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Redesigning a manufacturing system based on functional independence: the case of a tree nursery

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Abstract

The engineering of manufacturing systems encompasses two main areas of development: the manufacturing process (manufacturing technologies, and flow and handling of materials), and the production management (flow of information - signals). These two areas must be designed to perform according to the expressed needs. This paper shows that the Axiomatic Design (AD) theory can be used to analyse a manufacturing system to find the origin of the lack of productivity, and, subsequently, to redesign a solution avoiding the weakness points. A case study of a tree nursery of a large wood production enterprise was used to show the application of the axiomatic design principles, particularly through analysing the design equation and including new design parameters with the independence in mind. The redesign solution based on the independence of functions promoted the simplification of the information (signals) flow, avoiding the identification of each production element, and avoiding errors, which increases the productivity and the production volume, by elimination of waste of time in production operations. The proposed solution brought results that encourage the application of AD to increment the productivity of manufacturing systems, in alternative to expensive investments.

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Keywords: Manufacturing system; axiomatic design; tree nursery

1. Introduction

In a generic way, production processes transform the input means of production, namely materials, energy and signals (information) in products and waste, which are the outputs of the manufacturing process, as shown in Figure 1 [1].

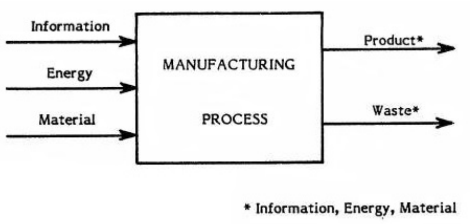

Fig. 1. Diagram of conversion material, energy and signals through a production process [1]

The production processes of material products involve the handling of raw materials, intermediate products, finished products and waste materials, which its flows are managed by signals along the production system.

When the flows of materials are independent it reduces the idle times, since it reduces the need for synchronization of entries and exits of the workstations at the production line [2]. Furthermore, the amount of signals required for management of the production system is reduced significantly, since the identification of the input materials and the output of the resulting products is not necessary, due to the fact that they have their own circulation channels and there is no mixing between them.

Any manufacturing system aims to maximize productivity [2], which is defined by equation (1).

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Productivity can be augmented by increasing total added value or decreasing production costs and investment, or by the reduction of one of the last two.

$$Productivity = \frac{Total\ added\ value - Production\ costs}{Total\ investment} \quad (1)$$

In generic terms of business operations, the added value of a product (or process or service) is brought by its functions, performances, suitability, quality, and price. This added value is a result of actions from several areas related to marketing and sales, development of the product, manufacturing, assembly, quality, and logistics.

With regard to the manufacturing process, the added value can be obtained by two ways: 1) better use of available time, which allows getting more value per time through the increase of quantities produced; 2) quality of manufacturing operations, which allow obtaining the specified functions at right-first-time, and thus making the production time more effective.

The minimisation of production costs – regarded as specific costs – can be achieved by increasing efficiency of production factors or by more efficiency of purchasing.

Investment is a factor, which goal is its minimisation. Usually, one has as objective the maximisation of the productivity to a certain investment, or the minimisation of the investment to a certain production.

In the context of this paper, the added value results from the quality of production and from the reduction of the idle times associated with operations. To maximize the productivity of a manufacturing system, it must be designed so that the functional requirements (FRs) can be easily satisfied at any time.

The study developed in this paper is focused on the manufacturing cell. It proposes a solution to material supplying systems and the exit of products from the workstation, based on the independence of how functional requirements are accomplished.

A real case of sorting plants at a plants production facility is analysed through the principles of Axiomatic Design theory (AD), particularly in what concerns to independence of functional requirements (axiom 1). Based on it, a new solution emerged. The consequent redesign of the production lines showed appreciable productivity increase.

2. Plant Production by cloning cuttings

A tree nursery is a managed site designed to produce tree seedlings grown under favourable conditions until they are ready for planting on the ground where they will grow. The goal is to produce high quality plants to satisfy customer's needs [3].

Tree nurseries can provide optimum care and attention to seedlings during their critical juvenile stage, resulting in the production of healthy and vigorous plants. In many cases, successful reforestation requires nursery-grown seedlings, since degraded areas have unfavourable conditions making natural regeneration or direct seeding not feasible.

The activities in a plant nursery are seasonal and production plants encompasses of different kinds of operations which can be identified in two main groups recognized by its seasonal nature: planting and sorting.

2.1. Planting

A group of operations that takes place during half of the year is the planting of cuttings. It is basically composed by the set of operations that is necessary to develop for the placing of cuttings in containers with soil (substrate) for germination and development.

After placing the cuttings in the containers, they are placed in "Shadow Houses" and "Weathering" for growing.

The growing of cuttings is not uniform for all plants. Along the time, plants will have different developments and sizes. So, it is necessary they are selected and grouped by size.

2.2. Sorting

The other group of operations that takes place during the rest of the year is the sorting. It involves: i) collection of plants in the field and its transport to the production unit; ii) selection according to their size; iii) cluster size in three classes (A, B and C) of similar sizes; iv) placement of equal size plants in containers.

After that, containers are moved to shade houses or dispatched to customers, depending on the size they present.

3. Case Study

3.1. Initial Situation

Containers with plants of various sizes are placed in the beginning of a conveyor line, comprising a single flat conveyor belt with horizontal and unidirectional movement.

The containers are moved along the conveyor line and the operators, placed along the conveyor, remove it with mixed plants for their workstation.

In each workstation weeds and plant residues are removed, which are placed in rubbish bins, to be later deposited in landfills.

The plants of similar size (three classes) are placed in the same container, which when it is full with similar size plant, is again introduced into the same conveying line.

The plant production unit that provides the basis for this study was composed by two production lines, each one with 10 workers producing in average, 48 containers-boards in an 8-hours day. Each container-board has 360 trays with 60 plants each one. These values correspond to an average production per worker of 648 plants per hour.

In figure 2 are shown the kind of trays with tube flowerpot and the containers-boards used for handling the plants.

The existing transport system had an average capacity of 20 trays per minute working alternately to feed the cells stations and to transport the finished sorted trays.

In this working method, the advance of the trays with same size plants is conditioned by the withdrawal of the trays with mixed plants to be sorted, and vice versa. Under these conditions, operations are interdependent.

Fig. 2. Photograph of containers-boards and trays with tube flowerpots in which the plants are moved in plant production unit.

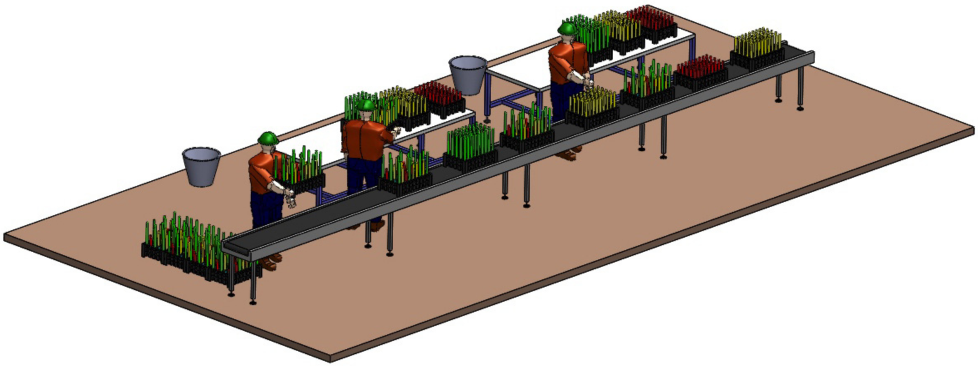

Fig. 3. Schematic representation of two cells in the plant production line

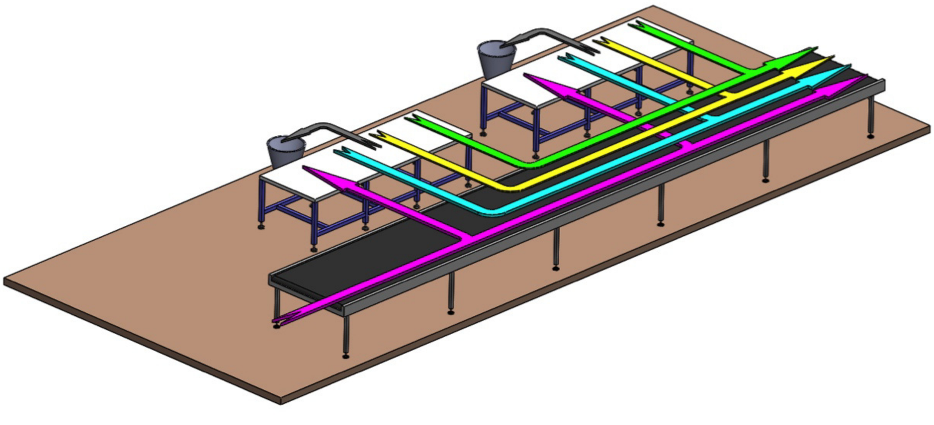

Fig. 4. Schematic representation of the material flows in two cells of the plant production line: mixed plants (violet), sorted plants A, B and C (blue, yellow and green) and waste (grey)

The figure 3 schematically depicted the operations in the line production. For better understanding, only two production cells are represented.

In figure 4 are represented the different material flows: mixed plants (violet), sorted plants A, B and C (blue, yellow and green) and waste (grey).

The plant had the need to increase the production at least to 80 containers-boards per day which corresponds to an increase of 60%.

One could easily increase the production by the addition of another production line (50% increase) and by the addition of two cells in each line (20% increase). Nevertheless these options would strongly spoil the global efficiency besides the difficulty in feeding the last cells of the line and extracting the sorted trays in the beginning of the line.

Another difficulty of the initial situation was the identification of the state of the trays (mixed and sorted). That identification was made by eye with possible errors and consequent loss of time. Labelling was an alternative but with consequent increase of investment and exploration costs.

3.2. Axiomatic Design analysis

The statement of functional requirements is of crucial importance in any design (or redesign). Any design cannot be better than its functional requirements.

A careful analysis of this plant production line allows identifying the following functional requirements:

FR_1 – Feed trays with mixed plants to workstations;

FR_2 – Clean weeds and plant residues, select plants with similar size and place them in separated trays;

FR_3 – Transfer vegetable wastes;

FR_4 – Forward trays with similar size plants.

The existing solution encompasses the following DPs:

DP_1 – Conveying line to feed and forward trays;

DP_2 – Operators for the transfer, cleaning and sorting operations, and transport of bins with weeds and residues.

Equation (2) presents the design equation representative of the production line.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} \times & 0 \\ 0 & \times \\ 0 & \times \\ \times & 0 \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \qquad (2)$$

Axiomatic Design Theorem 1 states, “when the number of DPs is less than the number of FRs, either a coupled design results or the FRs cannot be satisfied”[4]. So, in accordance, equation (2) represents a coupled design.

Axiom 1 of AD states “maintain the independence of FRs” and as per Theorem 4 “in an ideal design, the number of DPs is equal to the number of FRs”. Thus, we propose the introduction of two new DPs with the goal to achieve independence of FRs. The proposed design has the following design parameters:

DP'_1 – Conveying line to feed trays;

DP'_2 – Operators for the transfer, cleaning and sorting operations;

DP'_3 – Conveying line to transport weeds and residues;

DP'_4 – Conveying line to forward trays.

Equation (3) denotes the new design equation which configures an uncoupled design where independence of FRs is achieved.

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \end{Bmatrix} = \begin{bmatrix} \times & 0 & 0 & 0 \\ 0 & \times & 0 & 0 \\ 0 & 0 & \times & 0 \\ 0 & 0 & 0 & \times \end{bmatrix} \begin{Bmatrix} DP'_1 \\ DP'_2 \\ DP'_3 \\ DP'_4 \end{Bmatrix} \qquad (3)$$

3.3. The new design

The proposed solution comprises more two conveyors per line in addition to the existing one. So, each line has three independent conveyors (DP'_1, DP'_3 and DP'_4) in order to satisfy FR_1, FR_3 and FR_4; one conveying line to feed trays, one conveying line to transport wastes and another conveying line to forward sorted trays.

The introduction of a conveying line to transport residues allow operators to dedicate to productive tasks.

By changing the previous DP_1 into two new DPs (DP'_1 and DP'_4), FR_1 and FR_4 became independent avoiding losses of time namely in waiting trays to be processed and waiting opportunity to introduce sorted trays in the line. Thus, the global efficiency of the system is increased.

The production management also became easier and errors on tray’s identification are eliminated because different tray stages do not flow in the same conveying.

This new redesign is schematically depicted in figures 5 and 6, where by simplicity reasons, are only represented two cells. In figure 5 are shown the three independent conveying lines. In figure 6 one can see the different independent flows; mixed plants (violet), sorted plants A, B and C (blue, yellow and green) and waste (grey).

The progress of trays with plants not sorted is independent of the progress of trays with sorted plants which always allow the presence of trays to be processed near each workstation there is a buffer.

On other hand, the transport of sorted trays is independent and the operator has the possibility of delivering and getting trays at any moment. For this purpose, none buffer is needed.

By introducing a dedicated conveying line to the automatic transport for wastes, the manual handling of bins is avoided and that lost time is used in productive tasks by operators. This means that the previous DP_2 was transformed into two new DPs; DP'_2 (transfer, cleaning and sorting operations) and DP'_3 (conveying line to forward trays).

Notwithstanding this productivity gains, the enterprise decided to create a third production line for a matter of total production needed.

Fig. 5. Schematic representation of the redesigned plant production line

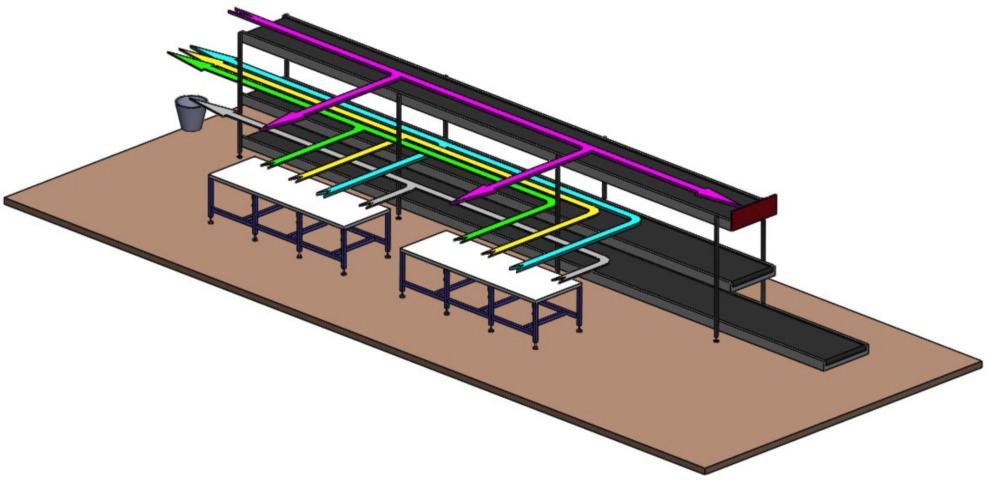

Fig. 6. Schematic representation of the redesigned plant production line with three independent conveying lines : mixed plants (violet), sorted plants A, B and C (blue, yellow and green) and waste (grey)

4. Results

The final configuration of production lines is shown in figures 7 and 8.

Fig. 7. Photography of the redesigned plant production line in accordance with the proposed solution

The redesigned plant production lines in accordance with the Axiomatic Design principles achieved better productivity values. Additionally, total production increased by the inclusion of a third line.

Fig. 8. Photography of the redesigned plant production facilities (3 lines) in accordance with the proposed solution

Tested productions achieved 112 containers-boards per day which in average corresponds to 1008 plants per hour per operator and represents a gain of productivity of 55%.

The total amount of plants processed changed from 48 containers-boards per day (103 680 plants) with 20 operators to 112 containers-boards (241 920 plants) with 30 operators. These figures represent an increase of production of 133%.

It is estimated that the direct cost of production of each plant has been reduced about 25%.

5. Conclusions

In the previous system, the conveying line was common to two functional requirements. So, the number of DPs was smaller than the number of FRs which, in accordance with Theorem 1, configures a coupled design. The analysis of the design matrix necessarily indicts the existence of idle times.

Each production line had a conveying line to transport trays with plants to be sorted and already processed. On the other hand, operators should clean and sort the plants and also transport the bins with wastes.

The new design arose from the analysis of the design equation. With the goal of achieving independence in the satisfaction of FRs, two new DPs were added to have an uncoupled design. The FRs satisfaction is only dependent from the followed order.

The proposed solution is based on the introduction of two more independent conveying lines separating the feed of trays to be processed, the transport of sorted trays and the transport of residues. This allowed the following main advantages:

-Increase of productivity;

-Reduction of the possibility of mistakes through simplification of information management;

-Cleanliness and organization of workstations.

To avoid idle times, the feeding line must have buffers. Buffers are not needed for the conveying line for sorted plants.

The introduction of a dedicated conveying line for the waste avoids the manual handling of bins and allows the operators to do productive tasks.

As a consequence of the redesign based on functional independence, the productivity of the redesigned line increased by 55%.

In conjunction with another created line, total production capacity increased by 133%.

It is estimated that the direct cost of production of each plant has been reduced about 25%.

The redesign solution based on the independence of functions promoted the simplification of the information (signals) flow, avoiding the identification of each production element, and avoiding errors, which increases the productivity and the production volume, by elimination of waste of time in production operations.

The proposed solution brought results that encourage the application of Axiomatic Design to increment the productivity of manufacturing systems, in alternative to expensive investments.

Acknowledgements

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