Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 63 (2017) 366 – 371

www.elsevier.com/locate/procedia

The 50th CIRP Conference on Manufacturing Systems

Framework for The Development of a New Reconfigurable Guillotine Shear and Bending Press Machine

Vennan Sibanda[a*], Khumbulani Mpofu[a], John Trimble[a]

[a]*Department of Industrial Engineering, Tshwane University of Science and Technology, Pretoria 0001, South Africa"*

* Corresponding author. Tel+27 62 482 2387; fax: +27-(012)-382-4847. *E-mail address:* vmsibanda@gmail.com

Abstract

In today's manufacturing world, consumer satisfaction is difficult to achieve owing to the dynamic and continuous changes in their requirements and the rapid change in product designs. Research has been carried out on several innovations addressing this problem with various machine designs having been produced to deal effectively with the dynamic customer needs. Reconfigurable manufacturing systems (RMSs) and machines (RMTs), having superseded the dedicated manufacturing lines (DMLs) with dedicated machine tools (DMTs); and flexible manufacturing systems (FMSs) with their machines (FMTs), have led to a new era that takes the best aspects of both DMLs, FMSs and machines to conceive a new manufacturing system, RMS and RMTs that satisfy the dynamic nature of customer requirements. The aim of this paper is to present a structured framework that will optimise the development process of a new reconfigurable guillotine shear and bending press machine to be used in sheet metal work. The framework provides a guide for designers and manufactures of sheet metal machines in developing the new machine. To develop the framework, research used various tools such as reviewing existing literature on RMSs & RMTs, DMLs & DMTs, FMSs & FMTs and expected product change responsiveness. Research also explored literature on the development of machine modules for reconfigurable machines and reconfigurable technology systems. The framework seeks to provide a structured approach towards the machine development by highlighting important steps to be taken and various aspects to be considered. The results give a framework that will guide the development of a reconfigurable guillotine shear and bending press machine tool that can be configured and reconfigured to enable cutting and bending of varying sheet metal products by a single machine with dual functionality.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: Innovation; Methodology; Reconfigurable Technology

1. Introduction

Many manufacturing companies are facing increasing unpredictable market changes that are driven by rapid introduction of new products and continuous changes in product demand. Sheet metal working is one of the most versatile processes in industry today, producing a variety of industrial and domestic products, such as motor vehicle body parts, vehicle trailers, scorch carts, door frames incubator housings, stoves, etc. In manufacturing, production patterns are changing, with large scale and mass production having declined significantly, and the pace at which one product is replaced by another has increased, [4]. Most machines used in production are failing to meet the changing product and production requirements due to the nature of their design. Current production machines are dedicated machine tools (DMTs) and computer numerically controlled (CNC) flexible machine tools (FMTs). This paper presents work in progress for the development of a reconfigurable guillotine shear and bending press machine (RGS&BPM). The machine has a specific target market of Small and Medium Enterprises (SMEs). Using DMTs and FMTs in production lines implies that two machine tools are required, a guillotine shear machine tool for producing blanks and a bending press for bending the blanks into required configurations. The development of a RGS&BPM will consolidate the best aspects of the DMTs and FMTs into a new machine that will perfume both functions as a single unit. The design concepts however, are based on RMSs

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2017.03.353

and RMTs, using the basic designs of the two machines. The aim of this paper is to develop and propose a framework that can be used by designers from the proposal stage to the concept evaluation stage. Research work review on different design frameworks such as the theoretical framework, conceptual framework, design recovery framework, agent based framework and modularity framework presented and a framework proposed.

2. Background

DMTs are designed to be fully dedicated for mass production of a specific product, involving operations like cutting or bending sheet metal. FMTs are designed prior to knowing the operational requirements, hence possess more features than will be required in their daily operations [16]. The increase in part variety and reduced product life cycle requires new production machinery capable of handling the changing product varieties as demand changes, hence the development of reconfigurable machines. Most research work on reconfigurable machines has been based on machining or metal removal processes and recently in bending presses and other related areas. Some of the developments in reconfigurable machines can be observed from machines such the Reconfigurable Bending Press machine, [9], Towards a Reconfigurable Inferior Limbs Exoskeleton for Assistive Rehabilitation and Empowering Application, [21], Design, Refinement, Implementation and Prototype Testing of a Reconfigurable Lathe-mill, [1].

Due to their design, it may be very expensive to change DMTs' configuration as product varieties change. FMTs are flexible but their flexibility is not commensurate with operational requirements and the manufacturer pays for the flexibility they may never use. Reconfigurable Machines Tools (RMTs) are developed to supersede DMTs and FMTs by adopting best features of dedicated and flexible machine tools to produce a machine that can handle changes in product and production requirements.

3. Reconfigurable Machines

Reconfigurable machines are designed around a specific part family of products and allow rapid change in their structure, [14]. The basic design of RMTs should include the following characteristics, Modularity, Scalability, Integrability, Convertibility, Diagnosability and Customisation, [5,13]. These characteristics can be explained as follows:

- *Modularity*: Hardware and software designed as modules that can be added or removed from the machine.
- *Scalability:* The machine should be able to adapt to new requirements like increasing the capacity of the machine.
- *Integrability:* Interfaces of modules are designed and used to connect various modules through transmission of motion, power and data.
- *Convertibility:* Changing from one configuration to another to be conducted with minimum effort.
- *Diagnosability:* The machine should be able to identify sources of poor quality products after reconfiguration. Inline inspection machines are installed to monitor inaccuracies and sources of error and thus improving ramp-up time, [13].
- *Customisation:* This is through design around a part family of parts, making it imperative that part families are clearly defined to match the production process, [13].

The key concept of modularity lies in the fact that the machine is designed from a library of precompiled modules. It employs modular design principles where components are grouped into modules according to similarities in their functions and manufacturing processes, [5]. The process has been used in the design and development of some machines, among them a reconfigurable bending press and reconfigurable vibrating screen, [9,18]. It is noted from literature that modular design also enables the manufacture of products simultaneously by allowing rapid changes to the manufacturing system. Developing a module for part family for instance, a dendrogram may be used. A dendrogram is a branching diagram that represents the relationships of similarity among a group of entities. Fig. 1 shows a Dendrogram of part families as they are developed.

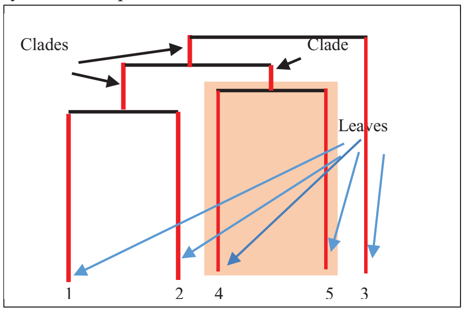

Fig. 1. Dendrogram of part families

The clades, which form different branches of part families, signify the number of part families in a module. The arrangement of clades indicates families with similar part features and the height indicates how similar or different these are from each other. Fig. 1 shows a dendrogram with 5 chunks and these chunks can be grouped according to similarity, for example chunks 1 and 2 can form a group and similarly chunks 4 and 5 form another group. Chunk 3 stands alone as it has totally different features from the rest. Using this graph, modules are designed for reconfigurable modular design of machine tools.

The development of a RGS&BPM must take into account its responsiveness to production requirements. RMTs are designed to deliver exact functionality and capacity when it is needed. Reconfigurability is achieved by changing the functionality and capacity of the machine through adding/removing and/or readjusting the existing auxiliary modules, [8]. This capability gives the machine its responsiveness as production demands change. To achieve the responsiveness RMT structure consists of a modular structure consisting of basic and auxiliary modules along with the open architecture software, [8]. The outlined six RMT characteristics determine the ease and cost of reconfigurability of manufacturing systems, and thereby enabling rapid responsiveness of the machine to sudden market changes, [13]. To further improve responsiveness studies looking at operational capability, configuration convertibility, machine utilization, and cost, have been considered, [7].

4. Framework for the development of RGS&BPM

A framework is aimed at easing the development process of a reconfigurable guillotine shear and bending press machine. The design should incorporate all the necessary processes to ensure that a sound product is designed. These include virtual product design, simulation, testing and validation before manufacturing of the machine commences. This will enable the determination of problem areas and weak points that should be modified before building the machine. The framework shortens the development process and thus reduces the development costs. In the development of a framework, two scenarios are observed. These are the Conceptual Framework and the Theoretical framework.

A conceptual framework is developed as a result of merging a number of related concepts to explain or predict a given event, give a broader understanding of the phenomenon of interest, [11]. It is argued that the concepts chosen for investigation, and any anticipated relationships among them will be appropriate and useful given the research problem under investigation.

A theoretical framework however, can be said to be a map or travel plan for the researcher, [22]. It guides the research activities by reliance on existing theory that has been developed by using an established, coherent explanation of certain kinds of phenomena and relationships, [11]. There are different research frameworks that can be used by both industrialists and academics. It is therefore important to understand the theory behind their approach to enable the researcher to identify their short comings. There are basically three types of frameworks used to develop machines and machine components, [19]. These are the Design recovery framework, Agent framework and Modularity framework.

The design recover framework is mostly used for the development of mechanical components. This framework is mostly used in reverse engineering approaches where:

- ➢ There are no drawings or design models for a product that must be replaced (worn, broken or damaged) and the original manufacturer no longer exists or the product is no longer being produced, [23].
- ➢ Created drawing models tend to fail to address new requirements, due to modified components during iterative prototyping design, testing and use; hence, rendering the existing documentation irrelevant, [23].
- ➢ There is need to compare a fabricated part with its computer-aided design (CAD) description or with a standard item for inspection or quality assurance purposes, [23].

An agent-based approach, comprising several agents, namely, Manager Agent, Designer Agent, Modification Agent, Communication Agent, Evaluation Agent, etc. can be used to develop a guide for a conceptual model design of a mechanical product.

The modularity framework provides a library of modules that provide the machine flexibility. It comprises literature related to the study that can be used to form the basis for research. A reconfigurable machine is based on modular architecture design principles and most modular designs are matrix based. Modular architecture allows the design of any system composed of separate components to be connected together, that is, they can be added or removed (one component or module) without affecting the rest of the system. Modular design breaks down complex systems into a series of standalone objects that can be easily manipulated. Modularity can be defined as the degree to which a product is composed of independent modules, without interactions between them, [6].

4.1 Conceptual Framework

The conceptual framework provides the system of concepts, assumptions, expectations, beliefs, and theories that support and guide the research, [15]. It attempts to connect to all aspects of inquiry (e.g. problem definition, purpose, preliminary research, literature review, methodology, data collection, analysis and personal experiences). A conceptual framework acts like a map that gives coherence to the research and it helps develop research questions.

The conceptual framework starts from generating concepts, screening, scoring, selecting and developing the best concept which leads to designs and prototype making. Fig. 2 shows the conceptual framework with steps taken towards the development of a prototype.

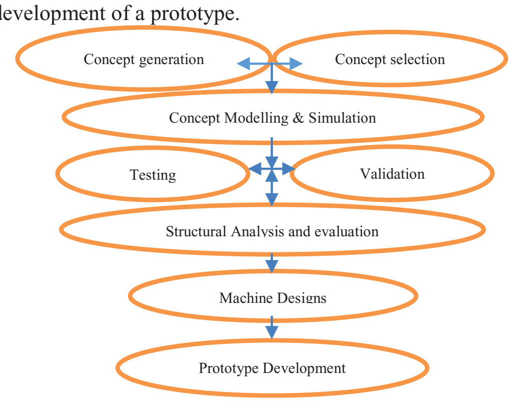

Fig. 2 Conceptual framework

4.1.1 Concept Generation and Selection

Concept generation involves developing ideas based on operational requirements of the machine. The concepts give an indication of how the machine will function. Concept generation can be achieved through several methods such as brainstorming, logical, morphological, axiomatic designs etc.

Brain storming involves ideas brought from one's imagination or thought. A group of people can openly discuss possible/conceptual solutions of the new design. These ideas are brought and acted upon to get the best from them.

Logical methods of concept generation use the Theory of Inventive Machines (TRIZ) developed by Genrikh Altshuller, [10]. It looks at factors that make the problem difficult to solve and then employs TRIZ's 40 inventive ideas to overcome the challenge. It encourages systematic innovation instead of using a trial and error approach, [10].

The Morphological method uses identified functions to push for ideas, [2]. It identifies the functions of the machine and develops concepts for each function with the aim of developing many concepts for each function identified in the decomposition process. It also combines the developed concepts to meet all functional requirements of the machine. Sketches are used to clarify individual functions.

The Axiomatic designs identify the independence of the machine functions. It develops concepts that ensure that a change in a design parameter affects only one function of the machine.

Concept selection follows a process developed by Stuart Pugh known as the Pugh Matrix. The matrix scores each concept based on its function. Fig 3 shows the concept generation to testing stages.

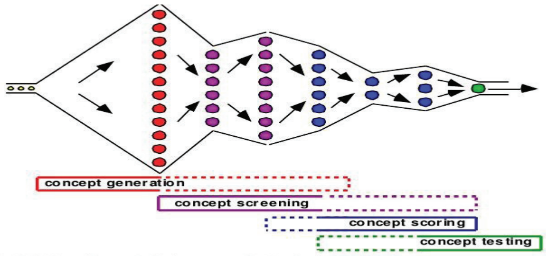

Fig. 3 Concept development and selection funnel [12]

4.1.2 Concept Modelling and Simulation

A selected concept is modelled and simulated to determine its behaviour. Concept modelling is the concept of a simulation model from the part of the real world it is representing, [20]. The machine requirements as defined by customers provide a basis for measurement. Real life conditions are imitated to determine the machine behaviour under operating conditions. The result gives direction to areas that need to be changed or improved. Fig. 4 shows the iterative process of modelling and simulation.

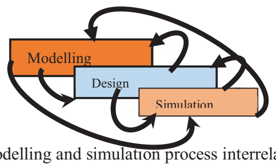

Fig. 4 Modelling and simulation process interrelatedness, [16]

4.1.3 Testing and Validation

Testing and Validation of the machine components determines the condition of the machine prior to its use. It seeks to determine whether the perceived system has indeed been developed. The processes mimic the real life scenarios and can give an accurate account of the behaviour of the machine under operating conditions. The results give a stress analysis of the structural members to validate the suitability of machine members for the type of work the machine is designed for. The processes enable the establishment of the limits of the design. The members of the machine are subjected to varying loading conditions that the machine will endure during its operation, to determine the suitability of the designs. Modifications are made if the members fail these tests. Components are tested among other things, for:

- Structural analysis, i.e. bending, buckling, failure due to reaching ultimate stress of the material before taking up full loading, torsion etc., due to applied forces in either cutting or bending operations.
- Machine behaviour during different loading conditions, joints performance, fracture of members, bearings failure and detrimental yield of the machine structure compromising its reliability.
- Bursting of pressure cylinders and pipes, behaviour of pressure regulators and pumps under different loading conditions.
- Leakages of hydraulic oil and jamming of moving members.
- Pressure gauges in monitoring pressure in various places of the machine.
- Stability and rigidity of the machine under different loading conditions.

4.14 Structural Analysis and Evaluation

The concept evaluation process of determines how to choose the best of the generated concepts for development into a quality product. The aim is to use the least number of resources to determine the concepts with the highest potential for becoming a quality product, [3]. It is a complex decision-making process that involves several inputs which include design requirements and constraints such as customer needs, product cost, and development time, [24]. Evaluation techniques require a comparison of developed concepts and how well they meet the design specifications. There are different methods used for evaluation, such as Selection of the fittest solution, Exclusion of improper solutions, grey relation analysis and product design evaluation, evaluation based on GO/NO-GO screening, and Evaluation based on a Basic Decision Matrix, i.e. the Decision-Matrix Method (or Pugh's Method).

Selection of the fittest solution is achieved by determining how well the "value" of alternative solutions fulfil the given task, [3]. This method compares the solutions for characteristic criteria, which are obtained from the design specification. The results of the evaluation are dependent mostly on strength, the criteria, in extent and objectivity, and the knowledge and understanding of the respective solution, [3]. Exclusion of improper solution looks at the short comings of the solution, [3]. The grey relation analysis and product design evaluation is used especially where there is uncertainty and in cases with multiple attributes by examining the similarity of each alternative to the ideal solution [24]. Fig 5 shows the comparison in the grey relation analysis.

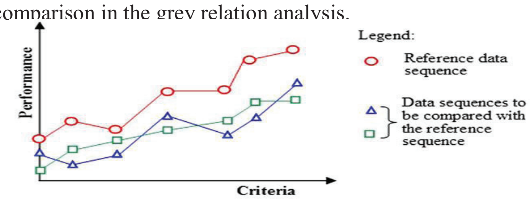

Fig. 5 Comparison of data sequences in grey relation analysis, [24].

Evaluation based on GO/NO-GO Screening criteria is defined by customer requirements. Each concept is evaluated in comparison with customer requirements and the fewer the no-go responses the better for the concept. This provides room for modification instead of elimination. The go/no-go screening can also be evaluated using the readiness of the concept to accept state of the art technologies or capabilities.

The information presentation for concept evaluation cycles can be seen in Fig 6. From literature it is noted that the evaluation process includes comparison and decision making. Comparison refers to weighing between developed alternative concepts and the requirements they must meet to obtain information necessary to make decisions. Alternative concepts and criteria must be in the same language and existing at the same level of abstraction.

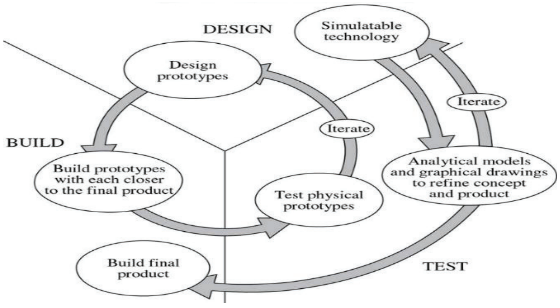

Fig. 6 Design evaluation cycles, [19].

4.1.5 Machine Designs Concepts

Designs are made by using software such as SOLID WORKS. The design concepts developed enable reconfigurability of the machine. This is done through the application of reconfigurable technology in the design process. The RGS&BPM achieves reconfiguration through vertical and horizontal modules and several mechanisms, such as hydraulic systems, flexible or solid joints, sliding mechanisms and rolling motion of bearings. Modules are added or removed as required. Fig 7 shows some types of drives that enable reconfigurability.

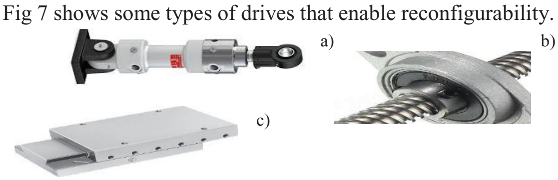

Fig. 7 Driving mechanisms, a) hydraulic, b) bearing, c) sliding joint.

4.2 Theoretical Framework

Research develops theories that are used to explain or forecast a particular phenomenon. These theories can be used in critiquing existing knowledge within set boundaries or scope of research taking into account existing assumptions. The theoretical framework therefore is a structure that presents direction and guides the theory of a research study. It provides and describes the theory that explains the existence of a research problem being studied, by clearly highlighting what has been covered and what has not, thereby clearly showing the gap. Fig. 8 shows how the theories interact to develop a reconfigurable guillotine shear and bending press machine. The basic understanding of these theories gives a foundation for machine development.

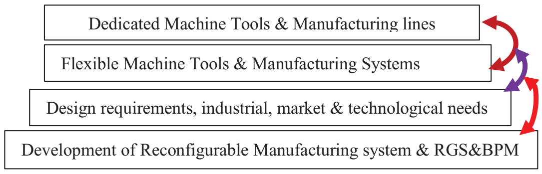

Fig. 8 Theoretical framework development

The framework, after considering all inputs, will have a simple structure as shown in Fig. 9. The structure combines both the theoretical and conceptual frameworks. Available designs have been used as a basis for the development of the framework. The thrust being to design a framework that can be easily and efficiently used.

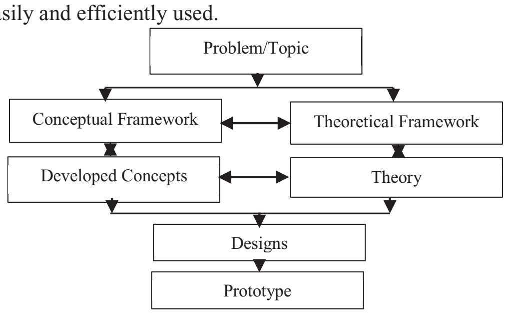

Fig. 9 Design Framework

5. Design Requirements

The following requirements and constraints are needed for a reconfigurable guillotine shear and bending press machine:

- The structure of the machine must be reconfigurable, that is, it must have a modular hardware that can be changed for different functions such as cutting and bending different size metal sheets.
- It must consist of software modules to control various tasks.
- It must have kinematic modules to enable motion transmission for required operations.

6. Results

The results show Pugh Matrix as the method that can best be used in concept selection for the development of a RGS&BPM. Aspects to look at are ramp up time and response.

6.1 The framework using Pugh Matrix

The basic concept of a Pugh Matrix is that it is simple and easy to use. Table 1 shows a completed Pugh Matrix that has been used to evaluate and select from a number of design alternatives. The scoring ranges from 1, 5 and 10, where “1” is a score below base standard, “5” - score equal to the base standard and “10”- a score above base standard.

Table 1 Concept Selection Pugh Matrix

Customer Requirements	Sliding Mechanisms	Hydraulic Systems	Joints & Bearing Mechanisms
Reconfigurability modules	10	10	10
Functionality/Responsiveness	10	10	10
Low cost	5	1	1
Ease of Maintenance	5	5	5
Criteria 6	30	16	16

7. Discussion

Reconfigurability and Responsiveness - These scored “10” signifying the importance of machine reconfiguring ramp-up time. The mechanisms’ response to reconfiguration gives the machine kinematic modules the ability to meet operational demand changes. It includes horizontal and vertical modules.

Low Cost- The low cost of the modules scored a max of “5”. Cost is an important parameter in machine configuration for a particular operation to meet customer needs economically.

Ease of Maintenance – Maintenance of machine modules depends on the reliability of the components that make them. A score -“5” signifies that machine modules are highly reliable.

From Table I, the total score of “30” indicates that the sliding mechanism plays a critical role in ensuring the machine responsiveness. As the machine is still under design stage more research still needs to be done to ascertain various aspects.

8. Conclusion

In order to develop reconfigurable machine tools, it is imperative that manufacturing systems that respond to changes in product designs be adequately reconfigurable and must embody the principles of customised flexibility. The future is also going to need personalised products and this will present further challenges, if these challenges are not already being experienced in some sectors. To provide customised flexibility the reconfigurable manufacturing system must have the capacity and capability/functionality to process a family of parts and therefore, the reconfigurable machine tool must be built around a family of parts to be produced. The development of a reconfigurable guillotine shear and bending press machine seeks to follow these principles. These operations are decomposed into a set of functions that the machine must perform. The functions are then converted to machine modules, with each module having an associated machine control module. The machine is then constructed from a set of modules and thereafter the control modules are connected. More work still needs to be done on the development of the machine as it is on its initial stages of development. As the machine is put into use modifications will be made to suit industrial and manufacturing requirements.

9. Acknowledgements

The Tshwane University of Technology, particularly the Industrial Engineering Department and IMDS research unit are hereby acknowledged for this research. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the institution.

References

[1] Aguilar, A., Roman-Flores, A. and Huegel, J.C., 2013. Design, refinement, implementation and prototype testing of a reconfigurable lathe-mill. Journal of manufacturing systems, 32(2), pp.364-371.

[2] Buede, D.M. and Miller, W.D., 2016. The engineering design of systems: models and methods. John Wiley & Sons.

[3] Derelöv, M., 2008. On Evaluation of Design Concepts.

[4] Dicken, P., 2007. Global shift: Mapping the changing contours of the world economy. SAGE Publications Ltd.

[5] Gadalla, M. and Xue, D., 2016. Recent advances in research on reconfigurable machine tools: a literature review. International Journal of Production Research, pp.1-15.

[6] Galan, R., Racero, J., Eguia, I. and Garcia, J.M., 2007. A systematic approach for product families’ formation in Reconfigurable Manufacturing Systems. Robotics and Computer-Integrated Manufacturing, 23(5), pp.489-502.

[7] Goyal, K.K. and Jain, P.K., 2016. Design of reconfigurable flow lines using MOPSO and maximum deviation theory. *The International Journal of Advanced Manufacturing Technology*, *84*(5-8), pp.1587-1600.

[8] Goyal, K.K., Jain, P.K. and Jain, M., 2013. A novel methodology to measure the responsiveness of RMTs in reconfigurable manufacturing system. Journal of Manufacturing Systems, 32(4), pp.724-730.

[9] Gwangwava, N., Mpofu, K., Tlale, N. and Yu, Y., 2014. Sheet metal productivity improvement through a new press brake design. African Journal of Science, Technology, Innovation and Development, 6(2).

[10] Ilevbare, I.M., Probert, D. and Phaal, R., 2013. A review of TRIZ, and its benefits and challenges in practice. Technovation, 33(2), pp.30-37.

[11] Imenda, S., 2014. Is there a conceptual difference between theoretical and conceptual frameworks? Journal of Social Sciences, 38(2), pp.185-195.

[12] Karl T. Ulrich and Steven D. Eppinger, 2004, Product Design and Development, Exhibit 7-4, Chapter 7, 3rd Edition, Irwin McGraw-Hill

[13] Koren, Y., 2013. The rapid responsiveness of RMS. International Journal of Production Research, 51(23-24), pp.6817-6827.

[14] Koren, Y. and Shpitalni, M., 2010. Design of reconfigurable manufacturing systems. Journal of manufacturing systems, 29(4), pp.130-141.

[15] Maxwell, J.A., 2005. Conceptual framework: What do you think is going on. *2005). Qualitative research design: An interactive approach*, pp.33-63.

[16] Padayachee, J., Masekamela, I., Bright, G., Tlale, N.S. and Kumile, C.M., 2008, December. Modular reconfigurable machines incorporating modular open architecture control. In Mechatronics and Machine Vision in Practice, 2008. M2VIP 2008. 15th International Conference on (pp. 127-132). IEEE.

[17] Ptolemaeus, C., 2014. System Design, Modelling, and Simulation: Using Ptolemy II. Berkeley: Ptolemy. org.

[18] Ramatsetse, B.I., 2014. Development of a reconfigurable vibrating screen. Master's Dissertation, Tshwane University of Technology, Pretoria, South Africa.

[19] Ramatsetse, B.I., Matsebe, O., Mpofu, K. and Desai, D., 2013, June. Conceptual design framework for developing a reconfigurable vibrating screen for small and medium mining enterprises. In Southern African Institute of Industrial Engineering 2013.

[20] Robinson, S., 2013, December. Conceptual modelling for simulation. In 2013 Winter Simulations Conference (WSC) (pp. 377-388). IEEE.

[21] Rodriguez, C.A., Lugo, E., Ponce, P. and Molina, A., 2015. Towards a Reconfigurable Inferior Limbs Exoskeleton for Assistive, Rehabilitation, and Empowering Application. IFAC-PapersOnLine, 48(3), pp.1496-1501.

[22] Sinclair, M., 2007. A guide to understanding theoretical and conceptual frameworks. Evidence-Based Midwifery, 5(2), pp.39-40.

[23] Urbanic, R.J. and ElMaraghy, W., 2009. A design recovery framework for mechanical components. Journal of Engineering Design, 20(2), pp.195-215.

[24] Zhai, L.Y., Khoo, L.P. and Zhong, Z.W., 2009. Design concept evaluation in product development using rough sets and grey relation analysis. Expert Systems with Applications, 36(3), pp.7072-7079.