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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].

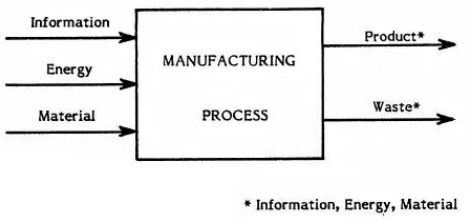

Fig. 1. Diagram of conversion material, energy and signals through a production process [1]

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.