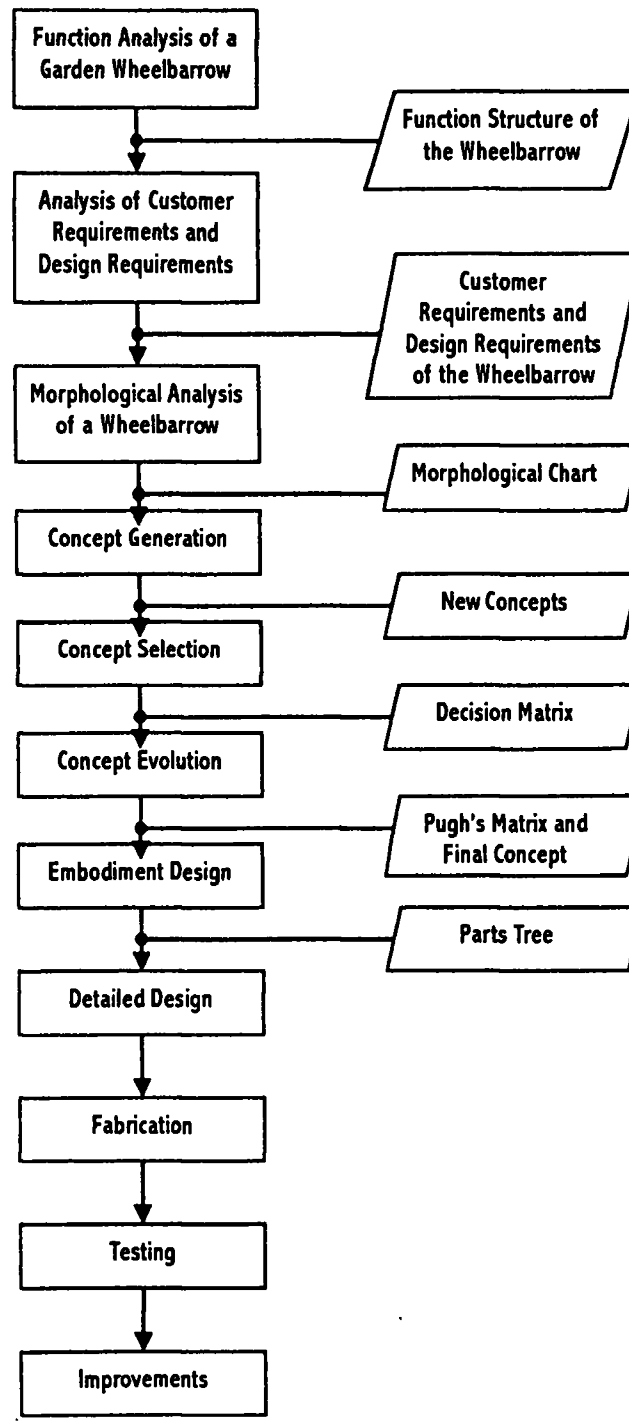


Figure 1 processes and Outcomes

3.1 Function Analysis

Dividing it into functional subgroups and then identifying the functions performed by each subgroup Function Analysis was carried out on the garden wheelbarrow. The functional subgroups identified are as follows:

a Provision of Handle
b Provision of Frame
c Provision of Foot
d provision of Motion
e Provision of Hopper

The choice of language here was left to reflect the system rather than to the semantics. Each of these subgroups performs a set of functions and the conceptual design can be given in the form of a function family tree as shown in Figure 2.

In adaptive design each of these functional subgroups are scrutinized to establish the relevance of it in the new circumstances. This is achieved by performing a customer and design requirement analysis of both garden and industrial wheelbarrow.

3.2 Requirement Analysis

In requirement analysis customer requirement and design requirement were established for both garden and the industrial wheelbarrows. This enables the identification of the important design requirement, which could be used as the criteria for concept selection and concept evolution processes.

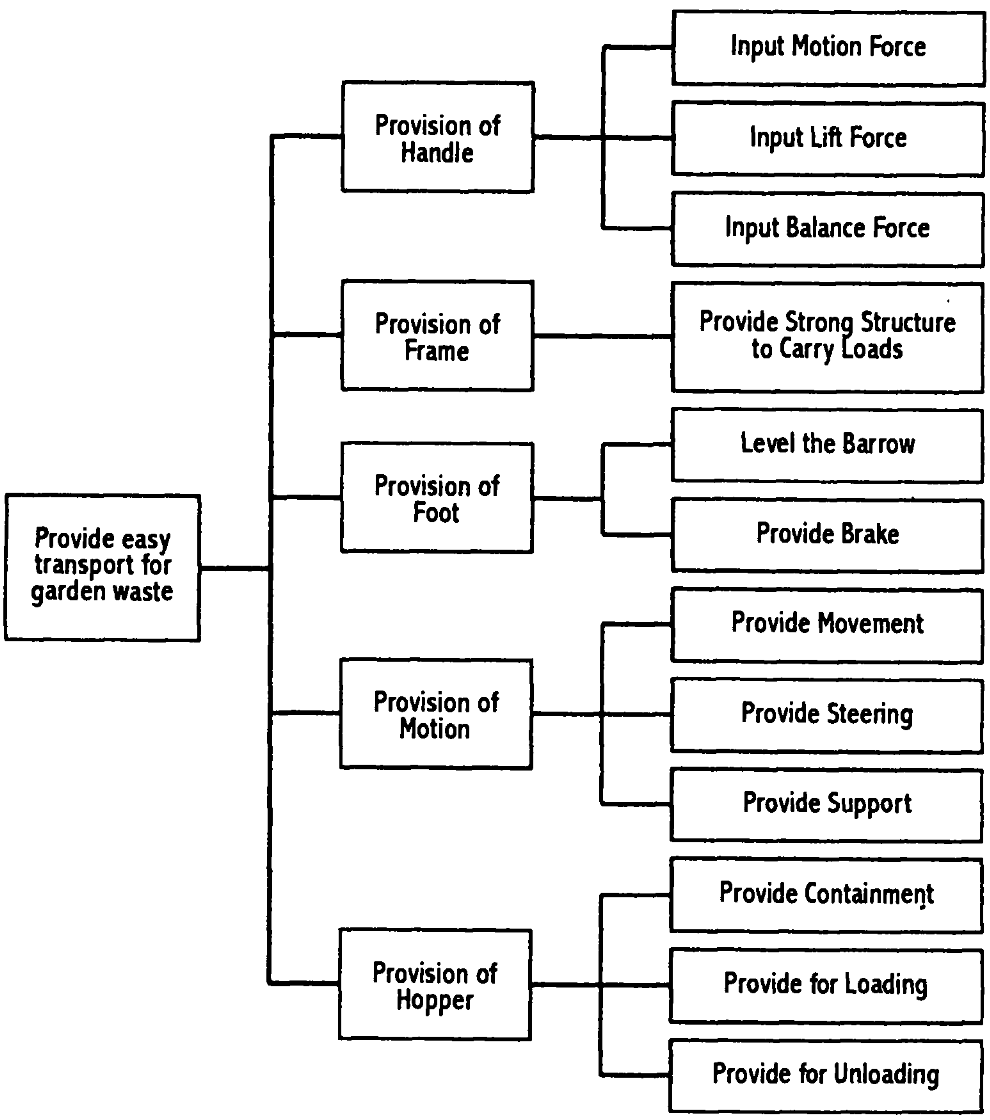
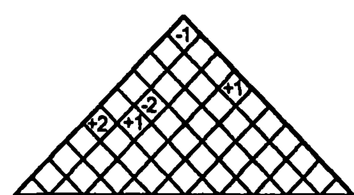


Figure 2 Functional Family Tree of a Wheelbarrow

Garden Wheelbarrow		Industrial Wheelbarrow
Customer Requirements	*Design Requirements*	*Design Requirements*
Easy to lift	Light weight	Load to wheels
	High leverage	Right capacity
	Right capacity	
	Low lifting height	
Easy to move	Low friction	Low friction
	Light weight	Light weight
	Large contact area	Large contact area
Easy to load	Low hopper height	Low hopper height
	Wide top	Wide top
Easy to unload	Low tip angle	Low tip angle
		No lifting
Low making and operating cost	Cheap materials	Cheap materials
	Cheap manufacture	Cheap manufacture
	Low complexity	Low complexity
		Standard Parts
		Adequate Capacity
Durable	Sturdy construction	Sturdy construction
Multi-purpose	Large	
	Water tight	
Low spillage	High lip	
	Filling guides	
Comfortable/Doesn't hurt back	Shaped handles	Shaped handles
	Handle height	Handle height
		No lifting
Easy to control	Small turning circle	Small turning circle
	Stopping facility	Stopping facility
Go any where	Ground clearance	
	Large contact area	
	Bump absorption	

From this study the group identified important customer requirements and important design requirements. A survey among willing students was then carried out to use Quality Function Deployment, QFD, in the design process to deploy the voice of the customer. A stage 1QFD chart was constructed to calculate the importance ratings of the individual design requirement.Figure 3 shows the stage 1 QFD chart. This chart shows the requirements as rows and,functions which meet these requirements as columns. The relative importance ratings of these functions were calculated as weights for later use in the Decision Matrix.



	Importance Ratings	Load to Wheels	Easy Rolling Friction	Low Hopper Height	Wide Top	Low Tipping Angle	No Lifting	Handle Shape & Position	Stopping facility	Standard parts	Adequate Capacity
Easy to Control	6		3						9		
Easy to Lift	9	9									
Easy to Move	6		9								
Easy to Load	9			9	3						
Easy to Unload	9				3	9					
Low Making & Operating Cost	6									9	9
doesn't hurt back	6		3			3	9	9			
Absolute Importance		81	90	81	54	99	54	54	54	72	72
Relative Importance		7	8	7	5	9	5	5	5	7	7
Weights		0.1	0.13	0.1	0.08	0.15	0.08	0.08	0.08	0.1	0.1

Figure 3 Stage1 QFD Chart

3.3 Morphological Analysis

In an adaptive design problem a starting concept is always available. In the case of the wheelbarrow the starting concept was a garden wheelbarrow. This has six functional subsystem. They are (a) tipping system (b) hopper system (c) wheel system (d) foot system (e) Frame system or structure and (f) handle system.Morphological analysis is a method of considering all possible options available for each of the functional subsystems identified in function analysis. The students considered the five functional subsystems identified earlier in figure 2 and the tipping method in their Morphological Analysis. Figure 4 shows their morphological Chart.

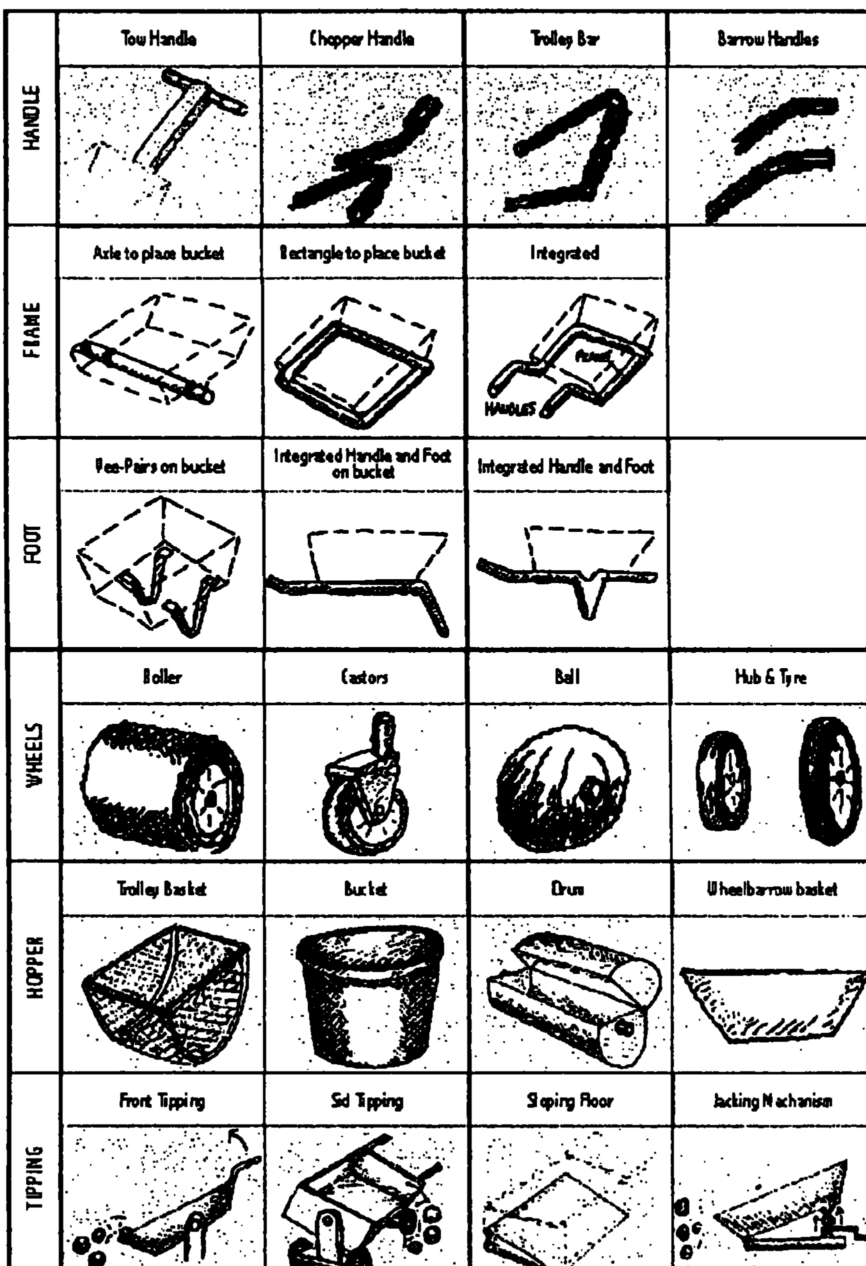


Figure 4 Morphological Chart for the Industrial Wheelbarrow

3.4 Conceptual Designs

The groups developed several concepts from the insight gained from the morphological analysis. All of them used sketches to express the concepts. Figure 5 shows some of the concepts.

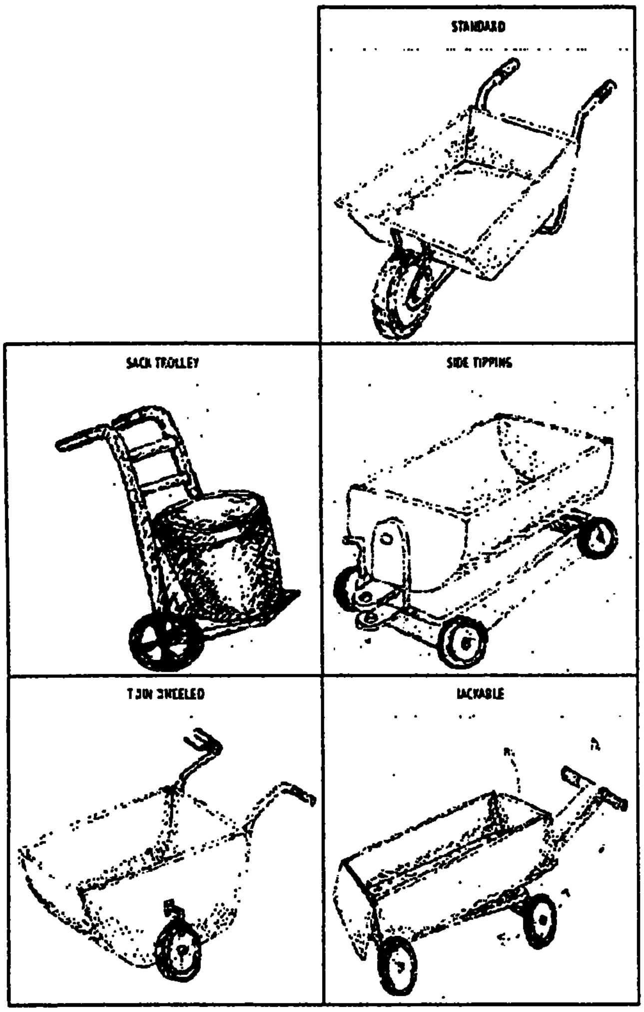


Figure 5 Some Conceptual Sketches

3.5 Concept Selection

At this stage the group had to decide which concept was the best. They constructed a decision matrix to identify the concept which best satisfies the criteria or the design requirements set in section 3.2 .They obtained the importance ratings of the elements of the criteria by converting the relative importance rating into weights. The sum of the importance ratings is 65 and hence to get the weights divide all importance ratings by 65. The Decision Matrix had the criteria as columns and concepts as rows. Each cell in the table was divided into two triangles. The upper triangle gives the rating of the concept with respect that specific criterion (in the column) on a 0-10 scale.The lower triangle gives the product of the rating and the weight of the criterion. The last column shows the sum of all the lower triangles in each row. The best concept would have the largest number in the last column. Figure 6 shows the Decision Matrix for concept selection constructed by the students. From the decision matrix the twowheeled concept had been identified as the best.

	Load to Wheels	Easy Rolling	Low Hopper Height	Wide Top	Low tipping Angle	No Lifting	handle position & Shape	Stopping Facility	Standard Parts	Adequate Capacity	
weights	0.10	0.13	0.10	0.08	0.15	0.08	0.08	0.08	0.10	0.10	
Standard	0 / 0	4 / 0.52	7 / 0.7	8 / 0.72	0 / 0	0 / 0	4 / 0.32	9 / 0.72	6 / 0.6	4 / 0.4	3.98
Sack Trolley	9 / 0.9	5 / 0.65	4 / 0.4	4 / 0.32	4 / 0.6	5 / 0.4	6 / 0.48	9 / 0.72	6 / 0.6	4 / 0.4	5.47
Side Tipping	9 / 0.9	5 / 0.65	7 / 0.7	9 / 0.72	6 / 0.9	0 / 0	4 / 0.32	4 / 0.32	4 / 0.4	3 / 0.3	5.21
Twin Wheeled	9 / 0.9	7 / 0.91	9 / 0.9	7 / 0.56	6 / 0.9	7 / 0.56	8 / 0.64	7 / 0.56	7 / 0.7	7 / 0.7	7.33
Jackable	9 / 0.9	5 / 0.65	9 / 0.9	9 / 0.72	7 / 1.05	6 / 0.48	8 / 0.64	4 / 0.32	4 / 0.4	4 / 0.4	6.48

Figure 6 Decision Matrix for Concept Selection

3.6 Concept Evolution

The selected two-wheel concept is then compared with other concepts for weakness identification and rectification. This has been achieved using the concept evolution process developed by Pugh [11]. The matrix constructed by the students is shown in Figure 8. From the matrix, by looking at all the + signs, it can be seen that the two-wheeled concept can be improved in (a) Easy-rolling (b) low tipping angle (c) no lifting (d) stopping facility and (e) standard parts. These improvements were then incorporated with the datum wherever possible and a better concept was developed. The improved design concept is given in Figure 7. This has wheels with spokes, meant for heavy-duty bicycles. Rolling of the wheels also became easy because of the large diameter they had. It has a bucket, which is shaped to require minimal tipping. The foot and the handle were integrated into one piece. In the first prototype it was intended to check whether making the bucket wider could increase the bucket capacity without any compromises. Also it was intended to find out whether the bucket could be lowered by bending the axle.

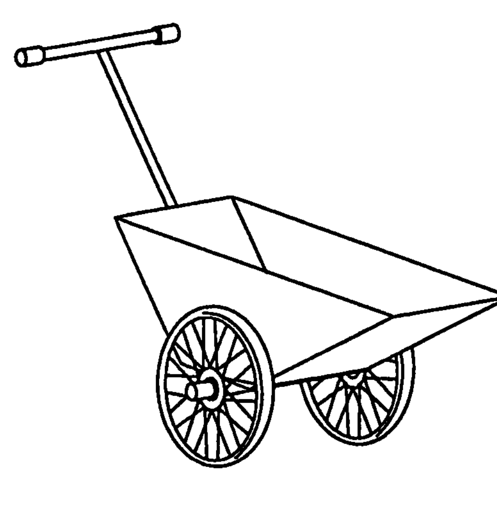


Figure 7 Final Concept

	Standard	Jack Trolley	Side Tipping	Twin Wheeled	Jackable
Load to Wheels	-	s	s		s
Easy Rolling	-	s	+		+
Low Hopper Height	s	s	s		s
Wide Top	s	s	s		s
Low Tipping Angle	-	-	+		
No Lifting	-	-	+		+
Handle Position & Shape	s	+	s	DATUM	s
Stopping Facility	s	+	-		-
Standard Parts	s	+	s		s
Adequate Capacity	-	-	-		+
$\sum +$	0	3	2		3
$\sum -$	5	2	2		2
$\sum$ s	5	5	6		5

Figure 8 Pugh's Concept Evolution Matrix

3.7 The Embodiment and Detailed Design

Once the concept is finalized the group established the embodiment design which essentially identifies the parts that constitute the product. It is traditional to construct a Parts Tree to describe the embodiment design. This normally is a good tool to find out which parts could be combined together without compromising functionality. However because the product was simple there was no necessity for a Parts Tree. It was decided to have a bucket that could carry 200 kg of steel balls. By calculating the Face Centred Packing density for 50 mm diameter steel balls the volume of the bucket was calculated. The axle was a 25 mm diameter steel bar, which was selected to suit the wheel. The wheel, which was a critical item, was selected by looking at what was available in the market. Drawings of the final design were made and given for fabrication.

3.8 Manufacturing and Field Testing

The first prototype barrow was manufactured using a one-inch diameter galvanized pipe for the stand and handle. The hopper was made out of 1.5 mm thick steel plate. The wheels were those meant for the heavy duty Wagon Bicycle. The axle was made out of one inch diameter bar. The handle was bolted on to the hopper using braces, which in turn was bolted on to the axle. It was found easy to maneuver the assembled wheelbarrow. The wheelbarrow was load tested with 70 mm diameter steel balls used in the cement mills at Puttalam Cement Company. The total load in the hopper was little over 200 kgs with room for some extra and the entire load was carried by the wheels, which enabled the user to handle the load with ease.Maneuvering the barrow was found to be easy. Unloading was particularly easy and the balls rolled out of the hopper. Howerver it was found with no front legs lodinghas to be done with care as more loads to the front of the barrow tips it unloading the entire load. Shortening the leg substantially in the second prototype has eliminated this problem. The extra six inches gaps between the wheels and the bucket were found to be unnecessary, as there was no necessity for changing the bucketshape or size. This also gave the required maneuvering capability in narrow areas of the cement mill floor. It was also felt that lowering the axle would not seriously affect the unloading and in fact would provide better stability and reduced spread. The bucket had indentation marks where the balls hit it during loading. This indicated that the thickness of the plate should be increased for durable buckets. With these minor improvements a new barrow was constructed. As a precaution it can be said that the barrow should not be left loaded for long periods as this may set creep in the wheels.

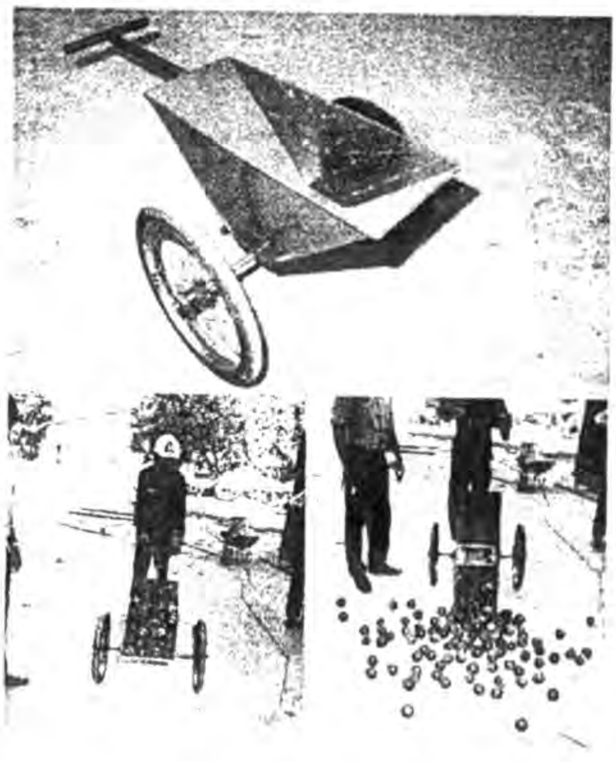


Figure 9 Pictures of the Field Testing

4.0 Discussion

Almost all groups had no difficulty in identifying the path they followed to reach the end goal. Even though there were instances where they experimented with the garden wheelbarrow they were mainly to get more insight of it than to test any new concepts. The students found it easy to establish the conceptual design of the garden wheelbarrow in the form of a Function Family Tree (or Function Means Tree) and to work out the new design from it. The design methods or tools they used enabled them to expand and express their ideas precisely and clearly. The project tends to show that Systematic Approach ideally suits adaptive design projects. This is because there is better insight available in adaptive design problems.

5.0 Conclusions

1. Knowledge in systematic design tools, in particular the design models and various design methods greatly enhanced the adaptive design process. Therefore it appears to be safe to conclude that this knowledge is a fundamental requirement for adaptive design.

2. All the groups followed the systematic approach. However a similar group on a new product development followed the conventional approach whenever the solution concept was not clear [3]. Therefore it suggests that systematic approach is more suitable for adaptive design.

3. In the case study the garden wheelbarrow was adapted to be a two wheeled industrial wheel barrow. The two-wheeled concept is an improved version in the following areas: (a) Easy-rolling (b) low tipping angle (c) no lifting (d) stopping facility and (e) standard parts. The developed barrow was fabricated and tested and the performance found satisfactory.

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