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Modeling Processing Cell Architecture by Material Flow Simulation

Popa Cicerone Laurentiu, Cotet Costel Emil*, Ionita Valentin, Gavrila Stefan

University Politehnica of Bucharest, Machines and Manufacturing Systems Department, No.313, Spl. Independentei, sector 6, Bucharest, 060042, Romania

Abstract

This paper is based on specific applications of Material Flow Theory (MFT) in industrial engineering material flow management (MFM). The accent is put on exploring different possibilities to increase productivity and profit in processing architectures using the MFM approach based on virtual modelling and simulation. In this context the paper presents a case study using virtual modelling of a flexible processing architecture and MFM simulation algorithms for diagnosis and optimization. The virtual model of the processing architecture will be used as a tool for identifying and eliminating the flow concentrators and obtaining an improved productivity of the system.

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Keywords: modelling; simulation; processing; AS/RS system; material flow

1. Introduction

The Material Flow Theory (MFT) aims to find solutions to optimization based on mathematical models or virtual models [1]. The flow optimization involves the maximizing or minimizing of performance indicators values according to their nature. For example, the cost represents a performance indicator defined as a function to be minimized. On the other hand, the productivity represents a performance indicator expressed as a function to be maximized. One of the most used optimization options in Material Flow Management (MFM) is based on the identification of the location where the material flow is slowed or blocked (bottlenecks) and on finding solutions to eliminate them with or without modifying the system architecture [2].

The Material Flow Theory proposes a general algorithm containing the following steps:

* Corresponding author. Tel.: 0040724979146; fax: 0040213107753.
E-mail address: costelemilcotet@gmail.com

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- Modelling of the preliminary system's architecture using the specific elements of a flow simulation. The main structural elements are defined: work points, buffers, transport and transfer systems software. The necessary parameters for these structural elements are introduced. The trajectories of the flow units (parts) are established.
- A simulation of material flows for the initial model is made in order to make a performance diagnosis of the preliminary system architecture.
- Based on the reports, an identification of the bottlenecks is made. There are two solutions for eliminating these concentrators [3]. The functional remodelling potentiates the processing architecture performance by modifying the structural elements layout or functional parameters but it does not introduce or eliminate structural elements. Technological remodelling allows processing architecture changes also when structural elements should be added or removed [4].
- A new system simulation is made in order to confirm the performance of the optimized system architecture [5].
- Economic validation of the investments in financial terms is made for the increased performance of the optimised system.

2. The preliminary system architecture

In order to compete successfully on the market and to achieve sales growth, companies need to diversify their products and to constantly improve their product portfolio. Thus, the ERP planning system should be completed [6] by the implementation of a system that allows final products packaging and wrapping in different configurations is a mandatory requirement for any company that processes different types of products, before the strategic definition of distribution nodes [7]. This paper main goal is to illustrate how a simulation diagnosis based on the virtual model of a cell architecture is necessary in order to determine the optimal operating parameters not only for manufacturing purposes [8] but also for processing [10]. In our case study we have chosen a processing system that should obtain pallets with a specific box configuration, depending on the customer requirements regarding three coffee type products to be implemented. Starting from the virtual processing model [9] and using the above algorithm and a simulation software (FlexSim 7) we will determine the optimized system configuration. In the system there are three types of products based on coffee: ground coffee, coffee beans and instant coffee. Each plastic can has 96x47x195mm (LxWxH) and a mass of 500g. The plastic coffee cans will be put on a box with a size of 300x200x400mm, a box will contains 24 plastic coffee cans, resulting in a weight of 12 kg/box. The boxes will be placed on a standard pallet with the size of 800x1200mm. The stack will consist of 4 layers, each layer has 16 boxes, resulting a total of 64 boxes, a height of 1600mm and a mass of 818kg, including the pallet's own mass of 50 kg. The system must be flexible in order to obtain a personalized pallet configuration according to the customer request, for example: 20 box of ground coffee, 30 box of coffee beans and 14 box of instant coffee. The pallets will be placed in a storage system using an AS/RS system. The preliminary system's architecture was modelled in FlexSim 7 simulation software and it has the flowing structure (see Fig. 1):

- 3 local storage systems (B1, B2, B3),
- 6 conveyors (C1, C2, C3, C4, C5, C6);
- 3 work points (Wp1, Wp2, Wp3),
- 4 robots (R1, R2, R3, R4),
- a wrapping work point (Wp4),
- a central storage system (Rack) with AS/RS system;
- human resources.

All three types of empty plastic coffee cans are found initially in the local storage system (B1). There human resources (Op1, Op2, Op3) are putting the empty plastic coffee cans on the conveyors. The empty plastic coffee cans are transported to the work points using the C1, C2 and C3 conveyors. The C1 conveyor is transporting the empty plastic coffee cans from the local storage system (B1) to the work point (Wp1). In the same way the C2 and C3 conveyors are transporting the empty plastic coffee cans from the local storage system (B1) to the work point (Wp2) and respectively the work point (Wp3). All three work points ensure the automatic filling of the plastic coffee cans as follows: Wp1 is filling the plastic cans with ground coffee, Wp2 is filling the plastic cans with coffee beans and Wp3 is filling the plastic cans with instant coffee.

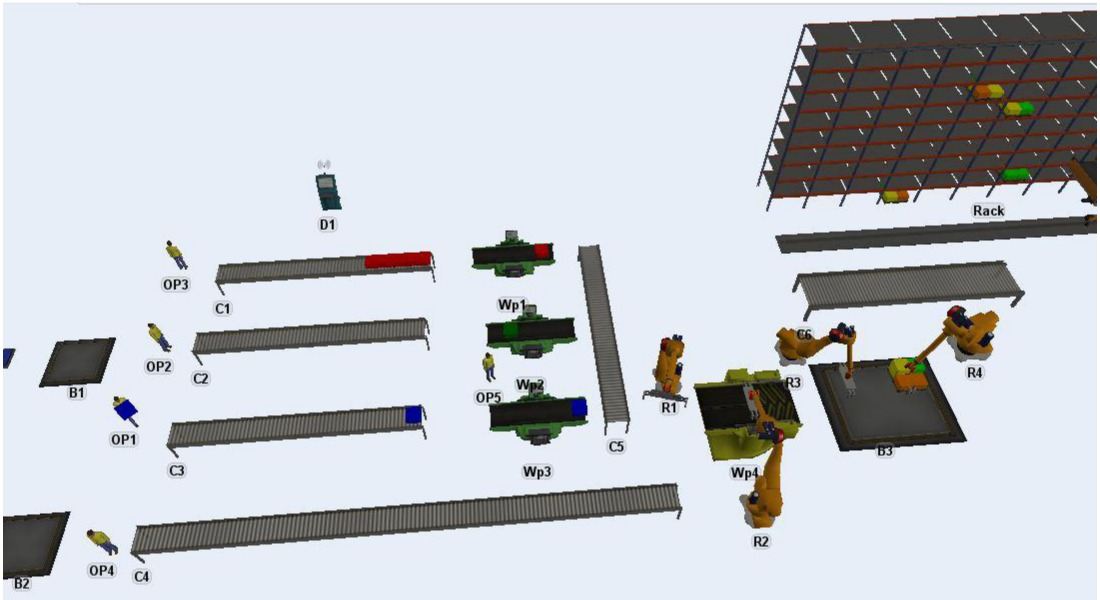

Fig. 1. The preliminary system architecture during the simulation using FlexSim 7.

For each work point a human resource is allocated (Op5, Op6, Op7) in order to supervise the process and to put the plastic coffee cans in boxes. The human resource places the filled boxes on the C5 conveyor.

The pallet is transported from the local storage system (B2) to the wrapping work point (Wp4) using the C4 conveyor. The robot (R2) takes the pallet from the transport system C4 and puts it on the wrapping machine table. The robot (R1) takes the boxes from the C5 conveyor and transfers them to the pallet using a defined palletised load program. After placing all the 64 boxes on the pallet, the stack will be wrapped. The robot (R3) takes the pallet from the wrapping machine table and puts it on the local storage system (B3). The robot (R4) takes the pallet from the local storage system (B3) and puts it on the C6 conveyor. From here the AS/RS systems takes the pallet in order to put it in a specified location of the central storage system (Rack).

We have modelled the system's structural elements using the database available in the FlexSim 7 simulation software. For the virtual model, the links between the system's structural elements were created using the system real parameters in order to reproduce the material flow trajectories. Then, using this virtual model, a simulation was performed in order to identify the bottlenecks and the long waiting times of the system. In the preliminary simulation, the parameters for the system's components were set to their default value. Following the preliminary simulation, reports have been generated for all the structural elements of the system.

Fig. 2. (a) C1 preliminary report; (b) Wp1 preliminary report.

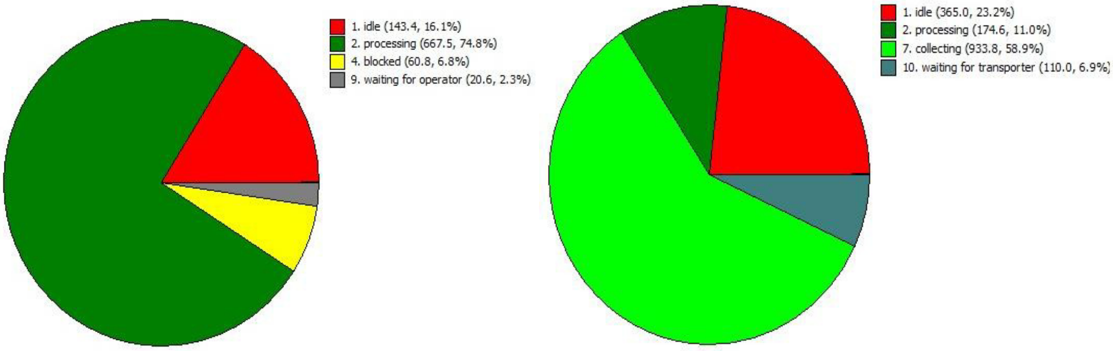

Fig. 3. (a) Wp1 report after the functional remodeling; (b) Wp4 report after the functional remodeling.

Problems were identified at the C1 conveyor and at the Wp1work points. For example, C1 is waiting for empty plastic coffee cans for about 66% of the total time and is conveying for 34% of the total time (Fig. 2.a), WP1 waits for about 11% of the total time for empty plastic coffee cans and for about 2% of the total time for the human operator. WP1 process the plastic coffee cans about for 40% of the total time and it is blocked 47% of the total time (Fig. 2.b). Also, the reports on C2, C3 and C4 conveyors show bottlenecks or large waiting times. The reports on Wp2 and Wp3 show bottlenecks. At the wrapping work point the activity of putting boxes on the pallet and of the wrapping represents 70% of the total time.

In order to obtain an optimized solution we have first applied a functional remodelling of the system by changing the structural elements parameterization. In our case study these changes occur mainly on the conveyors, at the work points, at the wrapping work point and at the robots. For each type of a processed product, the simulation will start from these default parameters of the system. Those parameters will be modified in successive simulations until an optimized version of the system in terms of productivity will be obtained. We have performed several simulations with different parameter's versions, we compared the reports and we retained the best version which had the biggest increase of productivity compared to the original version of the system, taking into account the avoidance of bottlenecks and long waiting times.

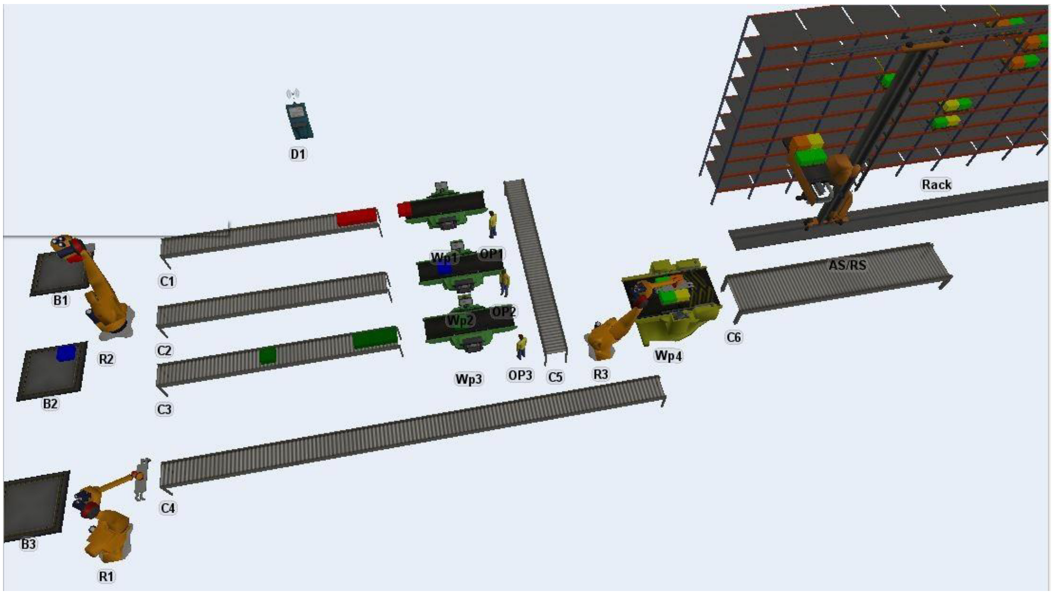

Fig. 4. The proposed system architecture after the technological remodeling.

The report results show that the Wp1 work point is blocked 7% of the total time compared to 47% resulted in the preliminary simulation. The processing time has increased from 40% to 75%. The conveyors still present bottlenecks or large waiting times. The wrapping machine has approximately the same result as in the preliminary simulation.

Nevertheless, we couldn't obtain an accepted parameterized version of the system using the functional remodelling. In figure 3 the reports after the functional remodeling can be seen. The bottlenecks and the waiting times are lower but they still occur and they still represent an important percent from the total time.

3. The system technological remodeling

The reports from the preliminary simulation and from the functional remodeling show long waiting times for the C1, C2 and C3 conveyors because the human resources allocated to feed the conveyors are not so fast and the systems needs more plastic cans than the human resources can process. The bottlenecks are present at Wp1, Wp2 and Wp3 because it takes too much time for the R1 robot to arrange the boxes on the pallets, so the C5 conveyor will be blocked, causing in turn bottlenecks at the work points. The preliminary wrapping machine type is also not very efficient. In order to improve the system performances and to obtain an optimized system, we made a technological remodelling of the system. We replaced the human resources Op1, Op2 and Op3 with two robots in order to take the empty plastic cans from the buffers and put them on conveyors. The robot R1 from the preliminary system architecture is replaced with a new and more efficient robot (R3). We changed the wrapping machine type by replacing it with a new one, with rollers that will transfer the pallet directly to the C6 conveyor, so the R4 robot from the preliminary system architecture was removed.

For the new proposed system we have changed the preliminary architecture, thus the system has the following configuration: 3 local storage systems (B1, B2, B3); 6 conveyors (C1, C2, C3, C4, C5, C6); 3 work points (Wp1, Wp2 , Wp3); 3 robots (R1, R2, R3); a wrapping work point (Wp4); a central storage system (Rack) with AS/RS system; human resources.

The empty plastic cans for ground coffee and instant coffee are found initially in the local storage system (B1), the empty plastic cans for coffee beans and instant coffee are found initially in the local storage system (B2). In the local storage system (B3) buffer are the pallets. Three human resources (Op1, Op2, Op3) were reallocated to the work points. In the new system configuration there are two robots: R1 is putting pallets on C4 conveyor and R2 is putting the empty plastic cans from B1 and B2 on the conveyors C1, C2 and C3. The empty plastic cans are transported to the work points using the C1, C2 and C3 conveyors. There are no changes made to the type of work points Wp1, Wp2 and Wp3. The human resources Op5, Op6, Op7 were removed from the system, now Op1, Op2 and Op3 are supervising the process and putting the coffee bags in boxes. The human resource places the filled boxes on the C5 conveyor.

The pallet is transported from the local storage system (B2) to the wrapping work point (Wp4) using the C4 conveyor. The robot (R3) takes the pallet from the transport system C5 and puts it on the wrapping machine table. Also, R3 takes the boxes from the C5 conveyor and transfers them to the pallet using a defined palletised loading program.

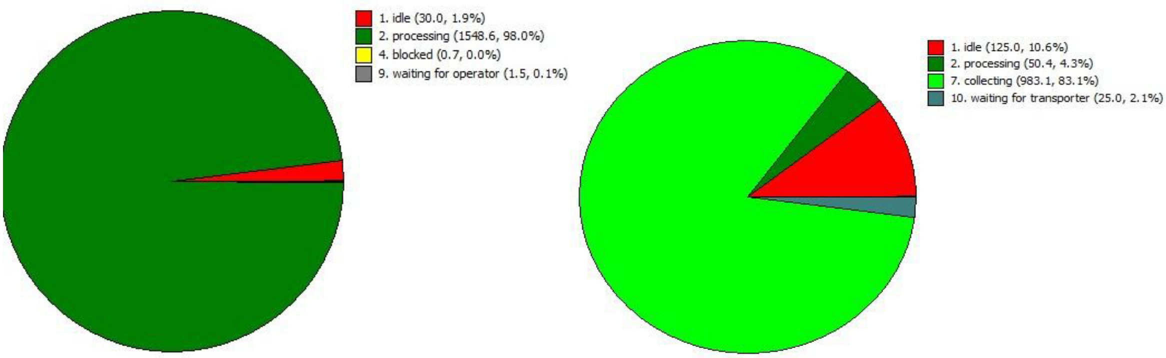

Fig. 5. (a) Wp1 report after the technological remodeling; (b) Wp4 report after the technological remodeling.

After placing all the 64 boxes on the pallet, the stack will be wrapped. The wrapping machine has rollers that will transfer the pallet directly to the C6 conveyor. For storage, the AS/RS systems will take the pallet from the C6 conveyor and will transport it on the central storage system (Rack). In order to validate our new system configuration, a new simulation was made (Fig. 4). All the bottlenecks from the work points were removed completely. For example, for Wp1 work point the bottleneck was removed completely. Now Wp1 is processing 98% from total time and is waiting 2%.

The reports are showing that the new robot (R3) is more efficient but is also more expensive. Because the R4 robot was removed, we can say that there are no supplementary costs for introducing a new robot (R3). The use of the R2 robot to feed the C1, C2 and C3 conveyors considerably reduced the long waiting times. The wrapping machine report shows improvements, the collecting and processing time was 70% and now is 87%. The goal of this case study was fulfilled. The reports resulted from the simulation after the technological remodelling are showing improvements to all structural elements.

Conclusion

In this paper we presented a flexible processing architecture for three products: ground coffee, coffee beans and instant coffee. We have chosen as case study a system developed from scratch and implemented afterwards. We have chosen the preliminary system architecture containing the main structural elements: work points, buffers, transport and transfer systems. The system must be able to obtain pallets with a specific box configuration, depending on the customer requirements regarding the three coffee type products. We used a virtual model of the system architecture designed in FlexSim 7 software in order to perform a preliminary system simulation and diagnose. As we expected, taking into consideration that the system was developed from scratch, the preliminary reports showed large waiting times and bottlenecks.

As a first solution we tried a functional remodelling that consisted of functional parameters modification for the system's structural elements. Successive parameterizations and simulations were made in order to obtain an optimized system. The results from the functional remodelling reports were not satisfactory, so we made a technological remodelling of the system by removing, replacing and adding structural elements to the system. The new simulation of the system validates the solution resulted from the technological remodelling. For our future research we want to include more coffee-type products in the system, for example a system that includes both plastic coffee cans and coffee bags. We want to develop an algorithm that assures a quick system reconfiguration based on the client's needs and a database that can store the parameters that must be set for each structural element of the system based on the parameterization specific to the product type without changing the system architecture.

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