Modeling and simulation of a production line for capability study purposes using Petri Nets

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Abstract: This paper presents the experience of an on going project aiming the installation of a non destructive quality control instrument and a capability study in a traditional production line of light metal industry (collapsible tubes). The production line has been modelled using Petri Nets and the locality principle has been exploited in order to obtain a model of the physical system, accurate and detailed enough for the capability study to take place. A combined top-down and bottom-up approach is proposed, which facilitates largely the communication between experts and provide a valuable tool to help the development of control charts. The QI Analyst tool has been used for the development of control charts, and ARTIFEX for testing the model and simulate.

Keywords: Petri-Nets, Enterprise modelling, Control chart limits *CSCC'99 Proceedings,* Pages:4731-4735

1. Introduction

1.1. Initial conditions and problems

The markets' requirements for sophisticated high quality products in small amounts and quick response to the demand necessitate production systems with high flexibility and acceptable quality [8] [9]. Quality, meaning meeting customers' requirements in the widest possible sense, is a vital competitive strategy. The implementation of quality systems i.e. an established and proven set of procedures which are revised to take into account of a changing environment, increases conformity to customers' requirements and therefore quality [5].

Inspection and testing is an explicit requirement for quality systems, concerned with establishing whether the inputs into the work process, the outputs and work at various stages in between, meet defined requirements. Arguably the better the quality system the less the need for after the event inspection.

Even though an effective system should not depend only on inspection and testing the supplier has to inspect, test and identify product as required by the quality plan or the documented procedures, establish product conformance to specified requirements by use of process monitoring and control methods. In addition the supplier has to hold product until the required inspection and tests have been completed and identify non-conforming products.

One valuable tool for inspection and testing is the statistical process control (SPC). A primary goal of SPC is to detect non random behaviour in a process as soon as possible after it starts. In this way the process can be adjusted to correct the problem and bring it back to control before heavy material losses occur. A first important step is to define a standard for the process based on its past performance data in order to compute control chart limits. A heavy restriction to the definition of the limits is that data points for which assignable causes can be found must be removed. The proper interpretation of control charts is critical to their use and several out-of-control criteria have been suggested.

Traditional modelling of the physical level through operation process charts and routings are a good start for identifying the main manufacturing processes [2], but are of little help when it is necessary to check whether samples belong to the same population. Alternatively IDEF-0 can be used, a well established methodology introduced in order to describe a structured representation of the functions, activities or processes within a modelled system [4]. The advantage of IDEF-0 is the use of a top-down approach, to a precise functional description of the required system at the necessary detail. However its use cannot be extended further.

Finally common practice for quality control activities is their representation via flow-charts which are not suitable for top-down refinement.

1.2. Objectives and methodology

A model is developed at different levels, ranging from major process activities to the fine details of the process. The modeling approach followed, proposes two different levels/models:

1. The production system level model
2. The detailed physical system model

Each one is constructed with its corresponding Petri-net, using the locality principle. The production level model is constructed with appropriate combined modules modeling the components of a production system (bottom-up approach) [6] [7].

The model is then used to verify that the measurments used in order to perform the capability study and create the control charts come indeed from the same production conditions in the correct order. When one or more of the out-of-control rules is violated a refinement of the appropriate module leads to a detailed model (top-down approach) until all the necessary particularities of the production process have been taken into account and the control charts established.

This procedure leads to an accurate model of the system, which can be furthermore used to perform qualitative or quantitative analysis by simulation in order to increase confidence [3]. Qualitative analysis checks the absence of deadlocks or overflows, the presence of certain mutual exclusions in the use of shared resources, etc. Quantitative analysis looks for performance, responsiveness and utilisation properties.

1.3. Structure

The paper is organised as follows: In Section 2, the case study is presented. In Section 3, the production system level model is presented as a Petri-Net using the ARTIFEX tool [1]. In Section 4, the detailed physical system model is presented, using Petri Nets and the results for the control charts created as the analysis proceeds in greater depth. In Section 5, the conclusions are presented and opportunities are identified for further research in this area.

2. The case study

2.1. The company

The company under consideration has been in the aluminium business since 1965 with the first production line for collapsible tubes. In the years that followed the company developed the manufacturing capabilities by successively installing production lines for aerosol cans and monoblock bottles. Close to Athens the company operates a full and completely specialised unit that covers the needs of the Greek market as the principal target and also exports to neighbouring countries.

2.2. Commercial and manufacturing policy

The Greek market of collapsible tubes remains traditionally under the direct control of the big multi-national companies of the cosmetics and pharmaceutics sectors. The survival of the national production depends on the supplier’s ability to improve continuously quality and increase flexibility. Flexibility is an important incentive for the customers as it makes possible for them to avoid the long term production planning and / or the maintenance of important inventories, in a market characterised by instability. As companies try to establish JIT techniques they prefer local suppliers in order to produce only when the forecasted demand becomes a firm customer’s order. In addition the company undertakes small orders in the important markets, which the big competitors avoid in order not to disturb their production plan.

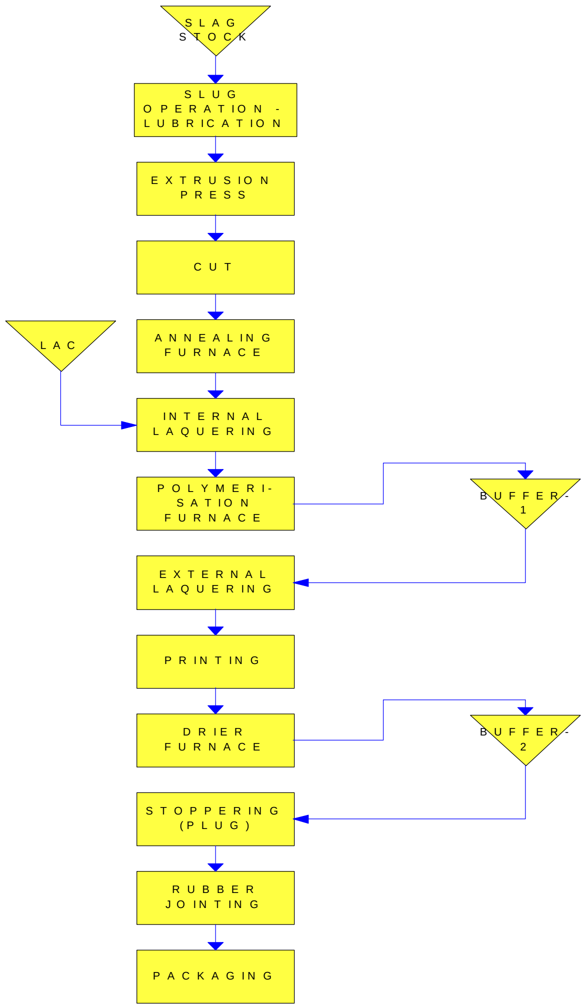

Figure 1. Production line of the collapsible tubes

The plant operates a slugs operation and lubrication unit a collapsible tubes production section a monoblock aerosol cans production section, a monoblock bottle production section and a quality control laboratory.

The production line of the collapsible tubes section under consideration is briefly described in Figure 1.

2.3. Installation of a non-destructive quality control instrument

A specialised instrument for the non-destructive measurement of the thickness of the internal layer of the varnishing colour has been installed in the quality control laboratory. The system measures the coating thickness on the inside of aluminium tubes, using Eddy current technique in a separate place in a non-continuous way. It is a specialised food / beverage container measuring system to measure the coating thickness on the inside and outside of aluminium containers.

In order to establish control chart limits a capability study has been performed for the identification of the natural tolerance limits of the process.

3. Development of enterprise models

3.1. The production system level model

The collapsible tube production system is modelled using three generic modules. The first level model is presented in Figure 2.

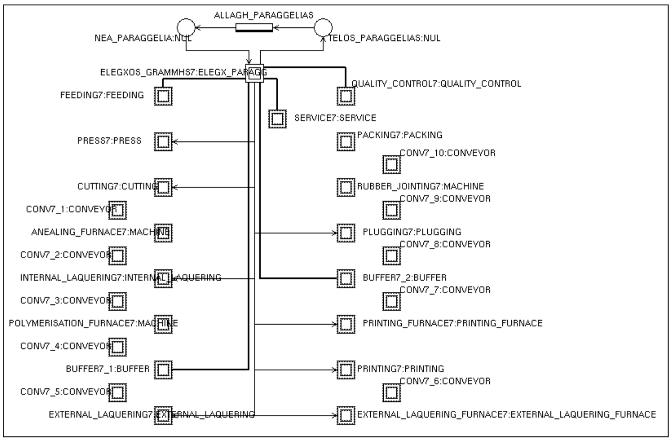

Figure 2. Production line – first level model

Three generic modules modelling a mono-operational machine, a buffer and a transportation system have been used in a bottom-up approach in order to model the production line. The first two are presented respectively in Figures 3 and 4.

In order to perform the measurements 50 tubes have been taken and numbered in the same order as they come from the buffer after the external lacquering. The thickness of the internal layer of the varnishing colour has been measured according to the instructions and the resulting control chart is presented in Figure 5.

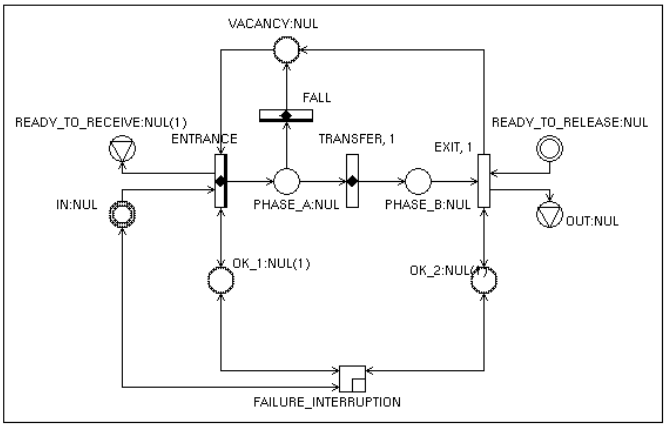

Figure 3. Mono-operational machine

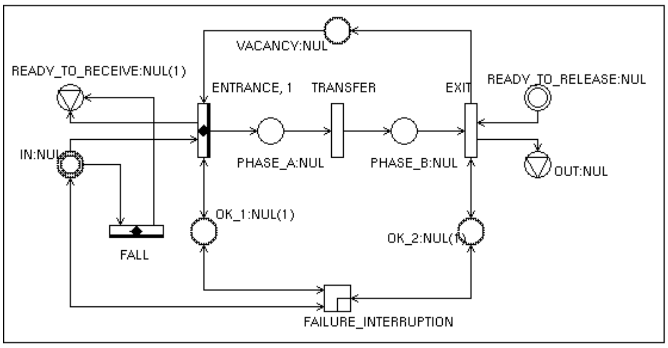

Figure 4. Conveyor belt

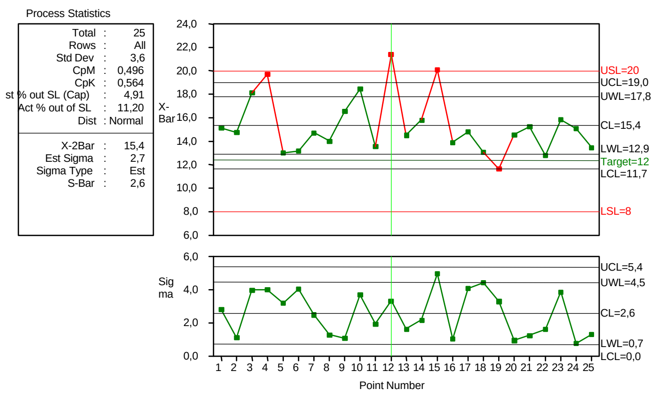

Figure 5. Control chart 1

It is obvious that this control chart corresponds in a production process which is not under statistical control. The results lead to the suggestion that the measurements do not belong to the same population. In order to have a more accurate picture of the production the locality principle has been used and a more detailed model developed for two critical pieces of the equipment.

The advantages of modelling using a Petri net-based approach will be used. In particular, the dichotomy places/transitions leads to a treatment of states and actions on an equal footing. This makes Petri nets superior to either purely state - or purely transition - oriented formalisms where one of the notions is explicit and the other has to be deduced.

4.The detailed system model

4.1. General Concepts

The existence of a locality principle on states and actions (transitions) is a direct consequence of its bipartite structure and marking definition. The importance of the locality principle resides in the fact that Petri net models can be locally modified, refined or made coarse, without altering the rest of the model. This means, in particular, that nets can be synthesised using top-down and bottom-up approaches.

Top-down synthesis is a procedure that, starting with an initial (very abstract) model, leads to the final model through stepwise refinements. In a bottom-up approach modules are produced, possibly in parallel by different groups of designers, and later composed.

We use a bottom-up (modular) composition method for the development of the first level model. This involves the specification of subsystems or modules and a systematic procedure for combining these modules with their interactions into an integrated system.

In this application three sub-systems have been used. The subsystems, which are simple and easy to verify are specified separately in detail. Interactions are represented by common places, in the individual subsystems. At each synthesis step, these interactions are considered, and the corresponding subsystems are combined through merging these places to a larger subsystem. Analysis of the combined net is done immediately after each synthesis step, so when the final stage of synthesis reached, the analysis can be simplified. At the end of the synthesis steps, the final system and some of its important properties are obtained.

Top down synthesis begins with an aggregate model of the system and neglects low-level detail. Then refinement is done in a stepwise manner to incorporate more detail into the model. The refinement continue until the level of detail satisfies the specification of the system. Top down methods have the advantage of viewing the system globally from the beginning to the end of the synthesis. In the application two modules representing a machine and a transportation system have been refined.

4.2. Description of the internal lacquering machine

The detailed model for the internal lacquering machine shows that the internal varnishing is performed by two separate couples of sprayers each one spraying every second tube as they are coming from the transportation system. Therefore, as far as the internal lacquering is concerned, control charts have to be developed for two separate production processes.

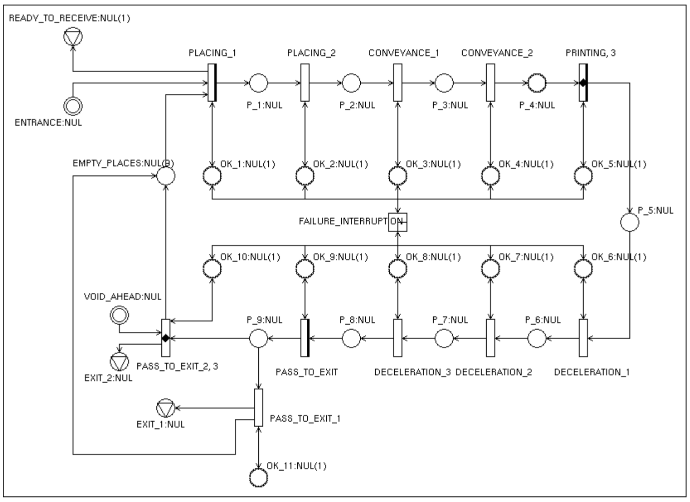

Figure 6: **Internal lacquering machine.**

4.3 Description of the transportation system after the external lacquering machine

The detailed model for the external lacquering machine shows that the order of the tubes is altered by a special transportation device which reverse the order of the tubes coming out of the machine as presented in Figure 7. Special care must be taken in order to have the tubes as they have been actually internally lacquered.

The thickness of the internal layer of the varnishing colour has been measured according to the instructions and the resulting control chart is presented in Figure 8.

This control chart corresponds in a production process under statistical control as none of the out-of-control rules is violated.

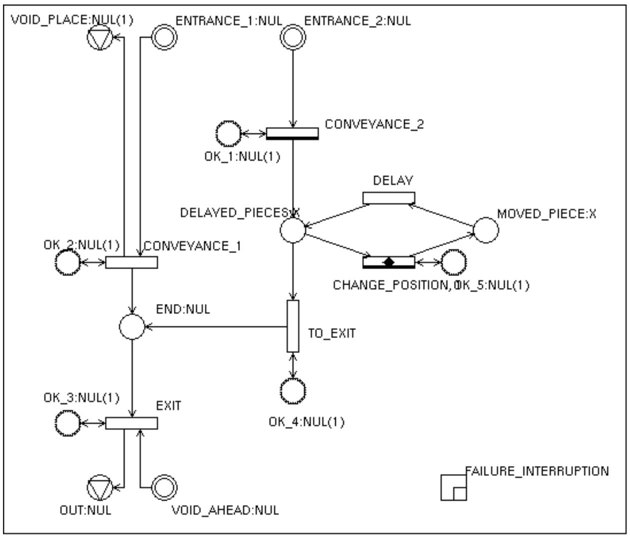

Figure 7. Transportation device.

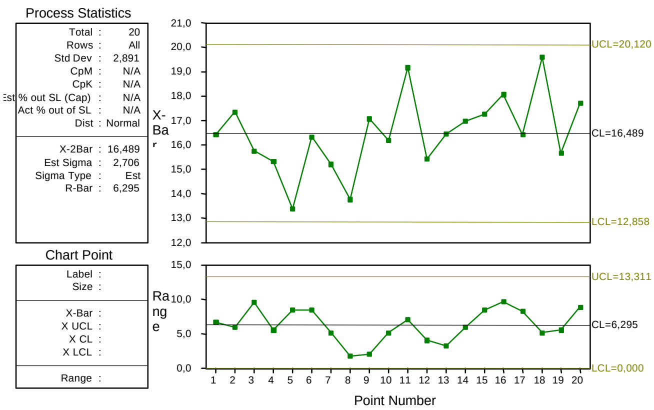

Figure 8. Control chart 2.

5. CONCLUSTIONS AND FURTHER RESEARCH

The possibility of the Petri net models to be locally modified, refined or made coarse, without altering the rest of the model is valuable for capability studies. Bottom-up approach leads to a quick initial model of the system using generic modules for every component of the production system. Top-down analysis can then be applied to each module in order to obtain a detailed enough model through stepwise refinements. In addition the same model can be easily used to verify some important properties through simulation.

An interesting subject of research is to further extend this approach, by integrating the model of the physical system developed with the quality assurance models (functional level) in order to support corrective actions.

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