# MANUFACTURING ARCHITECTURE DIAGNOSIS FOR A MILLING MACHINE MAIN SHAFT

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*Scopul lucrării este acela de a prezenta o metodologie de diagnoză a unei arhitecturi de fabricație în vederea identificării soluțiilor de creştere a productivității în condițiile menținerii unui cost optim de fabricație a produsului. Metodologia de diagnoză este bazat pe modelul virtual tridimensional al arhitecturii de fabricație utilizat pentru simularea fluxurilor materiale de semifabricate piese şi scule. Rezultatele simulării permit identificarea concentratorilor de flux (zonele în care fluxul material este încetinit sau chiar blocat). A fost folosită succesiunea de opera□ii pentru realizarea unui arbore principal de la un centru de prelucrare prin frezare pentru a ilustra această metodologie. Pentru validarea economică a fost folosită diagrama de corelare dintre costuri şi valoarea de întrebuințare.*

*The goal of this paper is to present a manufacturing architecture diagnosis meant to identify the solutions for an increased productivity at the same optimized product cost level. The diagnosis is based on a 3D modelling of the manufacturing architecture and a material flow (working pieces, parts, tools) simulation for this virtual manufacturing model. The simulation results allow identifying the material flow concentrators, the bottlenecks where the flow is slowed down or even blocked. This methodology was applied on a milling machine main shaft case study. Based on the input data and results of the economic validation the manufacturing process is modelled and simulated, thus gathering important information related to production and problems that may occur. The economic validation was based on the Cost / use value report.*

**Keywords:** manufacturing process, bottleneck, economic validation, production.

## 1. Introduction

In manufacturing systems design optimization [1], the simulation of the system material flow must succeed to CAD (Computer Aided Design), CAE (Computer Aided Engineering) and CAM (Computer Aided Manufacturing) analyses [2]. The methodology is centred on material flow simulation. There are agreed here with the thesis that within the class of stochastic simulation models,

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one further distinction is necessary: simulations can be either terminating (sometimes called finite) or nonterminating in nature, with specific algorithms for each category [3].

The proposed methodology will be applicable for terminating simulations (manufacturing simulation is made for a fixed period of time).

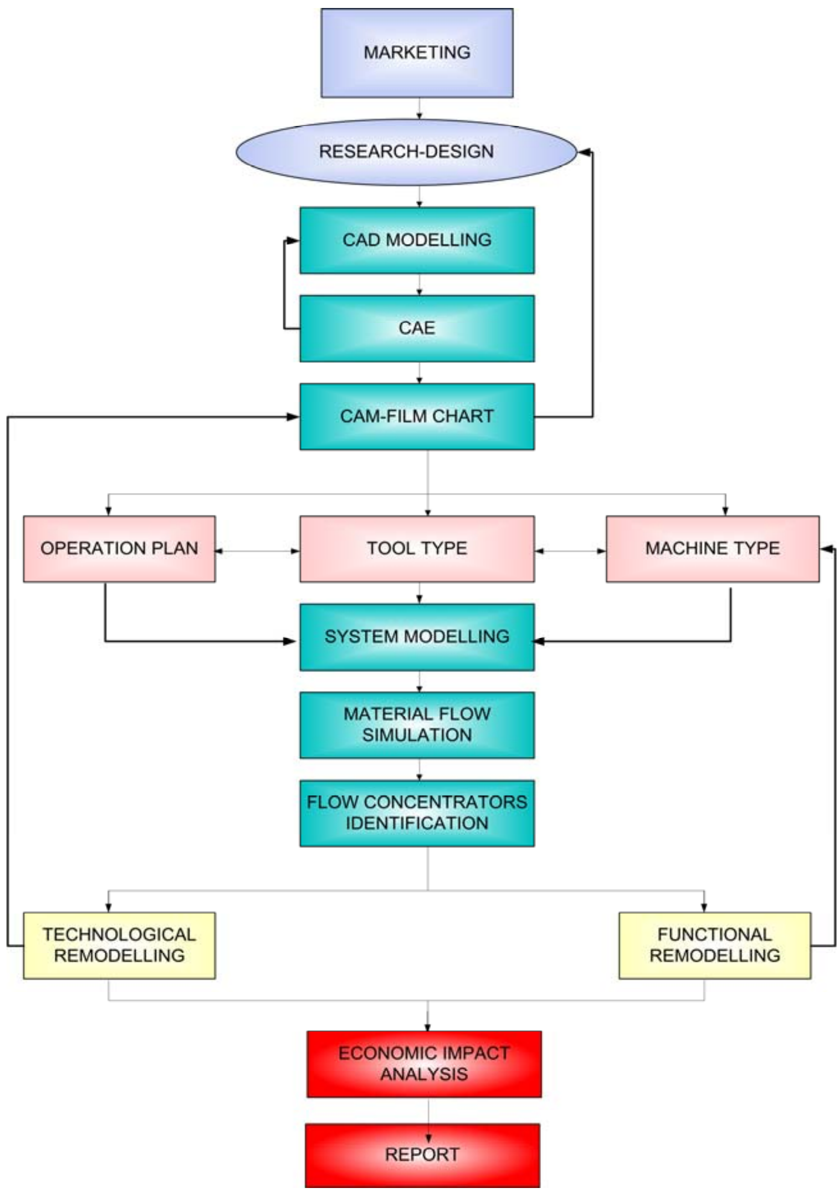



Fig. 1. Methodology of modelling and simulation for the design and manufacturing of a product

For a designed manufacturing architecture it is always useful to simulate the material flow conduct before applying our design into practice in order to avoid potential flow concentrators (bottlenecks) generating low productivity or even blockage. Flow concentrators also generate under utilization of the structural elements of the manufacturing system leading to financial loss [4].

## 2. Diagnosis

The methodology regarding the design and manufacturing of a new product can be described using the steps presented in figure 1 [1]. Here one can see the modelling and simulation methodology proposed in order to improve the manufacturing performances based on a 3D virtual avatar of the manufacturing system. Before starting a manufacturing process, we must use the marketing studies in order to include the customer demands in the preliminary product modelling CAD phase. Next step is to use the CAE module to simulate the product behaviour in exploitation, thus we validate the preliminary product virtual prototype. When this 3D model validated we need to study in detail the product machining cycle determining the necessary tools and machines as elements of the preliminary manufacturing architecture. In order to optimize and eventually validate this preliminary manufacturing architecture the next step is to virtually simulate the material flow in order to identify and eliminate flow concentrators that slow down or even block the production. An analysis will be made and in order to eliminate the flow concentrators we need to choose between:

A functional remodelling; it consists in changing some of the machines placement, the order of some operations, the speed of some conveyor belts or manufacturing times [5];

A technological remodelling; it consists in reconsidering all the manufacturing structure system data: the type of the machines, tools, transport and transfer facilities etc [6]. If technological remodelling is chosen, after using an economic analysis to compare the necessary investment with the increasing productivity benefits we finally validate the manufacturing architecture design improvement.

## 3. Case study

For this case study we will diagnose the preliminary manufacturing architecture of a diffused system based on the manufacturing cycle of a milling machine main shaft. We define diffused manufacturing systems as architectures with more than two working points using if necessary buffers, transport and transfer systems [1].

We will start by determining the machining cycle in order to transform work piece into a shaft with a diameter of 80 mm and length equal to 345 mm. We must calculate the manufacturing time needed in order to establish the number and type of the machine tools used in the production site. The main shaft requires a number of 23 machining operations in order to be obtained. For calculating the necessary time we must know some technological parameters from the machines used, like the cutting speed, rotation parameter, as well as the crossing numbers for each process, stroke, work piece diameter, etc.

It is very important to do a correct calculus of the necessary times because these will lead to a correct parameterization of the machines when running the simulation. If the necessary times are not calculated correctly the results obtained from the simulation are incorrect and so the manufacturer can't rely on them. For each machining operation we must calculate the manufacturing cycle time [6]. We determine the manufacturing times for all the operations, so in this phase we know the total amount of time necessary to manufacture the shaft.

*Table 1*

**Main shaft's machining cycle**

| No. | Machining operations |
|---|---|
| 1. | Frontal turning; t=2, diameter 80 mm |
| 2. | Drilling; diameter 18 mm, length 345 mm |
| 3. | Interior conic turning; from diameter 45 mm to 25 mm on 70 mm length and interior cylinder turning; from diameter 25 on length 30 mm |
| 4. | Debiting; from diameter 80 mm to 18 mm |
| 5. | Exterior turning; diameter 30 mm on 45 mm length |
| 6. | Exterior turning; diameter 35 mm on 20 mm length |
| 7. | Exterior turning; diameter 40 mm on 60 mm length |
| 8. | Exterior turning; diameter 45 mm on 40 mm length |
| 9. | Exterior turning; diameter 50 mm on 150 mm length |
| 10. | Exterior turning; diameter 60 mm on 5 mm length |
| 11. | Grooving; diameter 38 mm on 2 mm length |
| 12. | Grooving; diameter 38 mm on 4 mm length |
| 13. | Exterior turning; diameter 48 mm on 30 mm length |
| 14. | Threading M50 x 1.5 on 30 mm length |
| 15. | Threading M40 x 1.5 on 18 mm length |
| 16. | Keyway milling L = 36 mm; h = 4 mm; l = 8 mm |
| 17. | Milling L = 23 mm; h = 8 mm; l = 17 mm |
| 18. | Drilling and interior threading M5; h=8 mm |
| 19. | Improvement heat treatment |
| 20. | Tapered bore ISO 40 on 70 mm length |
| 21. | Exterior grinding; diameter 50 mm on 90 mm length |
| 22. | Exterior grinding; diameter 40 mm on 38 mm length |
| 23. | Exterior grinding; diameter 30 mm on 45 mm length |

For each operation we calculated the manufacturing cycle time using the formula (1). The symbols used in the formula signify: $t_{ef}$ – manufacturing time; i –

number of passes; cursa – length; w – feed rate; $D_{sf}$ – blank's diameter; $n_{as}$ – rpm; $v_{as}$ – cutting speed and s – feed.

$$
\begin{array}{ll}
t_{ef} = \dfrac{i \cdot cursa}{w} & cursa = \dfrac{D_{sf}}{2} + 2 \\
w = n_{as} \cdot s & n_{as} = \dfrac{1000 \cdot v_{as}}{\pi \cdot D_{sf}}
\end{array}
\tag{1}
$$

After applying the formula the results are listed below, in table 2, for all machining operations:

*Table 2*

**Calculated necessary manufacturing times for the main shaft surfaces**

| No. | **Machining operation** | **Necessary manufacturing time** [min] |
|---|---|---|
| 1. | Frontal turning | 2.1 |
| 2. | Drilling | 26.26 |
| 3. | Interior conic turning | 2.21 |
| | Interior cylinder turning | 1.16 |
| 4. | Debiting | 4.13 |
| 5. | Exterior turning | 16.45 |
| 6. | Exterior turning | 6.6 |
| 7. | Exterior turning | 15.5 |
| 8. | Exterior turning | 10.5 |
| 9. | Exterior turning | 30.4 |
| 10. | Exterior turning | 1.05 |
| 11. | Grooving | 0.05 |
| 12. | Grooving | 0.1 |
| 13. | Exterior turning | 0.95 |
| 14. | Threading | 1.33 |
| 15. | Threading | 0.66 |
| 16. | Milling | 0.18 |
| 17. | Milling | 0.27 |
| 18. | Drilling | 0.08 |
| | Threading | 0.08 |
| 19. | Heat treatment | 90 |
| 20. | Tapered bore ISO 40 | 20.57 |
| 21. | Exterior grinding | 24.21 |
| 22. | Exterior grinding | 10.52 |
| 23. | Exterior grinding | 12.37 |

After determination the total amount of time that takes to manufacture the shaft we can establish the five machine tools used in the manufacturing process. These are: debtor machine, lathe machine, milling machine, boring and grinding machine.

## 4. The cost / use value economic validation

Before starting any production cycle it is advisable to perform a cost / use value report analysis and then run a material flow simulation using dedicated software. By applying these analyses we can gather information can be useful both for beneficiary and manufacturer. For example, we can learn about the productivity rates, displacement of the work points, auxiliary manufacturing times, and human operators' role. For the case study we have defined 9 main functions. The calculated use values for those functions are presented in table 3.

The functions ensured by the main shaft are A (Driving motion), B (Fixing elements) and C (Positioning elements). These are also the functions with the highest usage value (table 3). The cost / use value report methodology described her is used twice in our economic validation.

*Table 3*

**Functions description**

| Symbol | Function name | $U_v$ [%] |
|---|---|---|
| A | Driving motion | 20.99 |
| B | Fixing elements | 16.05 |
| C | Positioning elements | 16.05 |
| D | Sealing | 3.70 |
| E | Allows access | 1.23 |
| F | Takes shocks | 11.11 |
| G | Bearing function | 7.41 |
| H | Takes loads | 7.41 |
| I | Centring elements | 16.05 |

In fig. 2 the structure of those functions associated costs is presented. There significance of the diagrams is: Blue line – labour costs, Brown line – indirect costs and Yellow line – materials costs.

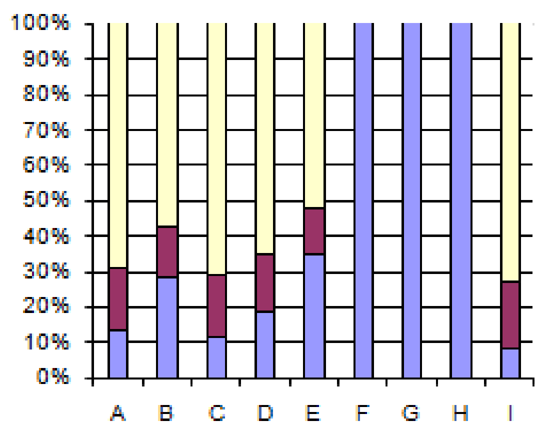



Fig. 2. Function histogram

The report of use value and costs is presented in figure 3. One can use this representation in order to check if for some functions the use value is smaller than the associated costs (example given: A, C and D). The Red line represents the costs and the Blue interrupted line the use value. After we identified the highly evaluated use values we can proceed by looking for the elements ensuring those functions and further more we must try to find solutions to decrease their production costs.

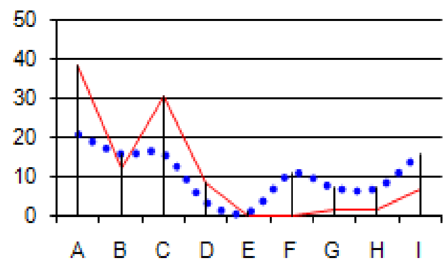



Fig. 3. Cost / use value correlation diagram

So, by analysing both the function histogram and the cost / use value correlation diagram we can determine which elements must be further analysed and in which cost category we must intervene.

### 5. Modelling & simulating the preliminary system architecture

In the mean time we start the simulation and optimisation process of the manufacturing architecture. So far we established the necessary machine-tools and the manufacturing times. All these data will be used as input in the Witness simulation dedicated software.

According to our previous considerations, before starting any production cycle it is advisable to run a material flow simulation using dedicated software [6]. The information gathered refers to productivity rates, displacement of the work points, auxiliary manufacturing times, human operators' role and eventual system blockages [4], [5]. Using the obtained data we are going to build the model for the production site (figure 4). The elements present in this model are: machine tools (debtor machine – D1, lathe machine – S1, milling machine – F1, boring and grinding machine – MAR1), each of them having an operator (L1 to L4) supervising the production cycle, conveyor belts (C1 to C4) used for transporting the blank (P1) from one work point to another. The buffer (B2) is used for depositing parts. With the help of this model we can simulate the real manufacturing site. For a correct reproduction of the manufacturing system exploitation conditions we will now do a parameterization of the machine-tools and conveyor belts. The necessary times were previously calculated as well as the order of machine placement of the operations.

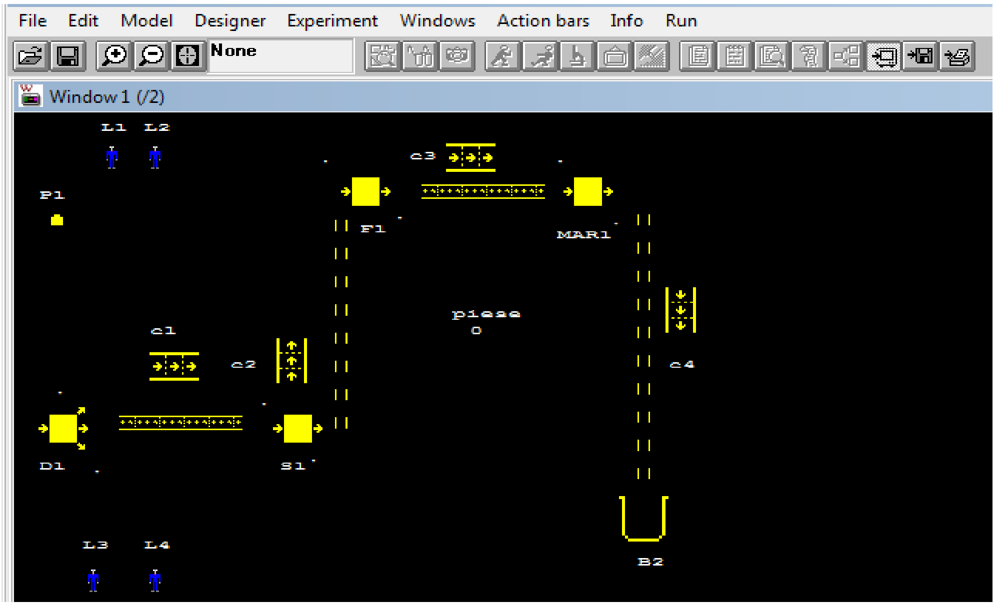
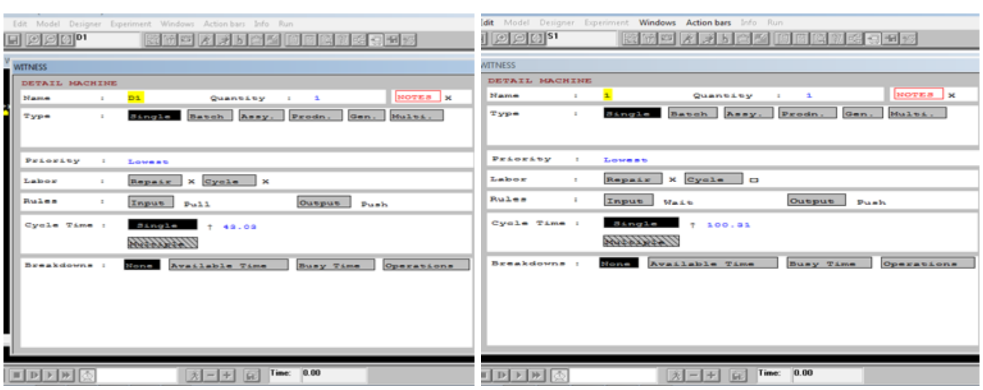



Fig. 4. Preliminary architecture of the production site

In fig. 5 we have an example for D1, S1 and F1 machines showing the total manufacturing times. The first problem that we noticed was the bottleneck situated on S1 entrance caused by the big manufacturing times that this machine has. Here the material flow is either slowed down or stopped causing problems throughout the whole system. The problem is caused by the manufacturing time on S1 which is almost 3 times bigger than the one of the D1. After analysing the results we start looking for optimisation solutions.



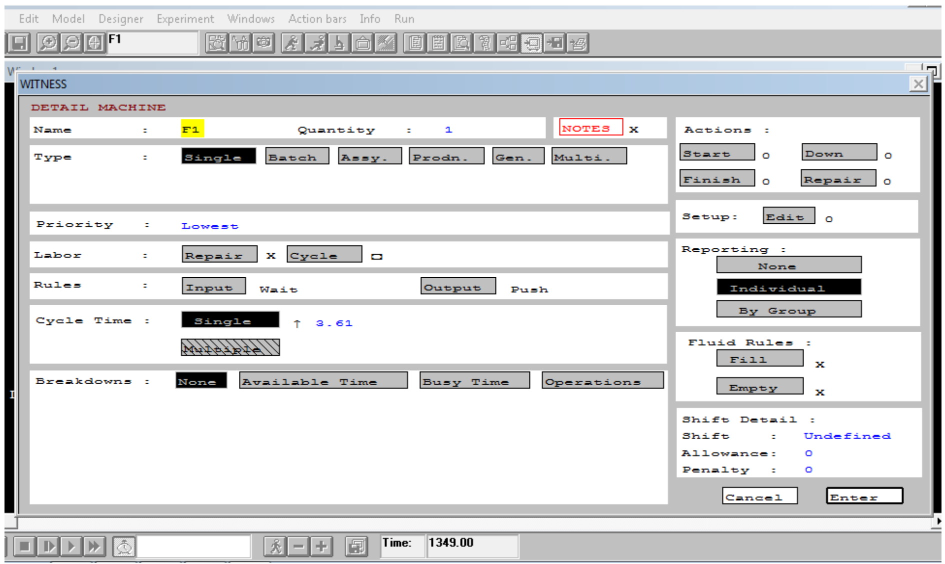



Fig. 5. Distribution of manufacturing times on machine-tools

In the first phase, functional remodelling was chosen but the results were not as expected. The second solution was technological remodelling. We reconsider the whole system and decided to add another lathe machine, two conveyor belts for ensuring transport facilities and a human operator to supervise the machine.

## 6. Some results & conclusions

In the case study we diagnose a diffused manufacturing system state of the art. The easiest way of doing that is by using functional remodelling, changing some of the machine placement in the production site, the order of some operations, etc. Of course if this doesn't work we will have to consider technological remodelling, modifying the manufacturing architecture. A new simulation must be performed to validate the optimized manufacturing architecture.

After rebuilding the model we run a simulation for this new model and obtained an increasing of the productivity of over 30%. In this way we eliminated the bottleneck presented in the previous manufacturing architecture. In this point, before we can continue with the optimisation processes aiming for higher productivity rates we must have in mind that by modifying the architecture, especially by adding work points we raise the production costs. That implies a second economic validation based on the cost / use value report.

We consider those results encouraging for the diagnose applicability. We intend to develop in further research a similar methodology for non terminating material flow simulation.

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