Challenges and Opportunities in Implementing Engineering Systems Thinking in Design, Manufacturing and Process Industries in Zimbabwe

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Abstract – **Engineering and manufacturing companies in industrializing countries such as Zimbabwe, largely employ traditional methods as well as conventional machine tools. Research carried out at five companies in Zimbabwe specializing in different business operations, similarly revealed that although such methods and tools are still applicable and productive, the processes are time consuming and the conventional machines often break down thereby delaying production. However, the research, which was conducted through interviews, direct observations as well as surveys, also revealed disconnections in 3 aspects of company policies, techniques employed and continuous professional development training. The research focused on establishing the challenges faced by the companies in implementing holistic approaches encompassing and integrating these 3 aspects. Recommendations were made for turning the various challenges into opportunities through adopting engineering systems thinking for integrating these aspects in order to improve capacity utilization, productivity and efficiency in the various companies.**

Keywords – **Engineering, manufacturing, systems thinking**

I. INTRODUCTION

Following the global financial crisis that affected many countries around the world in 2008 [1], many businesses in Zimbabwe, particularly in manufacturing were forced to scale down operations. Although the crisis was not anticipated to affect industrializing countries, Southern Africa was one of the worst affected because of heavy reliance on foreign aid. However the effects were dependent on individual countries' macro-economic situations. Zimbabwe was one of the worst affected, resulting in the second hyperinflation recorded in world history [2]. Many reasons have been advanced for this, ranging from economic sanctions, political instability or mismanagement. What was evident though was the failure by manufacturing companies in Zimbabwe to produce and provide services competitively, failure to substitute imported raw materials or spares and failure to export, let alone produce affordably for the local market. The combination of these factors contributed to the rapid increase of imports at an annualized rate of 13.2% during the period 2009 to 2014, with a widening gap of the trade balance between imports and exports [3]. Although the trend was similar for other Southern African Development Community (SADC) countries, it was at a much lower scale but with similarly declining Gross Domestic Products (GDPs) per capita, anchored by the semi-developed South Africa and diamond rich Botswana [4].

The hyperinflation led to the collapse of the country's currency and the adoption of multiple currencies in 2009 [5]. The country's manufacturing capacity utilization had reached its lowest in 2008 at 10% but the multiple currencies helped to gradually increase this to 32.2% in 2009, 43.7% in 2010 and a peak of 57.2% in 2011 [6]. This provided relief to the business community in Zimbabwe but it was not sustainable, evidenced by cash shortages in 2012 [7], attributed to hoarding and externalization. This forced the Reserve Bank of Zimbabwe (RBZ) to introduce small denominations of bond notes for trade within the country while encouraging businesses and the public to use plastic money [8]. However, this was not sustainable either as the bond notes were in short supply since the RBZ was not keen on introducing higher denominations for fear of hyperinflation [9].

Clearly, this chronology of events appeared to require more innovative ways to deal with the low capacity utilization and productivity issues in Zimbabwe's engineering and manufacturing companies. This paper is part of on-going research at 5 engineering, manufacturing and processing companies in Zimbabwe aimed at modelling the integration of engineering and manufacturing functions as well as related units and functions using engineering systems thinking. So far the results have revealed some interesting pointers to address the issues of low capacity utilization and productivity.

II. RELATED WORKS

Modern day engineering and manufacturing environments are continually changing and this comes with increasing degrees of complexity that simple methods and tools cannot solve easily [10]. Such complexity arises from the type of machine tools used, methods of production and provision of services, software driving the machine tools and a host of other technical issues. When engineers or production planners develop solutions to such complexities and challenges, they often focus on technical issues and sometimes overlook important external issues that may not have any direct impact on technical aspects. Such issues include the operating environment, company policies and their relationships.

The chronology of hyperinflation in Zimbabwe, collapse of the country's currency, introduction of bond notes and the liquidity crisis were growing challenges in the economy but despite measures put in place,

engineering and manufacturing companies continued to experience low capacity utilization and productivity challenges. These issues demand a holistic approach that encompasses all aspects that contribute to the development of products or provision of services. Engineering systems thinking, appropriately applied, provides an avenue to resolve complex problems in engineering and manufacturing by way of using and linking whole systems as opposed to individual aspects [11]. Several studies and research using systems thinking have been carried out in humanities, health and social sciences but more recently the use of systems thinking particularly in engineering and manufacturing has been gaining popularity ostensibly because of the outcomes associated with taking holistic approaches in solving complex problems [12].

Systems thinking has been definedby many practitioners in different ways but in general it is the ability to look at a system as a whole with all the elements, their interrelationships and functions rather than individually, in order to break down and resolve problems that may occur within the entire system [13]. This has been further refined to include interdependencies, analysis, synthesis and understanding of the interactions among system elements that can be social, technical or multi-faceted [14] in a set of elements designed for a specific purpose [15]. The interpretations in these is the ability to decipher interrelations among interacting elements of a system thereby enablingthe breaking down and holistically resolving complex relationships that may arise.

Various categories of systems thinking have been developed over the years by different researchers, targeted at solving particular complex problems. These include Individual Systems Thinking (IST) but more commonly Collaborative Systems Thinking (CST), sometimes known as Team Systems Thinking (TST) where teams from different specialities come together to use different forms of thinking approaches, design procedures and tools to resolve complex problems [16]. Whether it is IST or CST, practitioners are normally expected to have a certain level of appreciation of the elements of the system, even outside their practice to enable total accomplishment of set tasks or challenges that may require to be resolved by the approach.

Engineering and manufacturing companies are continually evolving in terms of machinery, methods of design and manufacture and more and more of what used to be the traditional disciplines of engineering such as mechanical and electronics have also evolved to become mechatronics. This has been largely due to the need to have engineers who have skills and understanding across several disciplines. As technology evolves, the traditional disciplines become interdisciplinary and complex, requiring engineers with a capacity for Engineering Systems Thinking (EST), a skill that enables engineers to perform tasks in an integrated manner [17] or more specifically, the ability to model their organizations from a systems perspective [23]. These abilities are usually a combination of knowledge acquired from tertiary institutions, professional skills from practice and behavioral competences from interacting with other professionals in practice [11, 18].

This paper is part of on-going research aimed at modelling the integration of engineering design and manufacture using engineering systems thinking that encompasses 3 aspects of techniques, professional training and policies and how they impact on capacity building, sustainability and retention of the skills within the profession. Having established the various challenges faced by Zimbabwean companies after the global crisis and the downward spiral of the country's economy, this paper focuses on answering questions revolving around; whether the companies have attempted to employ systems thinking, what challenges they faced and the opportunities for adopting a holistic approach to resolving the challenges in view of the increasingly interconnected aspects, their functions and how this will impact on capacity utilization, productivity, efficiency and competitiveness?

III. CASE STUDIES AND METHODOLOGY

The research was carried out at 5 companies based in Zimbabwe, all with distinct business portfolios in engineering, manufacturing and mineral processing. This paper comprises information derived from work studies carried out at the companies during the second half of 2015. For the purposes of company confidentiality, pseudonyms were used for the 5 companies as follows:

Furniture Co. is a wholly owned private Zimbabwean timber processing and furniture manufacturing company based in Harare, specializing in the production of domestic and commercial furniture from hardwood, with the raw timber sourced locally and from neighboring Mozambique. The plant comprised of a range of conventional wood processing machines such as crosscutters, spindle moulders, drum sanders and lathes.

Coach Build Co. is a subsidiary of a Zimbabwean government owned company also located in Harare, specializing in coach building and assembly of bus and truck bodies from knocked down kits imported from China. The company's workshop is equipped with various boilermaking and general engineering machine tools for milling, turning, bending and rolling as well as general sheet metal work.

Foundry Co., also located in Harare, is a privately owned Zimbabwean company specializing in the casting and machining of grinding media and other engineering equipment such as ball mills, valves and converters for the agricultural and mining sectors. The foundry consists of several induction, arc, cupola and crucible furnaces while the machine shop consists of conventional machine tools for milling and turning. In 2015 they acquired a state of the art computer controlled Continuous Casting Machine (CCM) for the production of flat and deformed bars, angle and channel irons. Their raw materials are mainly scrap metals sourced locally from steel merchants.

Bus and Truck Co. is a privately owned company located in Harare and specializing in the sales, services and backup of Scania heavy vehicles under franchise. The mechanical workshop is equipped with basic servicing

equipment and they also receive regular support from the parent company in terms of specialized expertise. All their products are imported fully assembled from Sweden.

Platinum Co. is a private foreign owned mining and mineral processing company with their metallurgical processing plant located 80 km from Harare and 4 portals and an additional processing plant located a further 70 km from the processing plant. The company specializes in the production of the Platinum Group Metals (PGMs). Both the portals and processing plants are fully equipped with automated mining and processing machinery such as haulers, crushers, ball and sag mills, concentrator, smelters and converters. Due to the lack of capacity, ore extracted from the 4 portals is processed to a concentrate then smelted to matte which is exported to the parent company for further refining and extracting of the PGMs.

The research methodology included a work study, data collection and analysis for 6 weeks at each company. The data was collected through surveys, structured interviews and direct observations of processes within the plants. The survey questionnaire focused on establishing the relationships, linkages and integration of the various units and was designed for 3 groups of respondents namely, senior managers, operation managers and engineers as well as artisans and shop floor staff in an anonymous way although they were requested to fill in their company titles and brief outline of duties. Observations made during the work study aimed at establishing the elements within the 3 aspects of company policies, techniques employed and continuous professional development training and how their integration or lack of, contributed to capacity utilization, productivity and efficiency. However this was not meant to compare the companies as they were involved in different businesses but to draw a basis between the economic environment and production planning, regardless of the business. The survey was based on the six steps and guidelines in accomplishing surveys set out by Creswell [19] as summarized in Table 1.

TABLE I
GUIDELINES FOR THE SURVEY AND QUESTIONNAIRE

Step	Objective	Details
1	Purpose	• General challenges • Integration with other units • Involvement and role in links • Specific integration challenges • Perceptions of staff on linkages
3	Sampling	Random sampling for ease of assembling
2	User-friendly	• Appropriate language
4	Pilot test	Revise survey for acctracy and reliability • Straightforward yes/no answers
5	Administration	Conducting survey confidentially
6	Data analysis	Statistical analysis and inferences drawn

Respondents were briefed on the purpose and importance of the survey before completion as well as allaying any fears of the survey's relationship with their performance evaluation to ensure that the information provided was as accurate as possible. The questionnaires were also designed to be completed in a few minutes by providing yes or no answers. The data collected from the survey was analyzed by content so as to synchronize issues. One on one interviews and observations were carried out with the same group of respondents at their workstations to validate the information from the survey. Theoretical saturation was also done to some convergence of information as is done in Delphi surveys [20]. The interviews were structured in a similar fashion and were conducted verbally, in some cases recordings were made after being granted permission to do so. Observations made at each company were compared with those made at the same companies prior to the collapse of the country's currency in 2009. Interactive and active observations of this nature were regarded as some of the most effective methods for qualitative research [21]. Data collected for the main research such as processing times, movement of parts and process flows were useful inputs to this paper for the systems thinking approach in so far as they impacted on the capacity utilization and productivity.

IV. RESULTS AND DISCUSSION

The common challenges identified included; conventional machines and traditional manufacturing or processing methods, inadequate infrastructure, waste management and disposal techniques and high staff turnover. Table II summarizes the findings in terms of *Policies*; whether there were documented company policies that they followed in their operations, *Techniques*; whether they made use of modern practices such as computer integrated manufacture, flexible manufacturing systems, concurrent engineering etc., *Training*; whether there were regular training courses and how often they were offered and on what basis. The *Integration* column was an interpretation of respondents' views together with the direct question on whether there were direct links among the 3 aspects.

TABLE II
ELEMENTS OF INTEGRATION

Company		Elements for Integration			
	Respondents	Policies	Techniques	Training	**Integration**
Furniture Co.	53	50%	50%	60%	60%
Coach Build Co.	6	20%	30%	20%	30%
Foundry Co.	59	55%	60%	64%	60%
Bus & Truck Co.	36	65%	50%	62%	65%
Platinum Co.	72	86%	90%	90%	88%

There was a clear pattern of a lack of sufficient and documented company policies to steer the various companies in their operations except for the foreign owned ones that had support from their parent companies. The techniques employed were largely traditional, purportedly because of the conventional machine tools. However,

Platinum Co. had a significantly high rating for documented policies because of their well-established Business Management System (BMS) based on ISO: 2008 quality management system [22] and their fully automated operations. However they slightly fell short due to lack of capacity for complete refinery of the platinum ore to precious metals although they had initiated plans for a base metal refinery. The company also had a clear policy for human resources development in all major areas including mining, engineering, metallurgical processing and associated areas, with frequent internal refresher courses and in some instances support for higher qualifications. Although senior management at the other companies indicated their desire to continuously develop staff, they were limited in terms of capacity and sufficient engineering personnel to offer graduate trainee programs. The only government owned company, Coach Build Co. showed very low ratings in all 3 areas because of the company's near collapse and lack of operations in 2015, hence the very small number of respondents. The extrapolated results for the existence of links and integration of the 3 elements provided a validation of the respondents' views, with most of the companies indicating a disconnection of these aspects assumed to have arisen from the challenges highlighted.

Table III shows the extrapolation of factors from Table II and information obtained from respondents. Productivity was derived from how much was produced from all inputs in the case of manufacturing companies and how many buses or trucks were serviced over a period of time in the case of Bus & Truck Co. Capacity utilization was estimated based on the number of resources available, human and machinery and how much of these were being utilized at any given time. The efficiency was observed and noted qualitatively by rating the operations as low, medium or high as it would have required a longer period of close monitoring of processes and operations in order to derive quantitative values similar to capacity utilization.

TABLE III
FACTORS INFLUENCED BY THE EEMENTS OF INTEGRATION

Company		**Estimated Factors**		
	Respondents	Capacity Utilization	Productivity	Efficiency
Furniture Co.	53	65%	67%	Medium
Coach Build Co.	6	10%	10%	Low
Foundry Co.	59	55%	63%	Medium
Bus & Truck Co.	36	75%	70%	High
Platinum Co.	72	90%	50%	High

The information gathered from the surveys and interviews provided a good foundation for interpreting the significance of challenges encountered by the companies and the failure to adopt and implement systems thinking strategies. The majority of those in senior management (88%) believed the cause for low capacity utilization was the economic crisis that the country was facing and that even though they wished to incorporate systems thinking, which some (66%) thought was a luxury, would not address the issues of capacity utilization and productivity. Almost 72% of respondents blamed low capacity utilization on continued power cuts and load shedding that the country had been facing since 2008. A significant number of senior managers (61%), small proportion of operation managers and engineers (44%) and virtually none of the junior staff understood what systems thinking was, although after explaining the principles, they felt it might be a good idea but not a priority. Most of the senior managers felt that even if they adopted it, their subordinates would not be able to implement it while on the other hand, junior staff felt it was purely a responsibility for those in management. While the majority of respondents (90%) from Platinum Co. were very satisfied with their working environment, machinery, level of automation as well as healthy and safety standards, 82%, particularly artisans and engineers from the other companies were dissatisfied.

The effects of hyperinflation, dollarization, introduction of bond notes and the general decline of the Zimbabwean economy since 2008 could have had a negative effect on the outcome of responses. However, by and large, the results were a true reflection of many companies in the country, particularly the low capacity utilization at indigenous owned companies. The low figure of productivity for Platinum Co. was attributed to the product being exported in unrefined form and the bulk of the ore was actually waste compared to the concentrate or matte extracted from it.

While adopting systems thinking to closely link and integrate company policies, techniques employed and continuous professional development may be beneficial, the biggest challenge observed was the lack of knowledge apart from the other challenges highlighted such as conventional machine tools and staff turnover. Naturally, organizations resist change particularly if they do not see any immediate benefits especially under the circumstances where companies in Zimbabwe have been scaling down operations. From the analysis, the general reason for failure to adopt systems thinking was the country's declining economy while the specific reasons were the lack of knowledge and capacity to adopt and implement the approach. The main focus for most of the companies was to survive the crisis. However, recommendations were made to consider internal refresher courses that can help all levels of staff to understand the importance of integration. Transformation is the cornerstone of how best organizations can learn from previous experiences and use that to model future operations [13] even in the face of the general economic crisis. In modern business environments, technology and the way to do business has transformed, with aspects such as policies, techniques and training increasingly becoming interconnected and cannot be handled in isolation.

V. CONCLUSION

The global financial crisis in 2008 led to the downscaling of companies in Zimbabwe. The interventions that were put in place were not adequate to address low capacity utilization and reduced productivity. Research carried out at 5 companies revealed a number of challenges that contributed to the failure to integrate policies, techniques and training. The research provided an innovative approach to identify and resolve these in a holistic manner in order to address capacity utilization, productivity and efficiency at these companies despite the difficult operating environment. The major limitation of this approach was the lack of knowledge and intellectual capacity at the companies to adopt and implement systems thinking, which required some initial training. However there was an appreciation of the need and potential that this approach can help in addressing capacity utilization, productivity and efficiency, albeit in an indirect way.

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