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Developments in sustainable manufacturing and environmental protection in Libya

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ABSTRACT

Sustainable production is a concept where companies integrate economic, social and environmental concerns into their business operation/conduct. The paper is designed to present recent developments in developing effective sustainability concept for case study manufacturing industries in general and cement industry in particular for Libya. The objective is to achieve the much desired profitability with enhanced competitive edge over competitors. Based on an overview of integration tools it demonstrates that how a witness optimization model is developed and validated to clearly show that parts needs changing and breakdowns need recovering for sustainable production and environmental protection. Interesting results based upon a case study industry single machine that disregards the influence of the labor force to show dire need for employee involvement with the help of autonomous software are presented to reach required levels of maintenance efficiency as technology has to inform management and management has to use technology to carry out tasks.

KEY WORDS: Integrating New Maintenance Tools, Effective Maintenance System, Sustainable Manufacturing Industries, Competitive Edge over Competitors, Case Study.

ABBREVIATIONS: APELL: Awareness and Preparedness for Emergencies at Local Level, **CMMS**: Computerised Maintenance Management System ,**CSR**: Corporate Social Responsibility, **ERM**: Enterprise Risk Management, **IMS**: Intelligent Maintenance Systems , **JIT**: Just In Time, **MPP**: Master Production Plan, **MRP**: Material Resource Planning, **SCM**: Supply Chain Management, **SPC**: Sustainable Production and Consumption, **TWRM**: Total Weight Raw Materials, **UNCSD**: United Nations Commission for Sustainable Development, **UNEP**: United Nations Environment Program, **UNIDO**: United Nations Industrial Development Organization.

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INTRODUCTION

During the last 50 years, world has seen a rapid transformation of the human relationship with the natural world more so than in any other period in our history with escalating use of natural resources leading to environmental degradation. As per recent estimates of United Nation Environment Program (UNEP) the consequences of this pace of consumption and trajectory of population growth is forecasted to reach nine billion by 2050 would be catastrophic. Under current trends, global extraction of resources is expected to reach 140 billion

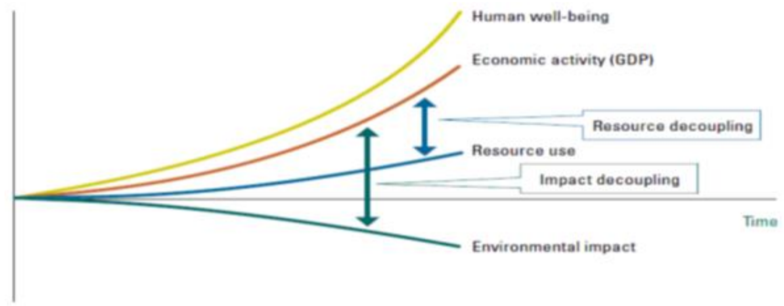

Figure 1: Decoupling economic growth from the use of resources and environmental burdens.

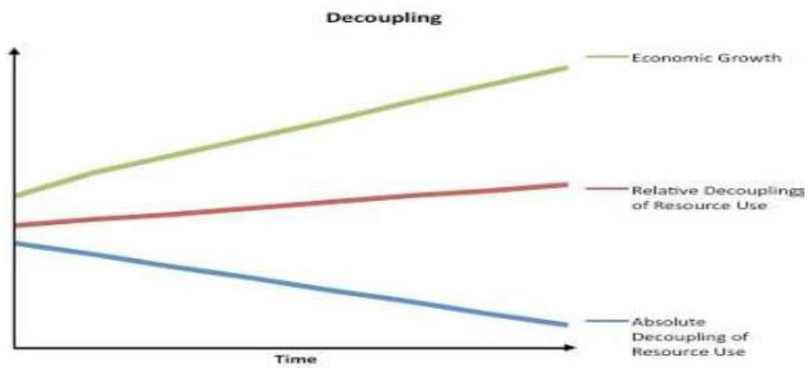

Figure 2: Relative and absolute decoupling.

tonnes by 2050, compared to around 7 billion tonnes in 1900. This would exceed the availability and accessibility of resources, as well as the carrying capacity of the planet to absorb the impacts of their extraction and use. Our planet cannot afford the waste, as resources are diminishing and prices are rising. Sustainable manufacturing is the key to transform the challenges of dwindling and finite resources into opportunities that would promote prosperous economies and a healthy planet for generations to come. Sustainable production poses a challenge to create development that balances the needs of the present against the expected needs of future generations. Sustainable production therefore means that we “may have to” lower our present expectations in order to ensure that future needs are met. It is a difficult challenge to protect of local resources/environment.

The natural consequences of the definition of sustainable production are if future generations’ needs are to be met, we cannot destroy the ecological balance due to global warming, over-fishing, destruction of rain forest, etc. The principles of sustainable production are in full agreement with theory and experience about continuous improvement. In order to achieve continuous improvement one has to take a long term perspective on the improvement work using rules for good team work which is an essential part of continuous improvement. The time perspective is dependent on the size of the system, if we talk about sustainable production we may talk about generations, 20 to 30 years, in a company wherein the time perspective normally will be 3 to 5 years. However, as per UN Ecosystem Assessment Report 2005 our current systems of production and consumption are escalating the risks connected to rapid resource depletion, degradation of ecosystems, and the threat of climate change with potentially irreversible consequences (Stamm et al., 2009). Pollution, competition for scarce resources and climate change may also intensify trends, such as desertification, further loss of biodiversity, sea-level rise, more frequent severe weather events and shortages of freshwater, leading, in the worst scenario, to resource-related conflicts and wide-scale migration (UNIDO, 2008). Figure 1 shows that despite growing recognition of these issues and risks, resource use, pollution and degradation of the environment have increased in absolute terms.

The way forward to ensure sustained growth is to decouple economic growth from resource use and pollution (Stammet al., 2009; Yumkella, 2010; von Weizsäcker et al., 2009). Decoupling can be either absolute or relative. Relative decoupling as shown in Figure 2 happens when resource use increases, but the

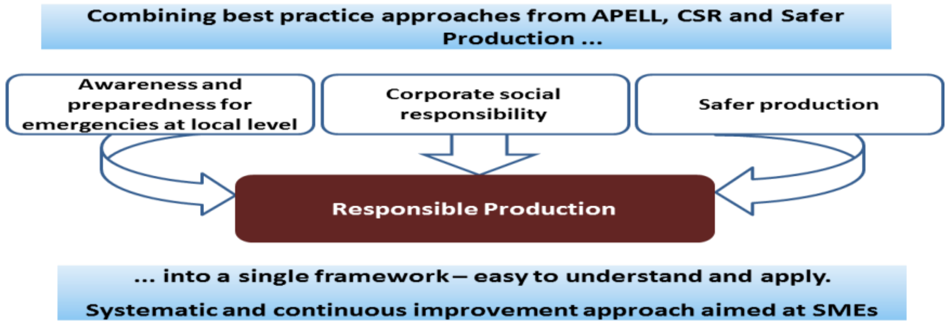

Figure 3: Sustainable production.

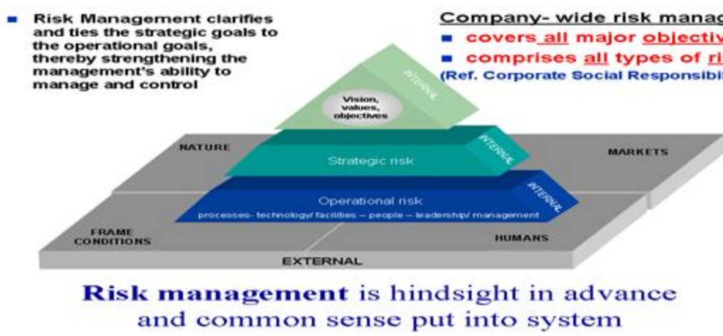

Figure 4: Enterprise risk management.

increase is less than economic growth. Absolute decoupling means that resource use is stable or decreases while economic growth increases (Stamm et al., 2009). Figure 3 shows that the Business's response to the challenge of Sustainable production is Corporate Social Responsibility (CSR). It is a concept where companies integrate social and environmental concerns into their business operation/conduct. Social and Environmental concerns are those hazards which may threaten sustainable global development. In order to deal with these hazards/threats, the company has to interact with multiple stakeholders (on a voluntary basis). A systematic, five-step model, for practical guidance and tools for assisting enterprises is given in this paper in identifying and understanding the hazards and risks related to products and operations on-site and along the value-chain. It Combines best practice approaches from Awareness and Preparedness for Emergencies at Local Level (APELL), CSR and Safer Production into a single framework easy to understand and apply. It uses ssystematic and continuous improvement approach. The Sustainable production benefits not only the external stakeholders but also to a very large degree the company culture and the employees with positive impact on financial results.

The workable methodology needs to encompass three aspects, sustainability, management risk and technology. The interaction between technology and business risks will create sustainable production. This is best achieved by dividing risks into internal and external risks as shown in Figure 4. The effective management of maintenance is integral to the success of all organisations to aid equipments life, product quality, costs related to maintenance and the underlying production cost itself (Roubi et al., 2009). Hence, a consistent affective maintenance system is of utmost importance in all industries to achieve the desired profitability and have that competitive edge over competitors. Maintenance as a whole consists of an array of different strategies and tools combined together according to industry and organisation, no single strategy or tool is sufficient alone to achieve maintenance goals. With the era of technology at hand with advanced computing and information technologies, more equipment and machines are equipped with sensors on critical parts of machines to warn of potential failures before they fail so they can be corrected before they stop production. Integrated computerised systems are the core of intelligent maintenance as well as e-maintenance, where computerised systems aid development of management in order to make a more informed decision with regards to undertaking or being prepared to carry out maintenance of all sorts. Intelligent maintenance systems (IMS) Predict and Forecast equipment performance so

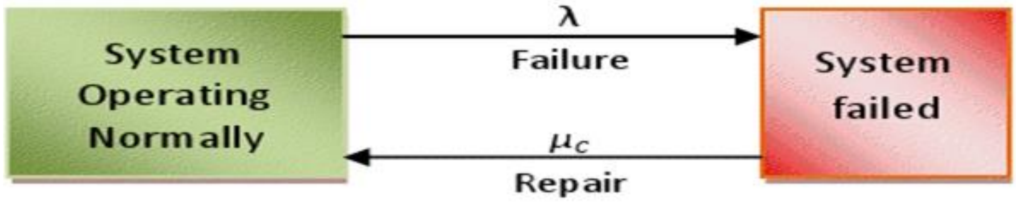

Figure 5: System operating state.

"Zero-Breakdown" status can be made possible and not a possibility of the past (Zineb et al., 2001; Wang 2002). Zero downtime focuses on machine performance strategies to minimize failures.

Data comes from sensors on equipment and machines and the information gathered by the organisation that is, quality data, past history, failures, repairs etc. Only looking at data from these sources from current and historical, it can help predict future performance. Industrial organisations today depend on sensor-driven management systems that provide alerts, alarms and indicators. Most factory downtime is caused by these unexpected situations. There is no alert provided that looks at normal wear and tear over time. If it were possible to monitor the normal wear, then it would be possible to forecast upcoming situations and perform maintenance tasks before breakdown occurs hence the need of intelligent preventive maintenance. Intelligent maintenance is to monitor equipment performance. If wear and tear starts to occur, there is enough time to carry out preventive maintenance on that particular area before failure. A machine can self-assess its health and trigger its own service request as needed and developed in this model with the automated response system. If this model works, then we can have a product that can manage its own service performance, send out alerts regarding preventive and corrective maintenances before the actual failure.

This indicates ways to keep it running in a high-performance manner and most definitely result in lean manufacturing. However, many industries due to economies of scale, global economies and increased competition from throughout the world simply and only focus on the bottom line**,** the cost of downtime has a big impact on profitability. For example, if equipment starts to wear, machines may be producing parts with unacceptable quality and not know it for a long time. Eventually, machine wear would seriously affect not only productivity but also product quality.

AN APPRAISAL OF INTEGRATION METHODS AND MAINTENANCE STRATEGIES

Integration of maintenance strategies, tools etc, can be segregated into two different integration methods known in the industry as hard integration and soft integration. The Hard aspects are with regards to integration which is aided by technology and computers, the Soft aspects are to do with human and the general working organisation integration. The hard aspects to a certain extent is almost a physical tangible means where as the soft aspects are more to do with the mental approach of the work force making it intangible. Now that the maintenance tool has been created using witness simulation that is a software tool, it can be classed as a hard integration as it is a tangible means of assessing maintenance. This tool has to be integrated within the maintenance strategy of the organisation in order to derive the best possible results.

The two integration variables are directly related to the prevention that is, they aid prevention of loss and increase efficiency. Integration has to aid and make easy the flow of information in all directions of the organisation regardless of hierarchy and managerial status in order to facilitate the decision making and planning process throughout all levels. Hard integration aspects of maintenance generally involves a computerised maintenance management system (CMMS) that deals with repairs and supplies, scheduling maintenance, condition monitoring technologies, built-in test solutions, reliability data software on electrical and mechanical component parts, and decision support. Soft integration aspects of maintenance deal with the staff members that include managers, technicians and operators etc.

In general, any one that has an interest which affects the underlying maintenance strategy, however, technological advances in the manufacturing industries has given rise to increased machinery being used decreasing the involvement of humans directly in the manufacturing process.

The integration of maintenance tools and strategies are absolutely integral to increase the availability and reliability of manufacturing systems in order to meet production plans and keep costs down. Integration is achieved by the combining of optimal maintenance strategies to have the advantages and evade the shortcomings of individual maintenance strategies. Hence, an affective maintenance programme should have different maintenance plans according to different machinery (Zineb et al., 2001). A machine system of one failure mode can have one of two states in a normal operating mode or in a failure mode. Figure 5

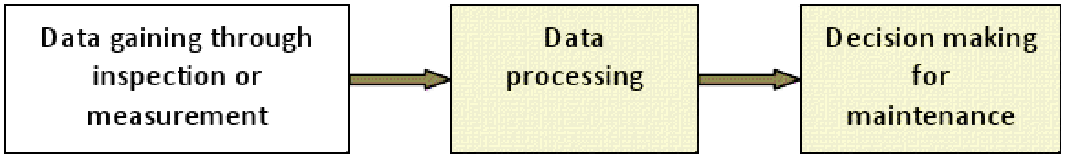

Figure 6:Steps of maintenance decisions.

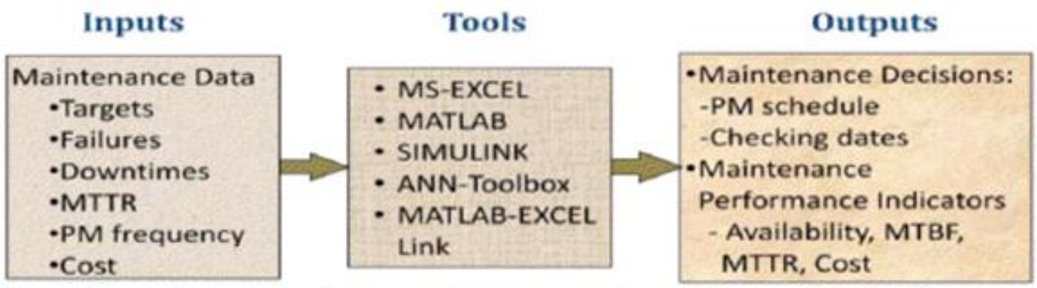

Figure 7: Data flow from input phase to output phase.

shows an example diagram of a single system that can either be operating working state or a failed state.

The purpose of a good maintenance management system should be to decrease the failure rate and increase repair rate. In actual maintenance applications, variables and attributes are scrutinised and used to determine the future reliability of machinery or component parts that is, estimated time for preventive and corrective maintenance. Figure 6 shows the process in maintenance decision making and Figure 7 enhances the process with greater detail as it shows the data flow from input to output. This same system can be applied to the current developed maintenance tool, the simulation model developed provides very good information according to need, the existing parameters are shown according to usage and the failure rate is clearly visible indicating the chance of failure.

The automated response system allows all aspects of the machine to by notified to all members, as message alerts arrive for when tasks need to be carried out and when tasks have been completed. Witness simulation can be made fully integrated as other techniques and other tools are easily implemented within it. Figure 7 shows inputs that is, failures and downtimes, after which the tool are shown such as witness simulation that aids the decision making process output that is, availability and MTBF. This system also has to work closely with management and manufacturing philosophies such as Just In Time (J.I.T) and supply chain management (SCM) that talk about the need for not only software integration to help increase efficiency but the need for a combined effort from industrial assets and industrial labour. The labour within industrial organisation is the key to maximising asset utilisation and in return the assets are the key to efficient productivity. In today economy, hard integration is used abundantly throughout all industrial and philosophies. There are many examples one can take into consideration that is, J.I.T is a software based system in industrial organisation used by world leaders such as Toyota in manufacturing cars. However, before J.I.T can be applied the enablers of J.I.T have to be adhered to as highlighted in the literature review.

The enablers of J.I.T includes the assets and labour force, their responsibility, this example clearly shows the need to integrate the two types of integration to enable effective use of tools and strategies with an organisation. The Master Production Plan (MPP), Material Resource Planning (MRP) and MRP11 has the same system in place, where technology is used to integrate the coordination of production and the materials needed with the aid of the available labour and industrial assets. Wang (2002) uses a stochastic approach in the decision making process for a condition based maintenance tool and Al-Najjar and Alsyouf (2003), uses a fuzzy approach in deciding the most efficient approach in maintenance. This highlights the fact that, even intelligent systems need to be validated and verified to ensure proper working order in order to achieve the best results and desired outcome.

UNCSD Rio+20 Focal Point on Development and Validation of Simulation Model for Effective Maintenance in Case Study

This study introduces the typical Libyan cement industry maintenance tools for its integration in sustainable manufacturing from start to finish with the aid of diagrams and explains what is involved throughout the processes. It demonstrates that how UNCSD Rio+20 Focal Point Libya promotes the Sustainable Manufacturing development / implementation of policies, strategies and practices that are cleaner and safer, make efficient use of natural resources, ensure environmentally sound management of chemicals, reduce pollution and risks for humans and the environment, It also shows that it establishes partnerships with other international organizations, governmental authorities, business and industry, and nongovernmental organizations.

Sustainable Production and Consumption (SPC) Branch of UNCSD is divided in 4 units

This four units comprises of the following (1) Business and industry (2) Integrated resources management (3) Goods and services and Sustainable UN CSD (SUN).

Business and Industry Unit is comprised of:

(1) Resource Efficiency and Cleaner Production (2) Safer and Responsible Production (including APELL) (3)Business and Partnerships.

Safer sustainable production for present and future comprises the tools, guidelines, and management principles implemented at site and local level to ensure both the sustainability and safety and health of workers in facilities that manufacture, store, handle or use hazardous substances, as well as the prevention of releases of these substances into the environment. Case study on the cement sustainable manufacturing process in Libya involves : quarry, raw grinding and burning, grinding, storage, packing, dispatch Figure 8. Also it introduces Witness Simulation approaches and how the construction of a model needs to be made with reference to the actual processes or stages of maintenance management tools during sustainable manufacture as described below.

The development of the model starts right from the beginning and moves forward that is, from raw materials to finished products as can be seen in the four stages of model construction in Figure 9. Once a certain element is developed this would be joined to the existing developed areas of the model. Ideally the model should represent as elements as shown in Figure 10 and 11 that come very close to what exists within the manufacturing plant as consulted.

Secondly, the actual construction is developed as the most simplistic approach with much consultation and rework where necessary, to aid simple understanding for all and lastly, all the elements within the model are in working order and materials flow as they should from start to finish in a logical process (Chan et al., 2002; Mike et al., 2009; Hokoma et al., 2008). The above has further been validated by the flow of materials from start to finish, that takes into account all the elements that represent the different aspects of manufacturing processes that exist in the model. The simulation model developed is validated using the Bayesain Network Modelling and Hugin Software (6), the essence of these techniques is embedded into this software by providing a dynamic platform to take into consideration of all influencing factors.

Simulation Model Experiment and Some Results

With a view to discuss the results of the simulation model experiments, different scenarios have been used to test the simulations model itself and further its validity. The first simulation in Figure 7 is capable of testing, how long a single load takes to process from start to finish and any disruptions that may occur during the simulation.

The second test is based upon 15 trucks that unload twice a day producing 30 loads a day hence a single load every 48 min. This model is run for a full day. This test enables the identification of disruptions that is, bottlenecks and blockages that may occur and further the handling of all materials from start to finish. The final test applies the actual test of approximately 52 loads being loaded, based on a load arriving approximately every 26 to 29 min and the running of the model for a full day. This simulation is capable of testing all the machinery, conveyors and staff at work. The objective of this scenario is to explore increased capacities and the capability of the entire system as a whole.

This simulation is capable of testing all the elements that is, machinery, conveyors and staff at work. The objective of this scenario is of utmost importance because it tests the above mentioned elements with increased capacities and the capability of the entire system as a whole to enhance its sustainability. In the initial test run of this model, there are a few constraints that is, many of the machines and processors within the system process a single truck load at a time, and for example, the mixture tanks at the final stage of cement manufacture have a minimum process level. So these processors have to wait until the required amount has been entered into the processor to proceed. Hence, in order to combat this issue as the first test is only for a single load, many changes need to be made to all the processors and further some machine to ensure logical process. Further changes are also needed to be made on the time certain machine would take to carry out a task as for this test only, the materials would be far less and hence take less time to process. Once all the above constraints are adhered to the following results are obtained: As apparent from Figure 11, it is evident that there are three

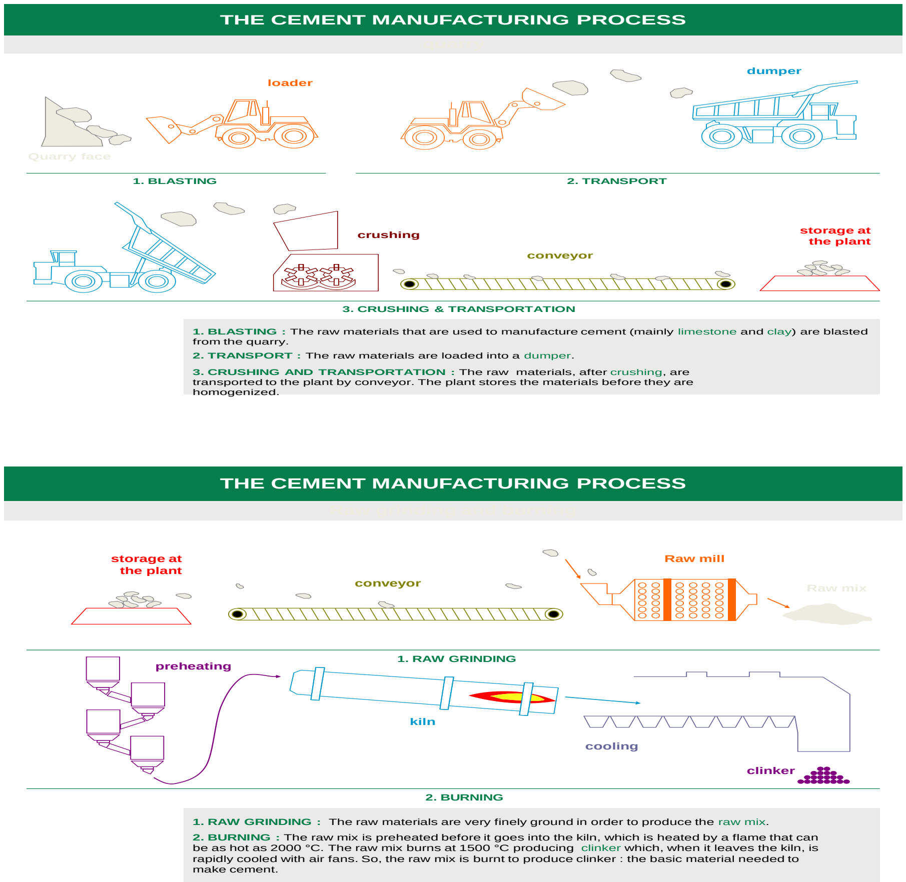

Figure 8: Cement manufacturing process.

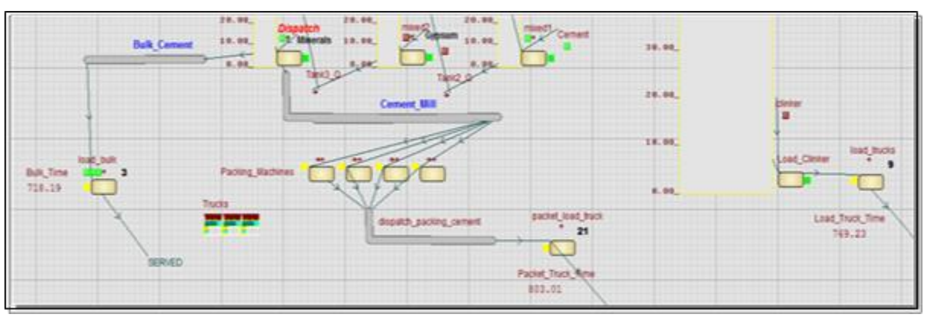

Figure 9: Final stage of running the model**.**

different stations labelled as 1, 2 and 3 near these stations exists as counters.

These counters represent the time taken for finished products in number of minutes. Bulk Time represents the bulk cement, which took a total of 718 min that is, approximately 2 min short of 12 h. Packet Truck Time represents cement in bags, which took a total of 803 min that is, 13 h and 23 min. Load Truck Time represents the clinker which took a total of 769 min that is, 12 h and 49 min. Figure 8 also shows, from the initial load from the quarry approximately 3 tonnes went towards bulk cement that is, station 1, over 1 tonne went towards cement bags that is, station 2 and approximately 9 tonnes towards the production of clinker that is, station 3.

Scenario 2 to 30 Loads

This scenario is more to do with, how the entire system as a whole copes with associated increased loads that enter the system and hence is a more logical approach. In order to cater for this need all the changes that are applied in scenario 1 to enable a single load to flow

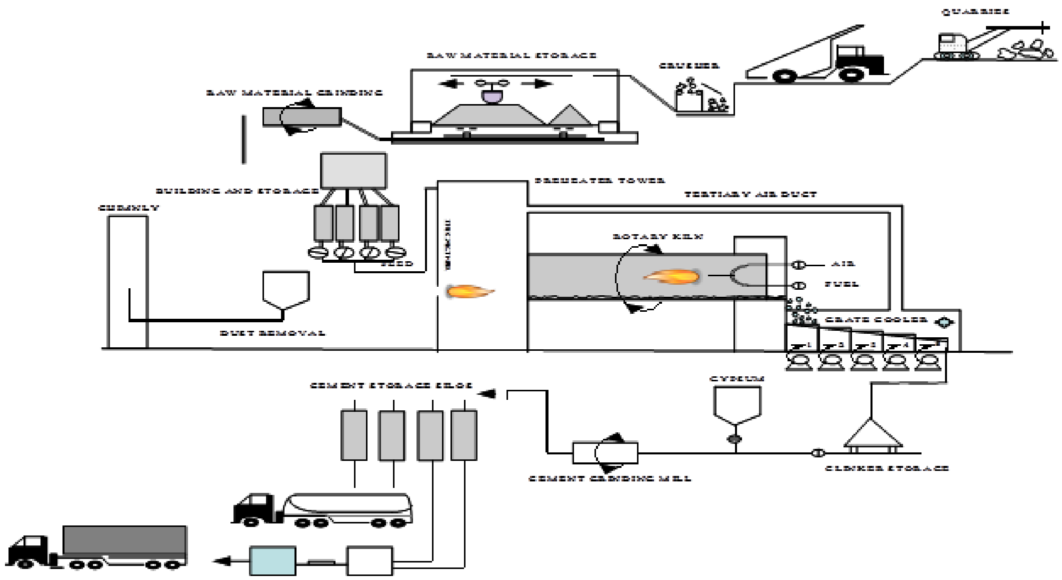

Figure 10: Stages of the production processes.

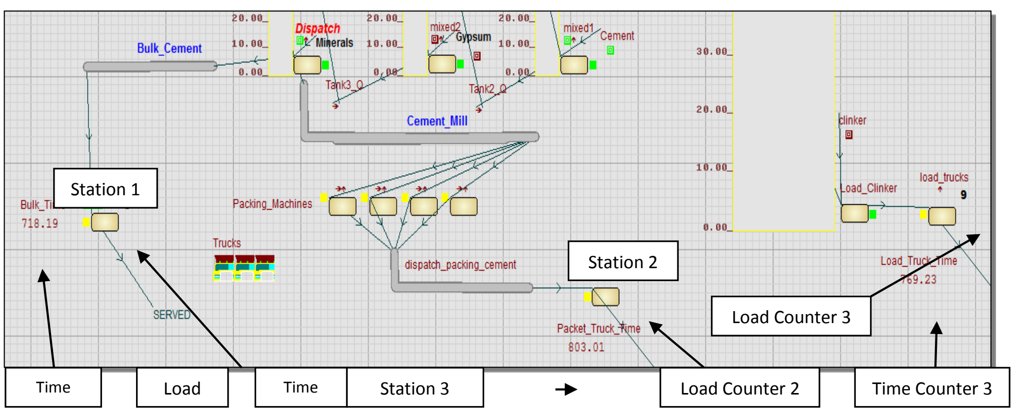

Figure 11: Different stations exists counters.

through have been changed back to enable a more logical process through machines that take in the approximate actual amount of materials and spend the designated appropriate time based on research and consultation. This model is capable of running for a whole day that is, 1440 min and a load is entered every 48 min based on a total 30 loads. This test shows the total amount of production for that day for implemented counters. One for the total amount of clinker produced and the other for the total amount of cement produced. This amount is based on production and not dispatch of products so once clinker is moved into tank, it is accounted for and further once cement is produced that is, entities move out of the last mixture tank where the manufacturing procedure is complete. Figure 12, stage 1 below provide an insight into what exactly happens in the model or what is happening when the time came to an end that is, at the end of 1440 min. The *TW RM* stands for total weight raw materials.

This tells us how much material in weight actually entered the system, in stage 1, 392.4 tonnes of raw materials entered with no current bottlenecks visible but however the pre-blending plants seem to have many raw materials loads still processing. In Figure 12 of the model, many raw material entities are still being processed hence much raw material still remains in the system and no bottlenecks exist. However this is further analysed by extracting the reports available from the software generated as package to help aid understanding as seen in the following tables. It clearly states exactly how much raw materials entered the system as mentioned above and how much of that material is manufactured into clinker and cement. Further, if the total manufactured material is taken away from entered material it should

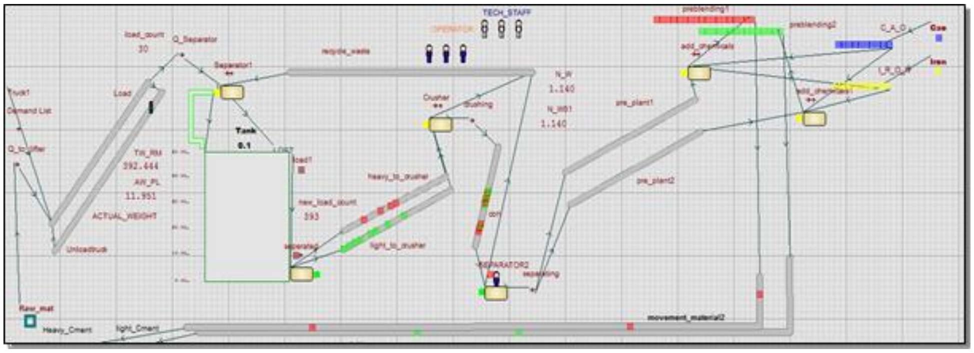

Figure 12: The model raw material entities in the system.

Table1: Resource statistics report.

Name	Operation	Tech_staf	Trucks
% Busy	23.10	7.27	4.20
% Free	76.90	92.73	95.80
Quantity	10.00	3	3
No. of Tasks Started	2604.00	285	13
No. of Tasks Ended	2597.00	285	12
No. of Tasks Now	7.00	0	1
No. of Tasks Pre-empt	0.00	0	0
Avg Task	1.27	1.10	15.00

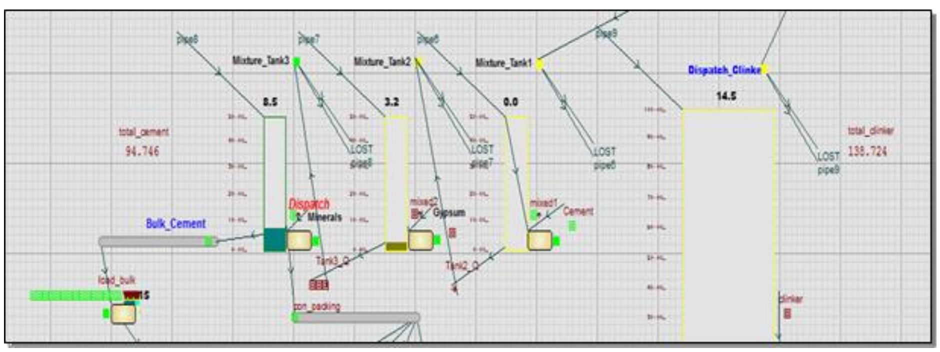

Figure 13: Stage 4 model after simulating for 1440.

show how much materials still remains in the system that is, 392 – (138 + 94) = approximately 160 tonnes remaining. From Table1 resource statistics, it is evident that, to a certain extent the organisation is overstaffed as resources are free majority of the time.

To combat this staff may be simply reduced enabling other staff to take up further responsibilities. From all the activities that exist within the model, the *load clinker* activity happens to be the only one that is blocked for a small percentage of time which has a logical explanation that is, as trucks load from the tank, further materials cannot be added to the tank and hence has to wait while loading the truck is finished.

Figure 13 shows the model after simulating for 1440 min. This is the final stage of cement manufacture that is, stage 4. On each side of this model the above mentioned counters exists to show the total amount of materials produced that is, cement and clinker as shown initially at the start via the use of the statistics reports.

Scenario 3 – 52 Loads

This scenario is the exact same as the scenario 2 but with an increased amount of loads and further a more logical approach to how and when the loads should arrive. In scenario 1 there is only 1 load, in scenario 2 there is 30 loads but each loads arrives every 48 min, respectively. However, after much research and consultation on this issue, a more logical approach is necessary that is, loads do not arrive every 48 min, they

arrive according to how fast the diggers can fill trucks in the quarry and how fast the trucks actually get from loading to unloading or vice versa. A conclusion is drawn and decided that as trucks arrive at a uniform time of 26 to 29 min firstly because a single load every 48 min for such a large manufacturing firm is not a logical approach.
This change enabled no specific times for arrivals of loads and no specific time between the arrival of loads and this would enable the testing of the model with an increase number of loads. This model is run for a whole day that is, 1440 min and a load enters at a uniform time of 26 to 29 min that equal to 52 loads of raw material. This test shows the total amount of production for that day with the help of the previously implemented counters and the statistics reports that are available. This simulation is capable of testing all the elements that is, machinery, conveyors and staff at work. The objective of this scenario is of most importance because it tests the above mentioned elements with increased capacities and the capability of the entire system as a whole.

RESULTS AND DISCUSSION

After defining Sustainable production and CSR the paper focuses on main issue of the inclusion of social and environmental concerns into the business planning and operation. The sustainability challenge needs to address multiple stakeholders' needs and continually measure, improve and demonstrate the health of the business. The method to systematically control business operation and development, that is, to achieve Sustainable Development, is Enterprise Risk Management (ERM). Successful implementation of ERM is a big challenge which needs commitment and systematic effort over long time. It is impossible to obtain Sustainable production without high quality information about performance. Balanced scorecard or another method would be the high level approach to performance monitoring. The balanced scorecard translates the strategy into operational objectives that drives both behavior and performance.
The main reason of implementing philosophies, is to gain a certain outcome for example, SCM is used to help increase efficiency by meeting customer demands in an effective manner. Therefore, the main question for any organisation regardless of industry is, "is this philosophy going to work" and if so," what would be the end results". This is exactly where simulation comes into hand and enables the eradication of many problems by the development of "what if" scenarios. First, no directly implementation or disruption to the actual organisation is required. Secondly, simulation enables time compression and therefore very little time is required to extract results. Lastly, the what if scenarios, that enable the developer to apply changes as many times as required until satisfied to check the model is fully sustainable and ready for the worst case scenarios.
The software enables the implementation of the organisational processes, the philosophies and thereafter the extraction of results. This enables the user to see exactly what effect a certain philosophy can have on the organisation and the results of the changes applied without effecting the organisation directly within a small period of time (Chan et al., 2002; Mike et al., 2009). The model constructed of the sustainable Libyan cement factory is based upon the existing factory with a SCM System and JIT system implemented, from raw materials right through to end products that is, this model is part based on assumptions to aid the SCM and J.I.T for example, chemicals and other minerals are readily available to be added, all the materials have to flow through the entire system in the designated loads, staff are always available to cater for the needs of production. Therefore, based on the assumptions the results extracted are logical and realistic as they represent different elements of philosophies, further as the development of the model increases and become more complex.
The assumptions can be reduced by replacement with actual elements that work with the system. This enables users to see and present what happens based on all the aspects of cement manufacture running smoothly and effectively, and the results thereof. Where if the results are satisfactory and can be verified, then the organisation can work towards this target, knowing what the end result should be and how all the processes should flow from start to finish. In scenario 1, where a single load is tested, it is very clear that materials could flow swiftly through all the designated elements that represent different aspects of cement production within a respective time. Although this does not represent a logical state of the facility it does however, represent the logical process materials have to go through within the facility. Scenario 2 shows how the entire system is in working order, processing a total of 30 loads in 1440 min, unlike scenario 1, this tests the different elements that exist within the model that have to cope with this increase loads. From this test it is clear that, the facility can handle this increased load but based on a fixed inter-arrival time of 48 min. Further, this test shows many other machines and conveyors begin to have entities waiting to be processed when the model is simulated.
This test also shows a moderate 232 tonnes of materials being processed within 1440 min. When running this model it is clear that a sufficient system of SCM is maintained right from the start that enables smooth flowing materials throughout the entire system. Scenario 3 applies further pressure on all the elements, loads are increased to 52, just over 60% increase by changing the inter-arrival time of 48 min, to the quarry supplying loads of materials every 26 to 29 min. This increase also helps surpass the capacity requirement of 300 tonnes per day

to 352 machines and conveyors start to arise as bottlenecks appear and further backlogs and blockades, due to a constant stream of materials being delivered. Hence, the logical model constructed needs to be more accurate to a true-to-life representation of the existing factory and further detail needs to be added to extract a more precise and valuable result. This model tests the SCM process in place and displays fragility with increased loads that should not be the case in real life.

CONCLUSION

After highlighting the importance of sustainable production the paper presents an effective maintenance tool for case study sustainable manufacturing industry machine breakdowns. Witness simulation is fully integrated with many other techniques that are easily implemented within the software just as the chain rule has been implemented and the existing parameters considered by witness simulation. Witness simulation alone is a hard integration process however; the actual processing of integration and consistent use of the software involves much soft integration with regards to adequate use. The simulation model developed clearly shows that parts needs changing and breakdowns need recovering that is, highlighting the fact of employee involvement with the help of autonomous software.

Therefore, actual integration involves a combined effort of both types of integration as it works hand in hand. Neither one alone is sufficient enough to reach required levels of maintenance efficiency as technology has to inform management and management has to use technology to carry out tasks in a sustainable manner. Hence, effective integration decides the outcome of the tool developed as even the best tool implemented in an incorrect manner can give rise to incorrect information and therefore cause more problems than intended good.

Finally the study is based upon a single case study manufacturing industry machine and disregards the influence of the labour force. There are opportunities for utilizing the approach to assist developing and transition countries to deal with pressing social concerns, while at the same time ensuring that these countries can grow sustainably. It is hoped that the technologies, practices and production methods deployed are sustainable. It is felt that if the opportunity for integrating sustainable production approaches and technologies in the industrial upgrading and development is missed, then it would face high costs and losses in the future due the need to clean up pollution and replace technological bases, missed business opportunities, resource scarcity, depleted ecosystems, and the inability to compete on the global market.

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