Simulation Modeling for Construction Chemical Operations

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Abstract

Construction chemicals are commonly used in the construction industry. These materials are divided into two main categories, liquid and powdered products. The process of producing the powdered products addressed in this paper consists of three manufacturing stages comprising of feeding, mixing and filling and packaging. This paper is intended to study the operations in two of the three. Currently, the average flow time in the powdered products plants is quite long; consequently, the lead time to deliver finished goods to customers is increased. It is anticipated that the customer lead time can be reduced by improving the construction chemicals operations. The paper studies the existing operations of the plants, conducts process mapping and time study, and develops simulation models for the current production system in Arena software for improving the total flow time, resource utilization, and waiting time in queues.

Keywords
Construction chemicals, process improvements, production systems, simulation

1. Introduction
In general, the manufacturing process in the manufacturing facility comprises of three main stages that take place in each production machine before the product is ready. Figure 1 illustrates the three general stages of the manufacturing process. Stage 1, the feeding stage, involves collecting and dozing the required RM and processing them into the mixers. Stage 2, the mixing stage, involves running the mixer vessel for a minimum amount of time until all the ingredients (RMs) are well combined. Stage 3, the filling and palletizing stage, involves filling the content (end product) of the mixer into the packaging bags or cans (depending on the product) and placing the finished good (FG) onto the wooden pallet in order to be transported for customer delivery.

Figure 1: Construction Chemical Production Stages

This paper explores and studies the powder section for identifying potential improvements. The powdered products comprise of a physical combination or mixture of several types of raw materials and chemical additives. The raw materials consist mainly of dune sand, cement, limestone aggregate and various additive powdered chemicals. The powder production section accounts for a larger portion of the production facility in terms of size as well as revenues.

One of the major problems faced by the company will be tackled is the long flow time. There is a wide variety of products that are made from a smaller variety of raw materials. This concept leads the company to store larger amounts of raw materials instead of finished goods. Therefore, when an order from a customer is received, there is a strong need to improve the speed of the production process in order to reduce the overall flow time of the manufacturing plants of the company to be able to reduce the total lead time for the customer. Furthermore, the company follows a Make to Order (MTO) strategy to a great extent. However, due to the current long flow time, the company still stocks large amounts of finished goods (as well as raw materials) in an attempt to meet the customer's demand for orders when placed. However, due to limited space in the warehouse, the finished goods are usually stacked in the premises of the production area taking up large space and very often obstructing the production process. Therefore, there is a need to reduce the total flow time in order to eliminate the need for keeping any stocks of finished goods.

The main objective of this paper is to provide methods for improving the manufacturing process of the production facility where there are several inefficiencies in the manufacturing process that can be simply improved while yielding great outcomes.

2. Literature Review

The aim of most production plants is to reduce the costs of production as well as to increase the quality of the produced products. Facility layout has a significant and important role in the cost of production as the cost of material handling and transportation depends largely on the locations of the different machines throughout the factory. Ulutas and Islier [1] explored the concept of dynamic facility layout while dealing with the arrangement of machines in a production facility in an attempt to reduce the material handling cost. Manita and Korbaa [2] identified a way to order the machines around an industrial loop in an attempt to minimize the total cost of transporting components in each production cell. Studying the flexibility of a production system in terms of carrying out changes in the system in order to cope with external changes is an important topic that should be looked at. An attribute of reconfigurable production systems is that they provide rapid alteration of the production capacity and workability as a reaction to unexpected changes in the market [3]. While carrying out the production process, several unforeseen incidents take place such as machine breakdowns. Such incidents result in interruptions and halts in the production that could lead to several drawbacks. In his paper, Bruccoleri [3] found that the degree to which a production system can be reconfigured is the latest factor that allows for strategies to cope with unexpected incidents in the manufacturing process. However, in order for the production system to maintain its competitiveness in the market where unexpected events happen frequently, flexibility to reconfigure needs to be accompanied by fast responding, cost efficiency, robustness and the ease of carrying out upgrades in terms of software and hardware of the production facilities [4]. A Reconfigurable Manufacturing System is a system that is designed while keeping in mind rapid alterations in the structure as well as the hardware and software elements of the system in order to change the production capacity or methodology in an attempt to cope with the external environment changes that would happen [5]. The single row layout problem includes the idea of finding the optimum arrangement of the machines of the production along a single side of the material handling pathway [6]. In order for companies to maintain their market share in this competitive market, they need to face the current market conditions of rapid change, shorter product cycle, product diversity and unexpected demand quantities [7]. The discussed factors are affected to a great extent by a helpful machine layout that could help the company cope with those market conditions [8].

In the context of simulation modeling, discrete event simulation is used mainly for modeling of systems of machines of largely deterministic attribute such as conveyor belts and automated machines [9]. However, in the case of the system depending largely on humans or any less deterministic process, careful statistical analysis methodologies and intelligent data collection techniques must be conducted in order to gain knowledge about the behavior of the less deterministic process or element that is to be modeled [10]. Ulutas and Islier [1] explored the concept of modeling human performance via probability density functions in an attempt to represent the variations in worker's task durations. Mason et. al. [11] defined the human performance variation HPV as "the variation in the time taken to complete a task by a direct worker under normal working conditions.

Process modeling is an important tool that is valuable to cover in the scope of this project. The two dimensional approach of modeling manufacturing process chains is used for considering the role of additive manufacturing technologies. Thompson et. al. [12] found that additive manufacturing can be better than traditional process chains in small production runs.

3. Construction Chemicals Plant

The plant consists of four main components as shown in the simplified design in Figure 6. The four main components are namely: Bucket Elevator, Mixer, Filling Hopper and Filli.ng Nozzle. The function of the Bucket Elevator, which is a vertical conveyor belt mounted with steel buckets along its length, is to transport the powdered raw materials from the elevator's inlet up into the Mixer. At the inlet of the Bucket Elevator, there is a steel stand on which the Collection Container is placed as shown in Figure 6. Then, the sliding gate of the collection container can be opened to allow for dispersal of the raw materials into the inlet of the bucket elevator. The outlet of the bucket elevator is connected directly with the mixer. The mixer has an additional gate that is accessible from the top. This gate is used to add small quantities of additives and chemicals manually into the mixer. A mechanical gate separates the Mixer from the Filling Hopper. Upon completion of the mixing process, the gate is opened and the end product is transferred to the Filling Hopper. The purpose of this gate is to allow for emptying the content of the mixer all at once in order to allow for the material of the new batch to be added while the filling of the previous batch is taking place. The filling hopper holds the end product in place while the material is discharged from the filling nozzle into the finished goods bags. The finished goods bags are then piled on top of each other on the wooden pallet until they are removed by the forklift for delivery. The next batch of raw materials is brought at the bucket elevator upon transferring the end product from the Mixer to the Filling Hopper.

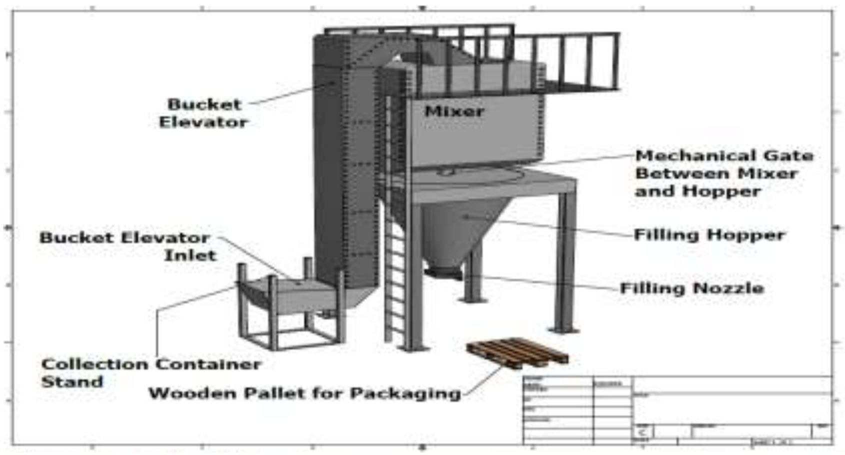

Figure 2: Simplified design of plant B

Raw materials are stored all around the facility. The raw materials come in three different forms, jumbo bags, paper bags and bulk material. The jumbo bags form the majority of the raw materials. The second form of raw material is the paper bags. They consist of pallets of stacked paper bags of cement and chemical additives. The third form of raw material is the Bulk Material. This form comprises of two main types, the Dune Sand and Limestone Aggregate. Those two items come in large hydraulic trucks that dump their content in the allocated storage areas.
Those two items come in large hydraulic trucks that dump their content in the allocated storage areas as shown in Figure 3.

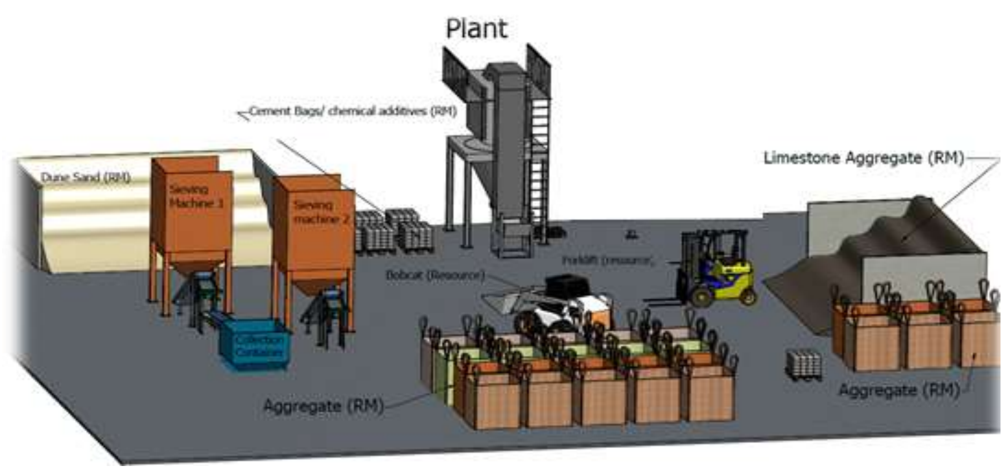

Figure 3: Plant Layout

Figures 4 shows the generalized process mapping that illustrates the sequence of processes along with the resources used in each process. The manufacturing process starts with the forklift loading a pallet of raw materials that comes in the paper bag form at the inlets of the plants.

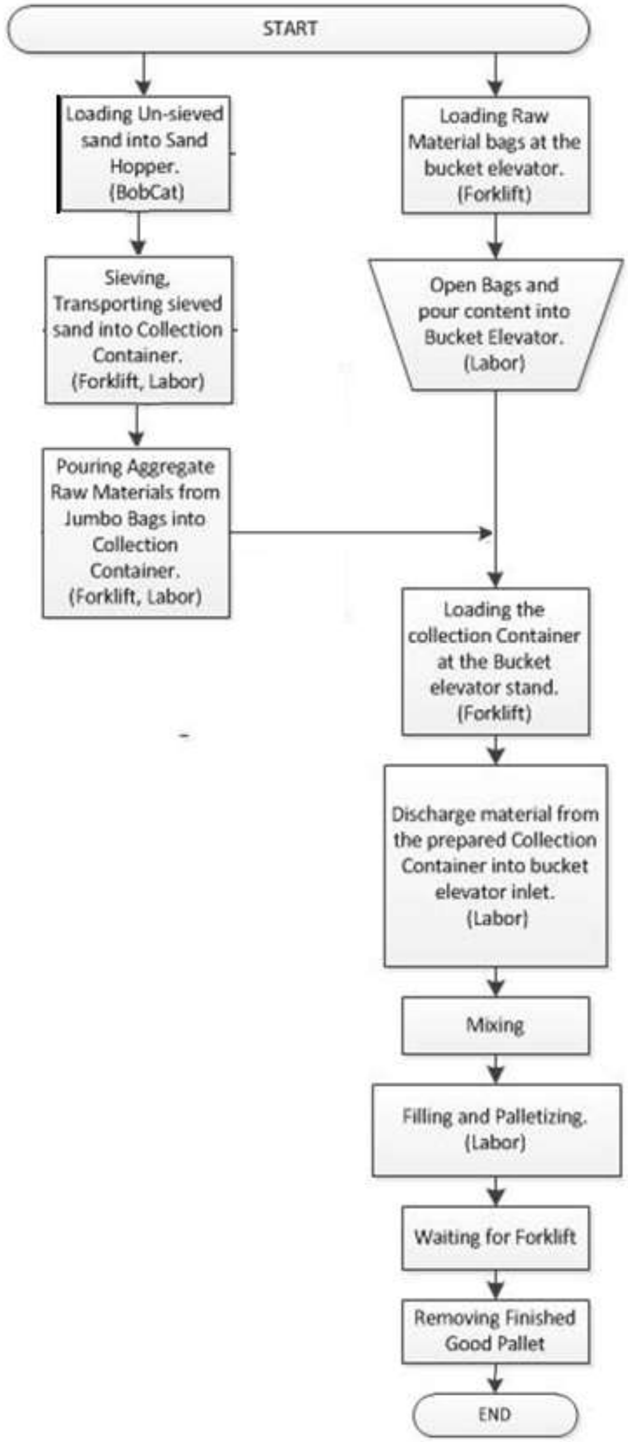

Figure 4: Process Mapping

Table 1 provides an approximate duration for each stage, the distance between each stage and its predecessor and the resources seized in the stage.

Table 1: Powder Products Manufacturing Process

Stage	Stage description	Stage Duration (min)	Distance from predecessor stage (m)	Manpower involved (labor #)	Heavy Machinery Involved (type)
1	Loading Gypsum at bucket elevator	1	-	0	Forklift
2	Open bag, pour material	15	0	2	0
3	Loading Hydrated lime at bucket elevator	1	2	0	Forklift
4	Open bags, pour material 1	2	0	2	0
5	Loading $CaCO_3$ at bucket elevator	1	2	0	Forklift
6	Open bags, pour material 2	3	0	2	0
7	Loading of the prepared container	1	15	0	Forklift
8	Discharge material from prepared container	5	0	1	0
9	Loading Arbocell & Chemical additives directly to the mixer.	5	5	1	Forklift
10	Mixing (2000 kg)	10	0	0	0
11	Filling (50 bags)	20	0	2	0

4. Proposed Simulation Model

The proposed simulation model is developed in Arena simulation software based on the process mapping shown in Figure 4. This simulation model includes all the activities that take place in the production process. It accounted for all the relationships, constraints and waiting times among the activities of the production process. The resource that is specific to the plant is the labor. The rest of the resources (Forklift, Collection Container C.C and Labor S) will be shared between the two plants. Table 13 shows a summary of the resources along with their capacities.

In order to feed the developed simulation models with the correct data of durations, a time study was conducted in order to identify the statistical distribution of the durations of each of the processes in the manufacturing process. These distributions were then fed into the proposed Arena simulation model. The study involved measuring the duration of the same step for a number of observations in order to be able to gather enough data for determining the statistical distributions for each process. The probability distributions of the processing times of “loading pallets at bucket elevator”, “pouring out contents of powder bags at bucket elevator”, “loading collection container at bucket elevator”, “pouring additives into the mixer” and “discharging powder from collection container” are summarized in Table 2.

Table 2: Probability Distributions of the Processes

Process	Statistical Distribution
Loading Pallet at Bucket Elevator (B.E)	UNIF(37.5, 45.5)
Pouring bag content	9.5 + 11 * BETA (1.21,1.49)
Loading Collection Container at B.E	27.5 + 38 * BETA (1.11, 1.02)
Pouring additives into mixer	59.5 + LOGN (5.17, 5.6)
Discharging material from collection container	4 + 2 * BETA (1.49, 1.06)

The process of manufacturing powdered products includes larger number of processes due to the nature of the product manufactured. Figure 5 shows the simulation model in Arena software. The outcomes of running this model for 1000 replications having the length of 8 hours yielded 17 batches out of the model as shown in Figure 25.

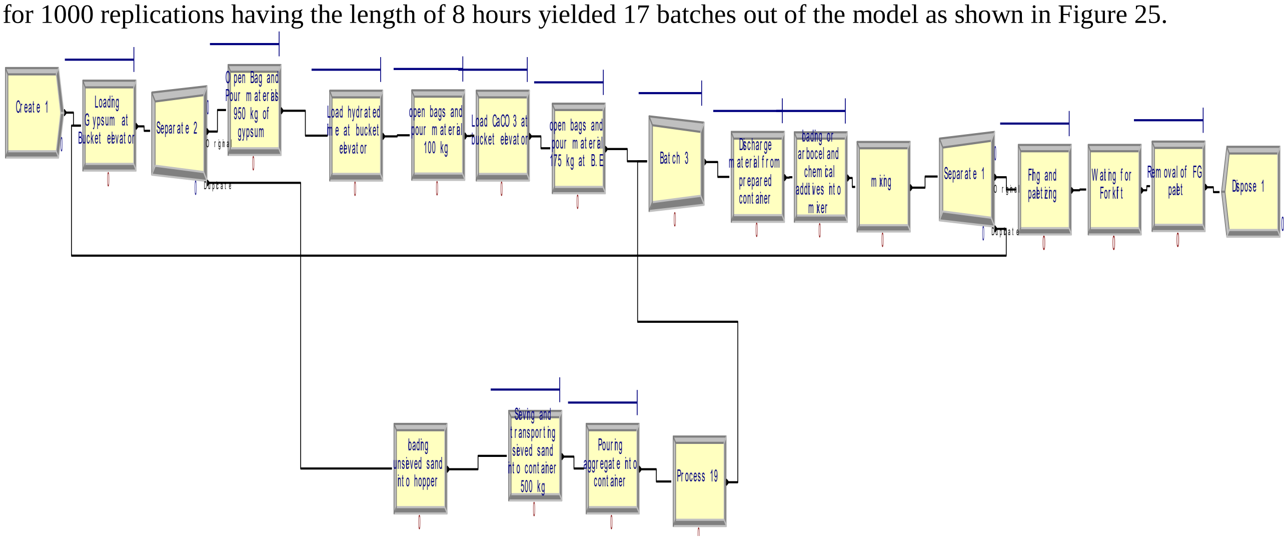

Figure 4: Simulation Model in Arena

5. Conclusion

This paper studied the operations of chemical construction plant that produces powdered products. The average flow time is quite long in the current production system. This results in an increased lead time to supply the finished goods to customers. It was expected that the total flow time can be decreased by improving the operations in the manufacturing plants of the company. We developed simulation model in Arena software to imitate the operations of the current manufacturing system in order to the current production system. The proposed improvements to the process contribute to reducing the total flow time of manufacturing, increasing the average resource utilization and reducing the total time wasted in queue. Some of the areas of improvements are interdependent in the sense that enhancements in one area can lead to enhancements of other areas. For instance, reducing the total manufacturing time will result in increasing the total potential production capacity due to the fact that larger quantities of finished goods can be produced in the same amount of time.

The results obtained from simulating the manufacturing process with improvements from the recommended alternative indicate 41% reduction in total flow time. This significant reduction would result in a substantial decrease in the total lead time required to supply the finished goods to the customers. In addition, the average resource utilization in the manufacturing plants has increased by 16% and the total time in queue was reduced by 2%. The last two parameters indicate a significant increase in the efficiency of the manufacturing process at the company.

References

[1] B. Ulutas and A. A. Islier, "Dynamic facility layout problem in footwear industry," Jounal of Manufacturing Systems, Vol. 36, No. 8, pp. 55-61, 2015.

[2] G. Manita and O. Korbaa, "A hybrid genetic algorithm for solving machine layout problem with considerations of industrial constraints," Vol. 46, No. 9, pp. 2038-2044, IFAC, 2013.

[3] M. Bruccoleri, Z. J. Pasek and Y. Koren, "Operations management in reconfigurable manufacturing systems: Reconfiguration for error handling," International Journal of Production Economics, Vol. 100, No. 1, pp. 87-100, 2006.

[4] M. Mehrabi, A. Ulsoy and Y. Koren, "Reconfigurable manufacturing systems: Key to future manufacturing," Journal of Intelligent Manufacturing, Vol. 11, No. 4, 2000.

[5] Y. Koren, U. Heisel, F. Jovane, T. Moriwaki, G. Pritschow , G. Ulsoy and H. Van Brussel, "Reconfigurable manufacturing systems," Annals of the CIRP, Vol. 48, No. 2, 1999.

[6] B. Keller and U. Buscher, "Single row layout models," European Journal of Operatioal Research , Vol. 245, No. 3, pp. 1-16, 2015.

[7] S. Benjaafar and M. Sheikhzadeh, "Design of flexible plant layouts," IIE Transactions, Vol. 37, No. 4, pp. 303-318, 2000.

[8] A. Drira, H. Pierreval and S. Hajri-Gabouj, "Facility layout problems: A survey," Annual Reviews in Control, Vol. 31, No. 2, pp. 255-267, 2007.

[9] B. T.S and K. J.M., "Human performance modelling as an aid in the process of manufacturing system design: a pilot study," Int'l Journal of Production Research, Vol. 40, No. 10, pp. 2321-2334, 2002.

[10] D. S. R. and Z. Z.Y, "A case for intelligent representation of dynamic resource in simulation," Int'l Journal of Production Research, Vol. 35, No. 12, pp. 3289-3302, 1997.

[11] S. Mason, T. Baines, J. M. Kay and L. John, "Improving the design process for factories: modeling human performance variation," Journal of Manufacturing Systems, Vol. 24, No. 1, pp. 47-54, 2005.

[12] M. K. Thompson, S. Allessandro and M. Mischkot, "Process chain modeling and selection in an additive manufacturing context," CIRP Journal of Manufacturing Science and Technology, Vol. 12, No. 2, pp. 25-34, 2016.

Biography

Mojahid F. Saeed Osman is an Assistant Professor of Industrial Engineering in the Department of Industrial Engineering at American University of Sharjah, United Arab Emirates. He received the Bachelor degree in Mechanical Engineering from Sudan University of Science and Technology, and MS degree in Industrial & Systems Engineering and Ph.D. degree in Industrial Engineering both from North Carolina A&T State University, USA. His research interests include modeling and analysis of production systems, applied operations research, dynamic network flow modeling, and linear and nonlinear optimization.

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