Preliminary Investigation for Value-Added Production Planning and Control of Plastic Recycling: A Case Study

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Abstract

Plastic recycling has the exciting advantage of having a low impact on global warming and environmental toxicity, as well as a high impact on waste reduction and environmental sustainability. The process can be classified into four categories namely; primary recycling, secondary recycling or mechanical recycling, tertiary recycling, and quaternary recycling or incineration**.** When conducted properly, it has the potential for not only maintaining a circular plastic economy but also improving the profitability of the enterprise. This paper presents preliminary procedural investigations on Z Company's typical plastic recycling organization. Using a case study analytical procedure, the pertinent recycling plant parameters were elucidated. Issues with the existing layout and methods of the plant were highlighted. A careful examination of the production planning revealed great potential for improvement of the profitability of the enterprise. The result shows that the application of appropriate process optimization techniques can result in improving the fault lines evident in the existing system.

Keywords
Technical specification, production planning, plastic recycling, environmental sustainability, procedural investigation

1. Introduction
Plastic recycling has been found to be the safest option for plastic waste management (Al-Maaded, et al. 2012), due to its low impact on global warming, low impact on environmental toxicity, and reduction in the environmental carbon footprint (Santagata, et al. 2020). It has been declared the most effective recycling technique because of the many benefits associated with the process. Plastic recycling is highly sustainable and creates a source of raw materials for new products. Developments in new recycling technologies have been the driver in facilitating greater participation in recycling for various organizations (Hulvej & Jaroslav 2015). Investing in such technologies has proven to be essential as plastic pollution is an ongoing global issue attacking developing countries the most, of which South Africa is a typical example (Palos, et al. 2019; Cervantes, et al. 2018). On average, the yearly plastic consumption in South Africa ranges between 30kg to 50kg per person (Muller 2019). The threat caused by plastics in South Africa can be attributed to population growth, seasonal changes, economic growth and changing consumption patterns (Ayeleru, et al. 2020). Other consumer related reasons can be related to the characteristics of the plastic, such as; its durability, low cost, strength and its lightweight. The plastic waste industry in South Africa is characterized by inefficient waste disposal techniques such as, landfill, picking and open burning (Canopoli, et al. 2018), (Bhattacharjee and Bajwa 2018). Landfill increases pollution levels and causes health issues to individuals in the surrounding communities. The health issues are caused by the toxins released into the environment during decomposition (Al-Maaded, et al. 2012). In South Africa, Plastic waste pollution is mostly present in marine eco systems due to a lack of infrustructure (Rensburg, et al. 2020), (Ayeleru, et al. 2018), (Witteveen, et al. 2017). Other plastic waste

initiatives in South Africa include pickers, buy back centres, municipalities and private organizations (Rensburg, et al. 2020), (Friedrich and Trois 2016). Pickers collect plastics from trash and sell them to buy back centres. Buy back centres target low income groups by allowing them to sell any recyclable materials to them (Oyekale 2018).

In order to overcome all requirements present in the complex mechanical recycling process, this paper aims to investigate the combination of an effective production plan and factory layout in facilitating the effectiveness of plastic recycling in a typical plastic company, designated as Company Z, in this study for confidentiality.

2. Materials and methods

This paper follows a case study approach with the use of both primary and secondary data. The primary data used in the study was collected through a thorough on-site observation of the recycling processes of the case study Company. This was accompanied by the use of interview with the factory manager. The interview was used in order to determine the functionality of the processes, the production plan and the organizations implementation of any of the operations management principles. The secondary data was collected from journals, articles and books which were collected from online databases and repositories. The combination of both the primary and secondary data highlighted the patterns of plastic recycling in South Africa. The recycling processes, the layout, the environmental impact analysis and the production planning techniques of the facility have been summarized and analysed. This was done in order to assess the functionality of the processes in the organizations. The combination of the secondary and primary data highlighted the gaps in the recycling industry in South Africa. This study includes an analysis of current production planning techniques and other forms of energy sources applicable to recycling. This was done in order to highlight possible recommendations for the case study organization. The impact analysis was conducted by the use of the eco indicator 99. This process highlighted points of highest negative environmental impacts in the process with the use of predetermined standard indicators, which are found in the eco indicator manual.

3. Plastic recycling at Company Z

Company Z is a recycling company that focuses on primary and secondary recycling of a vast range of plastic types. The types of plastics recycled are not limited to any scope. In order to test new plastic types, an assessment by the use of water and a flame is conducted. Secondary recycling takes place in order to produce pellets, which are resold to the original manufacturers. In order to maintain product quality, additives are not added into the plastics during the recycling process. The secondary recycling process implemented imitates the order of steps determined by the International Organization of Standardization (ISO) 15270:2008 (Maris, et al., 2018). The steps have been depicted in Table 1. The recycling process implemented in the organization is standard for all plastic types regardless of their different properties. Machine operators are to ensure that different plastic types are not mixed together. The facility does not have plastic washing machinery. Therefore, plastics are taken to another organization for washing. The maximum lead-time for one batch of material to be recycled takes up to two days. This excludes machine cleaning and servicing. This process is completed by a team of skilled machine operators as well as sorters. Table 1 captures the Plasti recycling procedure in Company Z.

Table 1. Plastic recycling process

1	Weighing	Plastics are weighed in order to pay suppliers or pickers according to the amount (Kg's) of plastics delivered.
2	Sorting	Identification of the plastics takes place through visual identification by 8 personnel. An average of 850kg of plastic is sorted per day. Sorters remove metal components and damaged plastics.
3	Cutting	The cutting takes place by the use of a band-saw cutter.
4	Granulating	The equipment used in this process is a high-speed rotary cutter at temperatures between 200˚C and 300˚C. This is done in order to melt the materials and further breakdown the plastics. During this process**,** harmful gases could be released into the atmosphere.
5	Agglomerating	Plastics from the granulator are shredded by rotary knives in the presence of heat. This breaks down the plastics through hydro destruction as water is added into the agglomerator during the process.
6	Extrusion	A screw driven extrusion head is used in this process. The plastics are melted and purified by heat. The plastics are released from the extruder in a cylindrical form.

7	Cooling	Immediately after extrusion plastics fall into the cooler or small wash barrel. The water passes through a filer machine, which purifies the water at room temperature.
8	Pelletizing	A pellet cutter containing a rotary knife is used to transform plastics into smaller granules or regranulates.

3.1. Plant layout at Company Z

The layout in the factory can be defined as flexible. This is in agreement with suggestions held by past researchers: that layout can be changed according to daily or weekly requirements (Horta, et al., 2016). In size, the case study factory is about 807m in length and 388,4m wide. There are eight functioning machines and 1 non-functional machine. These machines have been placed in a random order which affects the flow of materials in the factory. The materials begin to flow from the front end of the factory and end up at the back end of the factory. The random order and spacing of machines increases lead-time as the materials take time to move from one workstation to the next. This also increases waste as materials are lost between material transfers. Plastics delivered for recycling arrive in large quantities and different varieties; therefore, the materials are stocked in a random order. No other automated storage techniques are implemented in the facility in order to identify the stock that has been placed in random order. This negatively affects the first-in first-out (FIFO) method applied in production planning. In order to manage the large amount of stock waiting to be processed the organization stores the materials outside the facility in an open area next to the parking space. Potential issues that obtain in the existing layout include:

1. Wasted time due to long distances between machinery.
2. Potential damage to stock.
3. Inefficient process monitoring.
4. Lack of storage space.
5. Potential damage to machinery.
6. Restricted housekeeping.
7. Restricted flow of air

3.2. Production planning at Company Z

Production planning at company Z is conducted manually by the use of daily work order forms. Each machine operator is required to accurately fill in these forms when conducting their tasks. Plastics are processed on a First in first out basis. Daily production is planned by the use of the work order forms. These forms represent a schedule and target for each step in the process. Each production sheet, which is readily available in the facrory is to be completed by the machine operators and sorters once they have completed their tasks. The documents are not uploaded into any electronic system. Instead, they are placed into storage. This sheets record work that has already been conducted. Therefore, no forecasting takes place. Future planning is done based on experience and knowledge. Waste in the facility is commonly caused by down time as machine operators are required to abort their tasks to assist with the agglomerator. One batch of plastics takes up to two days to process with 5% allowance for waste. Plastics are recycled on demand or based on the amount of plastics that are delivered. This is in agreement with the pull system described by past researchers (Low & Show, 2008).
Below are the list of production sheets used as well as their significance:

1. The extrusion planning sheet; records the machine operator's name, date of processing, process lead time, plastic types and quantity processed.
2. Stock in-stock out sheet; documents the customer's name, the receivers name as well as the plastic types and quantities that have been delivered.
3. The work order form; records the quantities and types of plastics, the machine type and processing time on the cutting machine, the cooler and the agglomerator.
4. Sorting sheet; contains the sorters names, the plastic type sorted and the quantities sorted.

4. Summary of findings at Company Z

The pre-existing recycling procedures found in the case plant during the research can be summarized as presented in Table 2 below.

Table 2: Plastic Recycling Problems in Company Z

Recycling Aspects	Problem Currently Experienced
Production planning	Conducted ineffectively as no pre-planning and control strategy is available. Hence, information recorded is not stored safely
Factory Layout	Layout of the machines is not effective in facilitating free flow of materials and men. There are avoidable encumbrances noticed.
Work orderliness	Poor work order implemented. There is lack of order in packing products for storage. This limits floor space.
Occupational Safety	Safety measures have been omitted in the factory for example there is no emergency exit, no provision for noise emission, no ventilation and the factory has poor lighting as well.
Recording	The production sheets do not record waste, and there is no strong emphasis in data gathering and recording. Sheets of paper still in use.
Staff Scheduling	The agglomerator requires more than one machine operator but not so in company Z. This results in adhoc use of other operators assigned to machines. This leads to down time in other steps as the ad-hoc operators are sometimes ade to abandon their work.
Machine Spacing	The distance between the machinery has been found to be larger than necessary. Processing times are ultimately increased by moving the plastics from one work space to another.

5. Conclusion

This research has elucidated the prospects for creating a more valuable production process and control of plastic recycling in the studied case. All the recycling aspects of the product were investigated on a workstation to workstation basis. The existing recycling methods present ample opportunities for improvement because of the absence of modern and better techniques. For example, the extended down time which leads to more waste, and the increased lead time resulting from reliance on personnel physical abilities in critical tasks can be reduced. At present, one batch of plastics takes up to two days to process with about 5% allowance for waste management. Plastics are recycled on demand or based on the amount of plastics that are delivered. We conclude that there exist significant areas of value-addition to the production process, to an extent that can motive further research in future.

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Biographies

Paul Amaechi Ako (*formerly* **Ozor)** is an associate Professor and Head of Department of Mechanical Engineering, University of Nigeria Nsukka. He is the West African Sub-Regional Coordinator of Industrial Engineering and Operations Management Society International. He holds a bachelor's degree in Mechanical/Production Engineering from the Enugu State University of Science and Technology, Nigeria as well as Masters and PhD in Industrial Engineering and Management from the University of Nigeria, Nsukka. He is a Senior Research Associate at the University of Johannesburg, South Africa, a previous Scholar of the Association of Commonwealth Universities (ACU), and was a fellow of The World Academy of Science. He had been a fellow of the global excellence stature (GES) of the University of Johannesburg. As an organizer, speaker and participant in international conferences, seminars and workshops, he has visited several countries on research grounds and has published research articles in many peer reviewed local and international Journals and conference proceedings. He has supervised significant local and international postgraduate students to successful study completion. He is an external examiner to both local and International Universities. Engr. Assoc. Prof Ako is a member of the Nigeria Society of Engineers (NSE) and registered member of the Council for the Regulation of Engineering in Nigeria (COREN). More recently, in Manila 2023 IEOM international conference, he was decorated as a Fellow of IEOM, which is the highest award of the revered and biggest single Professional Society across the globe.

Professor Charles Mbohwa is the former Pro Vice Chancellor of the University of Zimbabwe, Harare, Zimbabwe and a visiting Professor to the University of Johannesburg. He obtained B. Sc. Honours in Mechanical Engineering in 1986 from Department of Mechanical Engineering of the same University. He later bagged M. Sc. in Operations Management and Manufacturing Systems with a distinction in 1992, from Department of Manufacturing Systems Engineering, University of Nottingham, UK. He obtained PhD in Engineering (Production Systems focusing on Energy and life cycle assessment) from Tokyo Metropolitan Institute of Technology, Tokyo, Japan in 2004. Professor Mbohwa is an NRF-rated established researcher. In January 2012 he was confirmed as an established researcher making significant contribution to the developing fields of sustainability and life cycle assessment. In addition, he has produced high quality body of research work on Southern Africa. He is an active member of the United Nations Environment Programme/Society of Environmental, Toxicology and Chemistry Life Cycle Initiative, where he has served on many taskforce teams. He has published over 600 research articles in leading international Journals and Conference Proceedings. Prof Mbohwa had been keynote speaker in many international conferences and has supervised many local and international postgraduate students while playing host to several international postdoctoral fellows. He is a visiting Professor to the University of Johannesburg, South Africa, where he had served in various capacities; including Dean of Postgraduate Studies and Executive Dean of Faculty of Engineering and the Built Environment.

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