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Manufacturing in a Concurrent Engineering Environment in Developing Nations: A tutorial review.

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Abstract: *This paper discusses the need for implementation of Concurrent Engineering (CE) in less industrialized nations with the situation in Zimbabwe being focused on. The CE environment in a global arena is being highlighted and its tools for success are discussed in detail. The paper explores the implementation of Concurrent Engineering as a new trend in engineering and Management in the less industrialized nations, which addresses three main areas: people, process, and technology. The expectations of engineering graduates which will continue to change significantly in light of the popularity of CE philosophy are also discussed. The paper also focuses on major hindrances to the implementation of CE. Lessons for Companies in less industrialized nations like Zimbabwe are drawn from international role models in CE such as Boeing's Ballistic System Division and NCR. The author managed to put various literature of different researchers together since a lot of literature on concurrent engineering is scattered.*

Keywords: *concurrent engineering (CE), less industrialized nations, Third generation manufacturing, Tutorial review.*

I. Introduction

In an ever increasingly challenging and uncertain marketplace most organizations in less industrialized nations that want to stay in business are well aware of the managerial and business concepts like competitive advantages and core competences. They know that they should listen to the customers, understand their requirements and needs and translate them to an understandable language for the organization, provide them with quality products with competitive prices at the right time. Some organisations have even gone further and attain world class standards like ISO14001 and the ISO 9001:2008. In other words, they know that the global marketplace has no sympathy to mismanagement. However despite all these endeavours, it's rare to find companies in these emerging economies coming up with great innovations which are commercialized and brought to the market timeously. It is also rare to find these companies talking about Concurrent Engineering in their shop floors. Most of the reported successes are one-off achievements of major projects or technology implementation. There are very few reports on sustained use of CE as an on-going operation process in these organizations. Concurrent engineering has already become a philosophy that helped companies to attain world class stature [1].

II. Concurrent Engineering review

Concurrent engineering has become a common phrase in factory or business floors of industrialized nations since 1990. The process of concurrent engineering has also been known with various synonyms such as multidisciplinary team approach, life cycle engineering, parallel engineering, design fusion and producibility engineering, integrated product and process development or simultaneous engineering [2,3] .

Concurrent engineering is a systematic approach to the integrated, concurrent design of Products and their related processes, including manufacture and support. Typically, concurrent engineering involves the formation of cross-functional teams, which allows engineers and managers of different disciplines to work together simultaneously in developing product and process design. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements. [4].

The above definition is broad to illustrate that concurrent engineering principles are not restricted to manufacturing companies only, but they apply to any product development effort, the product could be software, service or even a financial portfolio.

2.1 Description of CE

CE is a Systematic approach to integrated product development that emphasizes response to customer expectations and embodies team values of cooperation, trust and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives, synchronized by comparatively brief exchanges to produce consensus**.**

Concurrent Engineering involves:

- Doing things simultaneously
- Focusing on the Process, being open to change
- Converting hierarchical organizations into teams
- Balancing and prioritising needs of customers, suppliers, quality control, marketing, sales and manufacturing

2.2 Concurrent engineering endeavors to achieve the following goals

- Greater competitiveness
- Improved profitability
- Raise sales and profits from new products
- Reduce new product time-to market
- Reduce human and capital costs
- Maintain or increase product quality
- Leverage knowledge and experience
- Close integration between departments and promotion of team spirit.

III. CE Environment

The concurrent engineering environment (CEE) is a conceptual arena created by any or all technologies enabling collaborative efforts in the manufacturing process.
In other words, the CEE is not a tangible object. It is a very significant perception with many useful and potential applications to the manufacturing industry.

CE environment aim to increase the concurrency of design by allowing teams of designers to remotely communicate on a network and share information in a common data base. The technologies establishing the CE environments are already developed to some useful levels across the globe .Some of these technologies are listed and explained below**.**

a. The Internet is a global system of interconnected computer networks that use the standard internet protocol suite.

b. Electronic mail, - commonly called email, is a method of exchanging digital messages or diagrams across the Internet or other computer networks

c. Intranet is a private network that is contained within an enterprise. It may consist of many interlinked local area networks and also use leased lines in the wide area network. Typically, an intranet includes connections through one or more gateway computers to the outside Internet. The main purpose of an intranet is to share company information and computing resources among employees. An intranet can also be used to facilitate working in groups and for teleconferences.

d. Extranet is a private virtual space to securely collaborate, share information or integrate operations with traveling teams, suppliers, vendors, partners, or customers. A few examples are a sales extranet containing order forms and client directories for the sales team, a partner extranet enabling management of joint tasks, or a customer extranet portal where one collaborate on specifications documents with clients. Since the above parties are spread over diverse locations, extranets use the internet as a network to reach out to these parties. A company typically may have multiple dedicated extranets for different parties depending on information needs and nature of relationship. Extranets can sometimes also be seen as an extension of the company "intranet" or internal network where external parties are brought into the fold of the company's private network with access to specific areas or information as shown in fig 1.

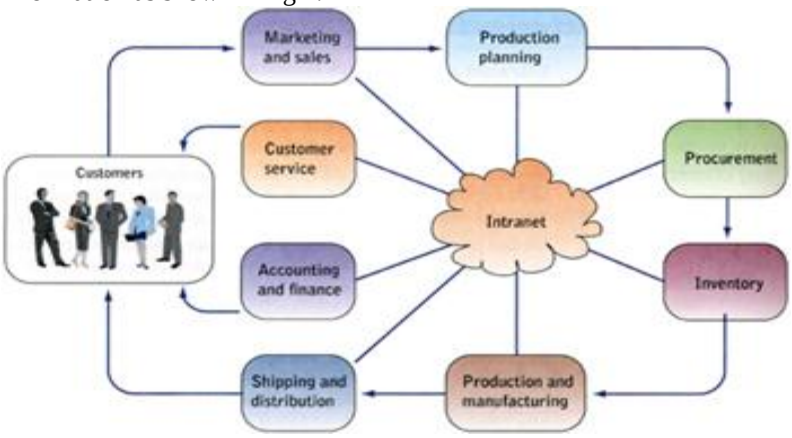

Fig 1: extranet an extension of the company intranet

e. GSM (Global System for Mobile Communications: (*Groupe Spécial Mobile*) is the most popular standard for mobile telephony systems in the world.

f. Mobile collaboration

Mobile collaboration involves people working and moving in space, mobile collaboration can encompass most of the traditional and online data transfer. Some of the features of mobile collaboration in the CE environment are notification to from mobile phones, viewing and searching of text based data through mobile phones for example task lists, document lists or aggregate production plans. A simple mobile collaboration system is shown below in Fig 2, where SMS is a short message technology used in mobile phones. The term WAP means Wireless Application Protocol which is an open, global specification that empowers mobile users with wireless devices to easily access and interact with information and services instantly. Hand held digital wireless devices such as mobile phones, pagers, two-way radios, smart phones and communicators from low-end to high-end are compatible with WAP.

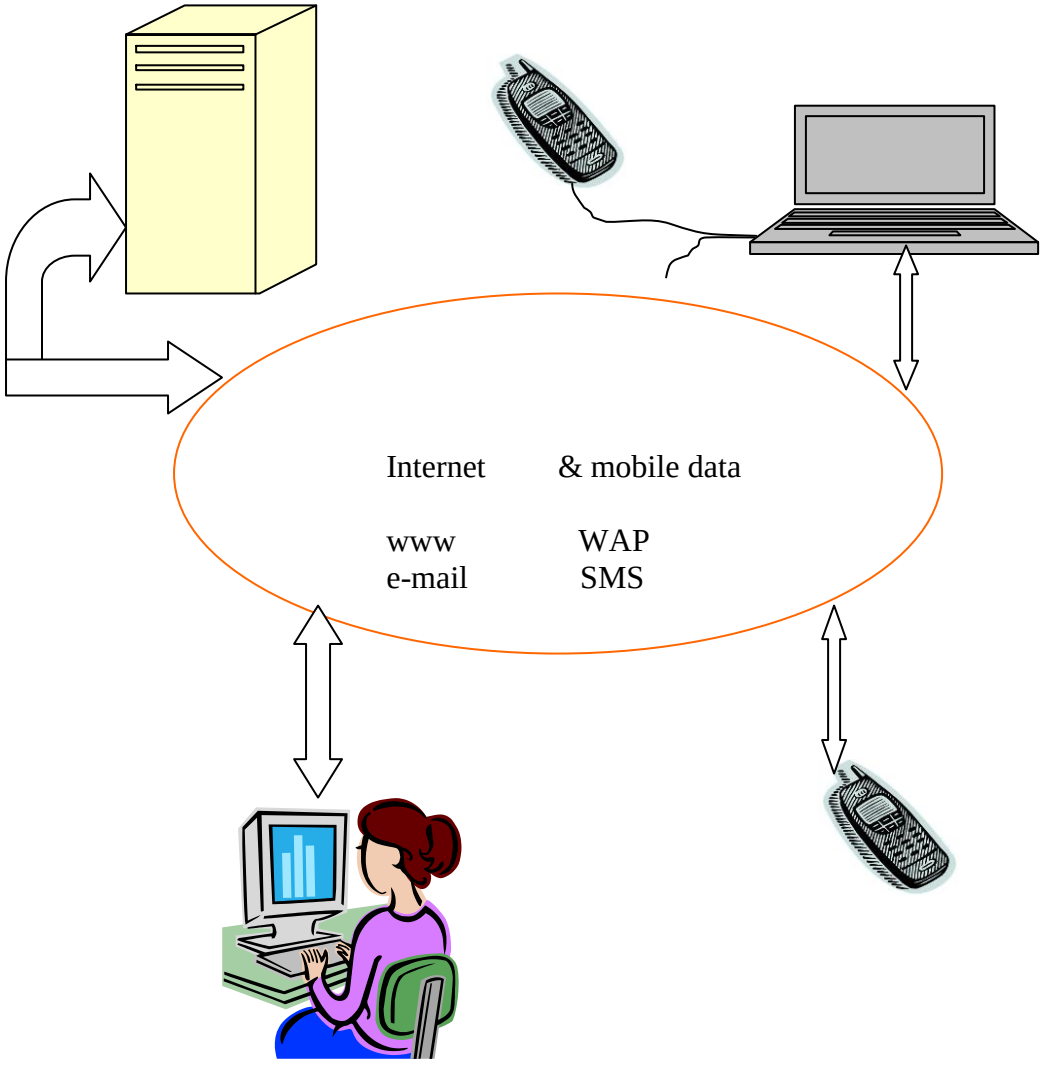

Fig 2: CE environment for multidisciplinary organisation with mobile devices

IV. Concurrent Engineering Tools

Concurrent engineering tools for design and manufacturing increase the concurrency of multidisplinary design by integrating enabling tools explained below.

(i) Computer Aided Design (CAD) which is a software used by architects, engineers, drafters, artists, and others to create precision drawings or technical illustrations. CAD software can be used to create two-dimensional (2-D) drawings or three-dimensional (3-D) models

(ii) Computer Aided Manufacturing (CAM) is the use of computer software to control machine tools and related machinery in the manufacturing of work-pieces [5].CAM may also refer to the use of a computer to assist in all operations of a manufacturing plant, including planning, management, transportation and storage [6]. Its primary purpose is to create a faster production process.

(iii) Group Decision Support System (GDSS**)** is an interactive, computer-based system that helps a team of decision-makers solve problems and make choices. [7]. GDSS are targeted to supporting groups in analyzing problem situations and in performing group decision-making tasks. GDSS includes a network of computers, usually in a face-to-face environment and the software which enables a group to exchange written comments and voting results

High level managers can spend 80% of their time making decisions in groups. Applied correctly, GDSS can reduce this time, arriving at a better decision faster. Some of the advantages of using GDSS in concurrent engineering are that it facilitates parallel communication which eliminates monopolizing thereby providing increased participation and better decisions. It eliminates too big domination of some group members in the meeting. It also makes it possible to find out the common and nonconforming opinions quickly among the group members. There is no need to take notes they are automatically recorded (Automated record keeping).GDSS can enable virtual meetings, what is only required is a software, hardware and people connected

(iv) Expert systems are a computer program that simulates the judgment and behavior of a human or an organization that has expert knowledge and experience in a particular field. Typically, such a system contains a knowledge base containing accumulated experience and a set of rules for applying the knowledge base to each particular situation that is described to the program. Sophisticated expert systems can be enhanced with additions to the knowledge base or to the set of rules. Every expert system consists of two principal parts which are the knowledge base and the inference engine. The knowledge base contains both factual and heuristic knowledge. Factual knowledge consists of items commonly agreed upon by spokesmen in a particular field. Heuristic knowledge is the less rigorous, more experiential and more judgmental knowledge of performance or what commonly constitutes the rules of "good judgment" or the art of "good guessing" in a field. A wisely used representation for the knowledge base is the rule or if then statement. The "if part" lists a set of conditions in some logical combination. Once the "if part" of the rule is satisfied, the "then part" can be concluded or problem solving action taken. Expert systems with knowledge represented in rule form are called rule-based systems.
The inference engine makes inferences by determining which rules are satisfied by facts, ordering the satisfied rules, and executing the rule with the highest priority.

(v) Rapid Prototyping technologies (RP), it uses advanced computer and laser technologies to produce complex three dimensional prototypes in a fraction of the time required by more traditional technologies .The rapid prototyping process begins with CAD solid model output to the appropriate RP file format. The file data is sliced into cross sections of approximately0.076mm to0.25mm in thickness. The cross sections are then fabricated in layer additive process using any of the three RP technologies which are selective laser sintering (SLS), Stereolithography (SL) and 3D printing (3DP). Rapid Prototyping is a system for creating immediate prototypes of a new design that is used to evaluate it. The ability to create or manipulate a solid model on the computer is fast becoming a minimum pre-requisite to function in a technical capacity in the settings of a concurrent engineering environment. Rapid prototyping technology has caused industries to rethink from “a picture is worth a thousand words” to “a prototype is worth a thousand pictures.” By giving engineering, manufacturing, marketing, and purchasing a look at the product early in the design process, mistakes can be corrected and changes can be made while they are still inexpensive. Rapid Prototyping improves product development by enabling better communication in a concurrent engineering environment

The above technologies can not be implemented at once in organisation since they are costly. The basic technologies that can be required to initiate the concurrent engineering philosophy mighty just be a CAD software and internet. Most of the remaining technologies can be implemented using the concept of continuous improvement (Kaizen).

V. CE and Zimbabwean companies

The manufacturing industry in Zimbabwe is moving from the equipment and labor-intensive stage to the knowledge and information intensive stage. This is demonstrated by the fact that most Manufacturing companies in Zimbabwe are now using the CAD as the initial method of producing engineering drawings and designs .They have superseded the traditional manual methods of using the drawing board. Majority of Zimbabwean companies have invested in internet services in order to keep abreast with world wide trends.

The only mismatch is that majority of our Local companies use the traditional manufacturing practice or over the wall engineering which is sequential, that is each step is completed in order or sequence only after the previous steps have been completed [8]. Companies with CAD facilities produce detailed drawings in the drawing office; the drawings are then passed to the machinist who then uses the drawings to make a prototype. It is only after creating a prototype of the design that the engineer discovers that for example a hole was too small or that parts do not mate properly or that a fillet can not be manufactured. The part would have to be redesigned and the traditional sequential process repeated. This shows that the sequential manufacturing is expensive and time consuming.

In this competitive global manufacturing environment, the traditional or over the wall manufacturing is no longer adequate. In a matter of months, our local manufacturers may find that factors such as markets, material prices and technology, government regulations and tax laws, multiple currency regimes (currently prevailing in Zimbabwe) may change before they introduce their new products into market. This global competitive climate requires a company to design high quality products faster, better, and less expensive than their competitors. One solution to the traditional manufacturing paradigm currently practiced in Zimbabwe and other less industrialized nations is concurrent engineering.

In our informal survey carried out before the project, we discovered that most companies have the basic concurrent engineering technology enablers such as internet, e-mail, Fax, GSM, CAD/CAM. But what is lacking is the concurrent engineering philosophy.

An article in the march 22, 1990 issue of Machine design entitled". Teamwork in real engineering" describes how concurrent engineering was used to cut the development time on General Motors' (GM) LT-5 engine for the ZR-1 Corverte. By involving engineering and other functions concurrently in the development of the engine, GM was able to compress the development time from the traditional seven years to four years. The only technology enabler that they used was a fax machine. The fax machine was used for transmitting design changes between the design teams in Detroit, Michigan and Hethel, England and the manufacturing team in Stillwater, Oklahoma [9].

The illustration above emphasise that CE can be practiced in companies even if they do not have advanced computer support especially small companies who have very highly skilled and experienced people.

VI. Is Concurrent Engineering for local companies in lower income economies?

To ascertain whether the Concurrent Engineering is suitable for local companies in developing nations, the following questions should be considered:

i) *Does the company face any of the following problems in product development?*
- Increasing competitive pressure to develop new products
- Product launch delays
- Higher costs in processing and developing products than acceptable
- A predominantly internally focused product development process
- Little or not direct knowledge of customer requirements
- No or low involvement by the marketing staff in early stages of product development
- Shift in responsibility for product development from one function to another as the project progresses and transfer points often characterised by conflict.
- Poor transferal of learning from one product development project to the next.

ii) *Is the company able to provide the necessary enablers to this process? / What is the state of the organizational readiness**?***
- Willingness to change for improvement
- Senior management commitment
- Ability to encourage teamwork

iii) *Is the company able to answer the following questions* [10]
- How could implementing Concurrent Engineering be useful to the company?
- How will the teams formed?
- How will the opening of communication facilitated?
- How will the existing processes changed?
- How will the technology be implemented?

VII. How to implement CE in an organization

The implementation of Concurrent Engineering addresses three main areas people, process, and technology [11]. It involves major organizational changes because it requires the integration of people, business methods, and technology and is dependent on cross-functional working and teamwork rather than the traditional

hierarchical organization. One of the primary issues is the formation of teams. Collaboration rather than individual effort is standard, and shared information is the key to success. Team members must commit to working cross-functionally, be collaborative, and constantly think and learn. The role of the leader is to supply the basic foundation and support for change, rather than to tell the other team members what to do. Training addressed at getting people to work together in teams plays an important role in the successful implementation of Concurrent Engineering.
The implementation of concurrent engineering can be introduced along the following four phases in Fig 3, [12].

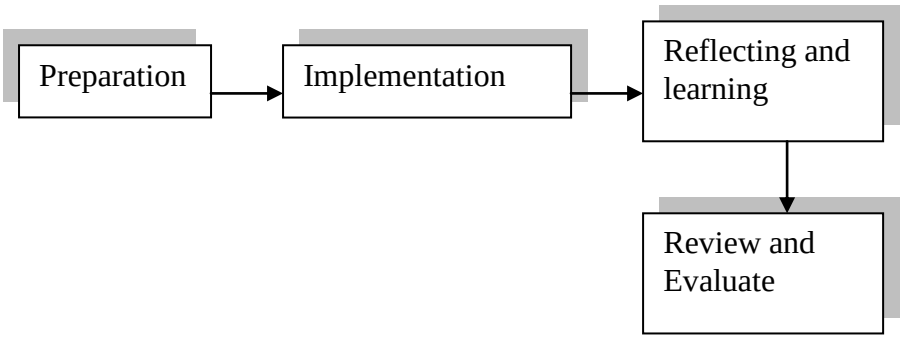

Fig 3: phases of concurrent engineering implementation

7.1 Preparation phase

(i) Improve the understanding of the principles of CE before any further work is done the principles of CE need to be understood by everybody involved in the organisation.
(ii) Identify the reason(s)that made the company to think of CE implementation
(iii) Identify the major objective(s) for implementing CE based on the reason to improve; one must know what the objective (s) is/are.
(iv) Create clear goals and measurements for the implementation that aligns with the company's strategy and the reasons to change
(v) Appoint a project leader in this stage assign a project leader who can provide necessary knowledge, skills and experience about CE to others.
(vi) Indentify which components of CE that should be used the components and activities in the list below is a selection of the most common used, it is mainly based on Salomone's summary of the basic concepts of CE[13]. The components are

a. Collaboration:
   - Organisational support
   - Multi-functional teamwork
   - Leadership required for the whole project
   - Knowledge -using existing knowledge Training personnel for the task
   - Experience, take into account the effects of the firm's organisational culture and prior experience.
   - Skills, talented and competent employees, managers and team members
   - Willingness to collaborate and learn
   - Mentor to support CE implementation

b. Information technology and Computer aided tools

(vii) Identify whether the right enablers and activities that underpin CE already exist in the Company? The enablers are:

- Culture of change
- . The positive attitude
- Good communication between different units/functions associated with the Product life cycle
- Open organisational structures such as matrix management and teamwork
- The knowledge and skills to understand the company's own needs and potential solutions
- Supplier and customer involvement

- Knowledge about CE and its components

(viii) Adapt CE to the company's circumstances, explore if there are any specific circumstances that need to be considered. A SWOT analysis can be very helpful in this stage to ensure that the company's circumstances are considered.
(ix) Identify the important points for integration; explore what activities can be performed in parallel? The priorities for the project need to be considered when deciding this issue.
(x) Determine the functions and personnel that should be involved in the CE process below are the most common functions that are involved in a New Product Development process.

- Product development
- Manufacturing engineering
- Marketing
- Sales
- Service
- Purchasing
- Finance
- Specialist vendors (e.g. machine tools and other key components)
- Main suppliers and customers

(xi) Verify that the implementation of CE doesn't result in any adverse side effects. When implementing CE one must make sure it matches with all the other concepts and strategies already existing within the enterprise. If there is a mismatch somewhere it has to be solved before the implementation process begins.
(xii) Verify that key performance indicators are in use and are aligned with the company's strategy and the reason to change
(xiii) Form an action plan for the implementation
(xiv) Form a budget for the project

7.2 Implementation phase

(i) Implement CE according to the developed implementation plan
(ii) Stabilize the CE process and collect data fore subsequent assessment
(iii) Follow the plan and monitor the milestones and measures

7.3 Review and evaluate phase

(i) Review the results of the implementation of CE
(ii) Revise the process, if necessary
(iii) Standardize the processes to continue the improvement
(iv) Establish measures for monitoring the process for changes

7.4 Reflecting and learning phase

(i) Assess the results and recommend changes
(ii) Continue the improvement where needed, standardize where possible
(iii) Seek other opportunities for improvement
(iv) Evaluate the learning from the experience

Concurrent Engineering is a business strategy, not a quick fix. It will take many years to implement. If management doesn't have the time or budget to go through the above steps, then it is unlikely that Concurrent Engineering will be implemented.

VIII. Major pitfalls of CE implementation

Many companies have problems introducing Concurrent Engineering. Warning signs include:[11] unwillingness to institutionalize Concurrent Engineering

- maintenance of traditional functional reward systems
- maintenance of traditional reporting lines
- no training in teamwork
- unrealistic schedules
- no changes in relationships with vendors
- a focus on computerization rather than process improvement

IX. Lessons for companies in less industrialized nations

By executing design in parallel, improvements occur in many areas such as communication, quality, production processes, cash flows, and profitability.

Companies in less industrialized nations like Zimbabwe can draw lessons from international role models in CE such as Boeing's Ballistic System Division achieved the following improvements [14].

- 16% to 46% in cost reduction in manufacturing
- Engineering changes reduced from 15-20 to 1-2 drafts per drawing
- Materials shortage reduced from 12% to 1%
- Inspection costs cut by a factor of 3

Another world class company which had remarkable benefits from CE is the NCR [12] which used CE to develop a new cash register and achieved the following benefits:

- Reduction in parts and assembly line;
- 65% fewer suppliers;
- 100% fewer screws or fasteners;
- 100% fewer assembly tools;
- 44% improvement in manufacturing costs;
- Trouble-free product introduction.

The success of the above world class companies is clear a testimony that if companies in less industrialized nations adopt CE they will be able to reap remarkable benefits such as the improvement of customer satisfaction through improved quality, reduced costs and faster product development. This will enable the companies to penetrate international markets and able to sustain their market share through continuous improvements of their products. By producing quality products timeously the companies can use the concurrent engineering platform to attain quality standards like ISO 9001:2008.Total quality management (TQM) and CE have many common principles. CE focuses mainly on the integration and concurrency in the design and manufacturing processes and TQM is the management approach of an organisation, centered on customer satisfaction, which includes improved tools and techniques to achieve business goals. One of the stumbling blocks in implementing TQM in companies is the lack of roadmaps to translate the concepts into practice, concurrent engineering is the answer.

Although CE is a relatively ease concept to understand, it takes much more for practical implementation. Shorter cycle time is one of the factors that influence the profit equation. The quality of the product and its cost are prime determinants of success in the market. If a company focuses on cutting cycle time, the end result would be poor quality products produced at premium costs in a shorter time span. This can be disastrous as the company can lose its market share, depending on the extend of the losses; the company may have to close its doors. It is Safe to assume that a hurried implementation of CE without careful planning and investment of time has high chances of backfiring. For example it takes most companies around eight months just to become comfortable with a new CAD/CAM system [15].

X. Relevance of CE in Engineering programs and other disciplines

The replacement of over the wall engineering with CE has introduced an exciting new world of opportunities for engineering graduates. The expectations of engineering graduates will continue to change significantly in light of the popularity of CE philosophy. It is the mandate of all engineering educators to consider these changes and prepare students to meet their future workplaces with confidence.

Most universities and colleges in Zimbabwe who train engineers and technicians do not have CE courses in their curriculum. This is a major problem since their graduates are going to be future managers and engineers of our companies. The end result is that Zimbabwe will have problems in developing new products and services as is evidenced by the country's major exports of raw materials and semi –finished products. CE encourages value addition to our raw materials.

The impact of concurrent engineering and associated industry needs should be translated into a new curriculum model for engineering programs and other disciplines

The development of a curriculum model for polytechnics and Universities that captures the concurrent engineering goal is by no means a simple task. In close comparison the colleges and Universities need to use the concept of CE in designing a curriculum that would prepare students for the challenges of a concurrent engineering environment.

XI. Conclusion

This paper presented concurrent engineering principles and how it can be used with other enabling technologies. Most manufacturing companies in Zimbabwe are still using the traditional sequential approach to developing new products or improving already existing products or services. As a developing country our industry needs to work at educating each other on the benefits that come with adopting a concurrent manufacturing setup. New technologies such as rapid prototyping, expert systems and Group Decision Support

System (GDSS) will then follow after the basic structures have been built. It is also important for our local companies to understand that concurrent engineering is anchored by the following three T's which are

• Tools - involves the material infrastructure
• Training - relates to the human aspect and includes educating personnel on the use of appropriate tools.
• Time - considers realistic expectations in terms of setting targets

Companies should realise that concurrent engineering is a manufacturing philosophy for the future or third generation manufacturing and should start implementing it now or risk being elbowed out.

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