# Value Stream Mapping Application on Mould Making Industry: Results and Discussion

**A. Costa, E. Henriques, M. Domingues and P. Peças**

**Abstract** This paper presents the results of a project aiming to understand the viability of value stream mapping techniques on the "one of a kind production" context typical of mould making industry. More than having a representation of a standard process, the idea is to use the mapping techniques to support the analysis and the discussion of the time-oriented performance of the whole manufacturing process. The project involved the creation of a VSM application tool which improves the analysis of the mould making critical processes, the automatic calculation of the main process indicators, and the generation of the value stream map of each process under analysis. Several mould makers were involved to support the design of the tool and to evaluate its potential in guiding purposeful improvement actions. The results presented are quite satisfactory. Even if the process is not a repetitive one, its time-oriented performance analysis reproduces repetitive time waste patterns in each company. Moreover, the visual nature of VSM techniques facilitates the process understanding and leads the improvement teams in focusing towards the global improvement.

## 1 Introduction

Mould industry has faced innumerous challenges at a global completion scale [1]. Moulds are getting technologically more complex and clients' demands on mould-makers are getting tougher as regards the payments schemes, life cycle guarantees

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and manufacturing lead time [2]. Especially regarding the mould manufacturing lead time a 30–50 % reduction was already accommodated, but the pressure is still alive [3].

In a one-of-a-kind production context, low production cost asks for a production system working close to its full capacity. But shorter lead times are easier to achieve if a certain level of resources idle time is available to manage the work in progress and to facilitate the operations scheduling for a fast throughput. Also the on-going lead time reduction is more difficult as far as moulds requirements, as regards functionalities, target performance and guarantee conditions, are harder to achieve. For the mould-maker this means that more complex moulds have to be designed, engineered, built and tested in a shorter time [4].

The one-of-a-kind nature of the mould manufacturing process should not inhibit the ability to represent the process and take advantage of value stream mapping (VSM) techniques, typical of repetitive industry. Even if it is necessary to make adjustments to the typical VSM approaches, such representation can contribute to structure and get the most out of continuous improvement practices focused on lead time reduction.

This paper is about the application of VSM techniques to the mould industry. The objective is to make possible the comprehensive understanding of the mould process chain, creating a common basis to drive the improvement team in its continuous effort to reduce the mould manufacturing lead time. Instead of relying on the local analysis and insular improvement, a VSM representation allows the global and simple view of the all process. Moreover, it facilitates the identification and quantification of potential waste (lead time waste) and creates the conditions to make sound decisions on improvement actions, based on their impacts on the overall process.

## 2 Mould Industry

The design and manufacturing of moulds are demanding engineering processes involving modern and capital intensive production technology. In its origins the competitiveness of national engineering and tooling industry was essentially supported by the low cost of manpower. However, it progressively evolved during the 90 s for a competitive industry based in advanced hard and soft technologies and high qualified human resources. The typical mould design and manufacturing cycle starts with a preliminary engineering design solution, which is validated and approved by the client, and ends up with the mould delivery after the demonstration of its ability to produce conformed moulded parts. In between, and just after the first outcomes of the detailed design, the mould construction process is carried out using basically a combination of numerically controlled machining processes, essentially milling, drilling, grinding and electro-discharge machining. A significant amount of time is spent to obtain the suitable moulding surfaces (frequently surface engineering technology is required), before arriving to the final adjustment and assembly of all components and to the trial-out of the mould functionality and performance in shaping the required parts.

A mould is composed by different sub-systems and hundreds of different components, each with a specific flow of manufacturing steps. Therefore, at the shop-floor each mould “explodes” in several manufacturing processes that concurrently converge to the final assembly. The need to reduce the total lead time has indeed push for parallel work, which made the companies often to start the rough machining after the approval of the preliminary design and before the detailed design is over. The approach of simultaneously carry out the design and the manufacturing operations can save to a couple of weeks in the total lead time, but sometimes it only pushes the waiting time forward if the detail design can’t provide in time the job-floor with the necessary information.

In fact, in a tough competitive context, the sustainability of any mould making company depends not only on a strong technological basis, but also on the ability to efficiently take advantage of the available production resources and, based on technological knowledge, of the continuous improvement of this efficiency of exploitation [5]. Since the mould making companies can have between 10 and 30 simultaneous moulds in production, each with thousands of components with their own process sequence, one can understand that the inherent process of generating value is indeed complex and deeply dynamic. The bottlenecks of the production vary in time, inducing different planning issues. Moreover, due to the high variability of the manufacturing processes, the inefficiencies and waste in the value stream are difficult to evaluate and their causes difficult to root.

## 3 Lean Manufacturing and Value Stream Mapping

Lean manufacturing relies on lean thinking five basic principles consisting on defining the value, defining the value stream, assuring the flow, let the client pull and chasing the perfection [6, 7]. These basic principles can provide important guidelines to improve the capability to create more value with the existent technological basis. In accordance to lean manufacturing definition, the approach seems to provide a framework to more efficiently fulfill the client’s expectations. Through the systematic elimination of waste all along the manufacturing process, lean manufacturing supports the reduction of lead time, increases the overall quality and efficiency and sustains a more competitive and market-responsive company. However, the omission of specific methods and guide-lines towards lean implementation in mould making companies has difficult its adoption. In fact, the opinion of general mould-makers about lean manufacturing points to a dominant skepticism. The skepticism is reinforced as far as they note that the proposed operational methodologies (Kanban control systems, cellular manufacturing flow, statistical process control, etc.) are designed for repetitive production systems and do not seem to have correspondence with the mould-making environment. More than that, the sporadic introduction of those operational methodologies in mould making has resulted in a limited success [8].

In spite of that, lean manufacturing basic principles rely strongly on the total manufacturing time reduction (and cost reduction) through waste elimination (waiting time, non-quality, rework, over-processing, resources under-utilization …). So, as far as time and cost are important competitive factors in mould making sector, one can believe that lean manufacturing dissemination within mould makers is essentially a question of adapting the lean support methodologies and tools to the particular one-of-a-kind engineering order context.

Lean manufacturing is supported by a set of techniques materialized as the antidote to waste all along the value stream [7]. One of these tools is value stream mapping (VSM). It allows a simple and intuitive visual representation of processes, from the client request till the final delivery of products. The objectives of any VSM can be listed:

- Make the current process visible (visibility improves understanding and promotes communication).
- Facilitate the identification of problems and opportunities for improvement in the current process.
- Establish a reference for evaluating impacts of improvement actions.
- Establish a working basis for an improved state of the process (the vision of the future process as it should be).

In fact, the VSM will not solve process problems, but facilitates their identification and evaluation, and creates a more robust basis to support informed decision making on what improvement actions will provide a greater impact on the overall process. In particular, it avoids the local views of the process, where each stakeholder strives in the optimization of their individual activity, forgetting the potential impacts on the global value stream [9].

Still it should be mentioned that a major novelty of VSM in relation to other more conventional mapping techniques is that the VSM considers and treats all activities: the ones that are necessary and add value to the process, and the ones, either necessary or not, that do not strictly contribute to generate value in the perspective of the final client. In reality both consume resources and induce costs and so both need to be controlled. When representing the process, any omission of non-added value activities just results into unknown hidden wastes, inhibiting action for their elimination/reduction [10].

Traditionally, the lead time improvement in mould making sector has been focused on the reduction of time needed for each manufacture step (rough milling, electro discharge machining, drilling, finish milling, etc.). Whenever one talks about improvement or "optimization" of the mould production process what is usually meant is the improvement or "optimization" of a step of the whole process, normally associated to a single technology. The underlying principle relies in the idea that if it is possible to perform a step quicker, then the total lead time for mould manufacturing will be shorter. However, this conjecture might be somehow tricky. To perform quicker one step in the process might not result in an effective improvement of the overall process, especially if that step is not a bottleneck or if the work in progress will then be waiting to go through the following step.

It is often considered that the mapping of the value stream is geared to large organizations, following a well-defined methodology (Fig. 1), and only applies to repetitive manufacturing. However, even if it is necessary to make adjustments and simplifications of typical techniques, such representation will allow the global visualization of the process and the identification and quantification of potential waste, creating the conditions to generate a common basis for the improvement team to discuss, design and plan their future actions. The global visualization will drive the team, shifting their traditional focus on local improvement, often with damaging effects, for an approach engaged in intelligent improvement measures judged based on their impact on the global process performance. More than that, the mapping can begin by evaluating the material and information flow as regards their time oriented performance, but can evolve to consider also the generation of materials waste and energy consumption, in an eco-efficiency perspective.

One should note that it is not intended to create a standard map of the manufacturing process of moulds, even because, due to the uniqueness of each mould, this standard map does not exist. It is rather intended to provide a tailored and simple technique to map punctually (periodically and systematically) the flow of

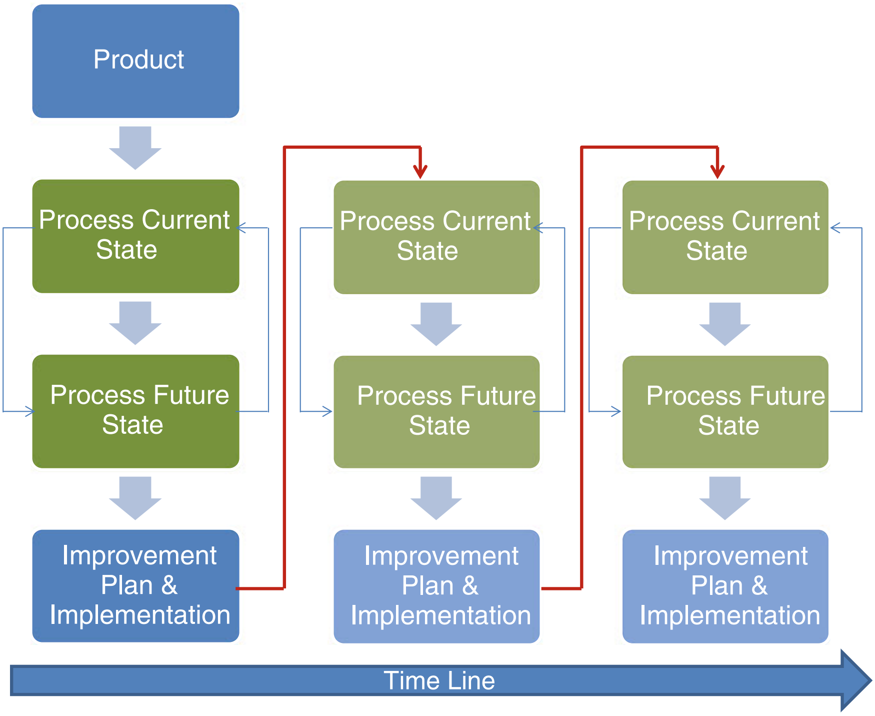


**Fig. 1** Methodology of VSM [10]

the main processes of a mould, in a visual format with both qualitative and quantitative information. This representation can then be used as a working and common visual basis by a multidisciplinary improvement team to facilitate the identification of drawbacks in the current process and the discussion of how the process should/could be. Moreover, it provides a supporting framework for the team to derive purpose oriented measures guided towards the process global improvement.

## 4 Methodology

The VSM was applied to a set of mould making companies along 4 different phases. The first one was a preparatory phase, concentrated in the companies' familiarization with the mapping and VSM technique, its scope, objectives, and procedures. It was decided not to address the process of a whole mould, but to deal with the mould components responsible for the critical path of the process, usually the mould core components. However, insofar as the choice and the process of a single mould might result in a map not representative of the typical performance, it was suggested to analyze 3 different moulds recently produced. If only one mould is studied, the analysis and discussion of value stream map will induce the stakeholders to justify inefficiencies and wastes with every kind of untypical and uncontrollable problems. If the same waste patterns is present in the processes of the 3 moulds this easy and tricky way of hide waste is overcome. In the second phase the data was collected and treated and the VSMs were created. Afterwards, the VSMs and the associated process indicators were discussed with the process stakeholders in half a day workshops leaded by the authors. The objective was to test the suitability of the approach and discuss and identify ensuing adjustments needs. The major result achieved with the second phase was the validation of the interest of the analysis and the fully motivation of the teams in all companies. The third phase of the project was then launched, intending to follow the process in real time. There, each company took the leading role following in real time the process of 3 moulds. To simplify the data collection and its analysis, a guide with a set of data collecting forms was provided, included in a VSM tool to support the automatic calculation of relevant indicators and the automatic generation of the value stream map of the process under analysis, ready for print in A2 format (or larger). On this "VSM application tool" the inputs are organized based on hierarchical layers, from more general information to the sequence of the process and the detail of each step in the process. Figure 2 gives an overview of this organization. The tool was developed in Excel, allowing the manual interaction if special instances are necessary to accommodate.

Besides collecting quantitative data (Fig. 2), the significant events along the process were also recorded as notes in the VSM tool. Considering the long duration of the typical mould-making processes (10–20 weeks), these registers are needed to help the companies in preparing the final internal workshops with all the

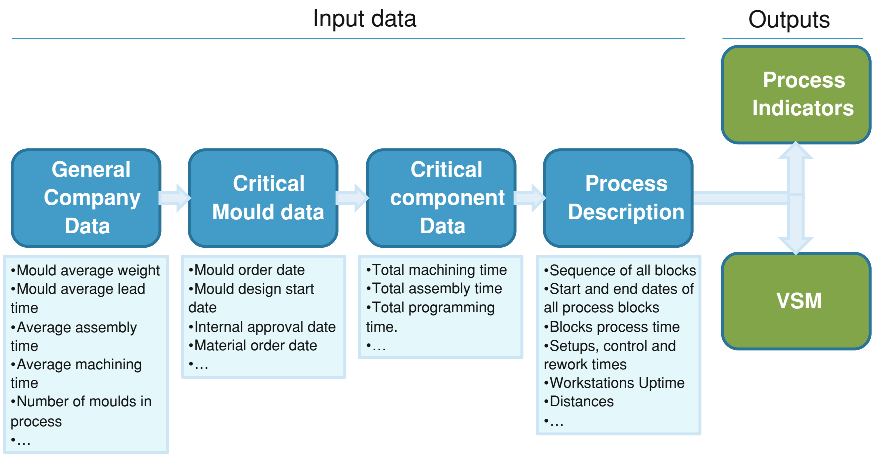


**Fig. 2** Inputs/outputs schema of the VSM application tool

stakeholders to discuss the performance, inefficiencies causes and, above all, to create the vision of the future process and identify the set of actions to turn this vision into reality.

In the following paragraphs we make use of the data collected in one company to represent the potential of the tool. Then we present some results of all companies as a benchmarking study. Because of confidentially issues, the companies are not revealed.

## 5 Results of the VSM Application

Figure 3 represents some relevant data collected in one company. After feeding the inputs, the VSM tool is able to provide the process indicators (Table 1) with the quantitative information about the whole process, and the VSM representation (Fig. 4) ready for printing and further analysis.

The analyzed mould was completed in more time than the average lead time of past recent moulds. As the mould complexity/size seems to be smaller than the average (mould machining and assembly hours are lesser than the average), this is something that justifies an analysis. One should note that the sum of the preliminary design lead time and the production lead time does not represent the total lead time of the mould. This happens because after the preliminary design is accepted by the client, the materials procurement is launched and, in parallel, the detailed design is started. The detailed design and CNC programming steps of the process develop in parallel with the mould material flow in the shop-floor. So the mould total lead time is indeed directly conditioned by the preliminary design, material procurement, and production lead time. However, if not synchronized,

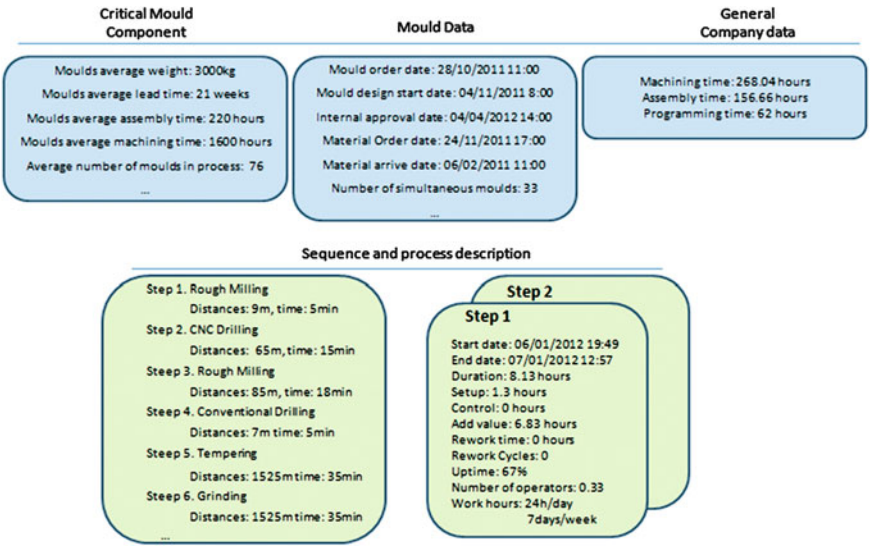


**Fig. 3** Some input data of the example case

delays in providing outputs from the mould design embodiment and CNC programming process might be responsible for the increase of the production lead time.

In the present process, the material acquisition took 1 day, but the material order only happened 5 days after the client preliminary design approval (ball 1 in Fig. 4). After that, materials arrived in 1.7 weeks (Table 1). This is an aspect that clearly points to an improvement. In in fact, the material procurement can start during the preliminary design, so that it can be launched as soon as the client approves the preliminary design. A significant reduction in the total lead time (1 week) would be achieved in this case. Another important aspect to highlight is the waiting time for the production process to start. Once the materials arrived to the shop floor, they stayed there for 1 month before starting the first production step (ball 2 in Fig. 4). It was noted that the average uptime of workstation involved in this first step was valued as 67 %, meaning that a shortage of workstation availability does not seem to be responsible for the delay. The elimination of this waiting time would result either in the reduction of the lead time, if production could start earlier, or in an economic benefit, if materials are ordered later just to make them available as soon as they are needed in the shop-floor. The causes for other significant waiting times between processes (ball 3 in Fig. 5), should also be particularly addressed.

Apart from the waiting times between processes, the utilization ratio of the whole process is a major waste indicator. Its value is 68.3 % (Table 1). It seems like the mould core component is waiting for something to happen in some steps of the process (inside some workstations). Some causes for that were pointed out: operators not available or few operators running a set of equipment, CNC

**Table 1** - Output indicators by the VSM application tool

| | | | |
|---|---|---|---|
| *Lead time* | | *Specific process steps* | |
| Recent past moulds average lead time (w) | 21.0 | Process time of all process steps (h) | 979.4 |
| Total lead time (mould in analysis) (w) (LT) | 22.7 | Add value time of all process steps (h) | 913.5 |
| Preliminary design lead time(mould in analysis) (w) | 2.9 | Utilization time in production process steps (h) (UT) | 693.1 |
| Production lead time (w) (LTprod) | 17.2 | Process time in production process steps (h) (TP) | 521.4 |
| Lead time for material deliver (w) | 1.7 | Add value time in production process steps (h) (Tva) | 484.3 |
| *Waiting times* | | *Time ratios* | |
| Waiting time inside all process steps (d) | 23.1 | Production lead time ratio (LTprod/LT) | 77.3 % |
| Waiting time inside production process steps (d) | 7.2 | Utilization ratio in production process steps (TP/UT) | 68.3 % |
| Waiting time inside critical process steps (d) | 7.2 | Add value time ratio (Tva/TP) | 93.3 % |
| Waiting time between all process steps (d) | 190.0 | Setup time ratio (Tsetup/TP) | 3.6 % |
| Waiting time between production process steps (d) | 70.9 | Control time ratio (Tcontrol/TP) | 0.3 % |
| Waiting time between critical process steps (d) | 83.4 | Rework ratio (Trework/TP) | 0.4 % |
| Total inefficiency time (d) | 106.5 | Waiting time between critical processes ratio (Twbp/LT) | 52.4 % |
| Total waiting time (d) | 203.1 | Waiting time inside critical processes ratio (Twip/LT) | 4.5 % |
| Total critical waiting time (d) | 90.6 | % Quality at first time | 27.2 % |

programmes not ready, missing tools, equipment failure, machines loaded with a batch of components meaning that one is waiting for the others,…

The total waiting times between and within process steps are important indicators to make the stakeholders perceive the process performance. In the example case, from the 159 days of lead time, 90.6 days were waiting time in the process critical path (preliminary design, materials procurement and shop-floor production steps). Globally, the core component spent 52.4 % (Twbp/LT ratio in Table 1) and 4.5 % (Twip/LT ratio in Table 1) of the production lead time waiting for "something to happen" between and inside the process steps, respectively, meaning that just in 43.1 % of the total time machines were effectively working on it. However, this includes yet the setups, reworks and controls, being the value added time 93.3 % of the process time (Tva/TP ratio in Table 1). So, only in 40.2 % of the production lead time value is effectively added to the mould core component. As far as this is the mould critical component, one can imagine how lower this time can be for the non-critical ones.

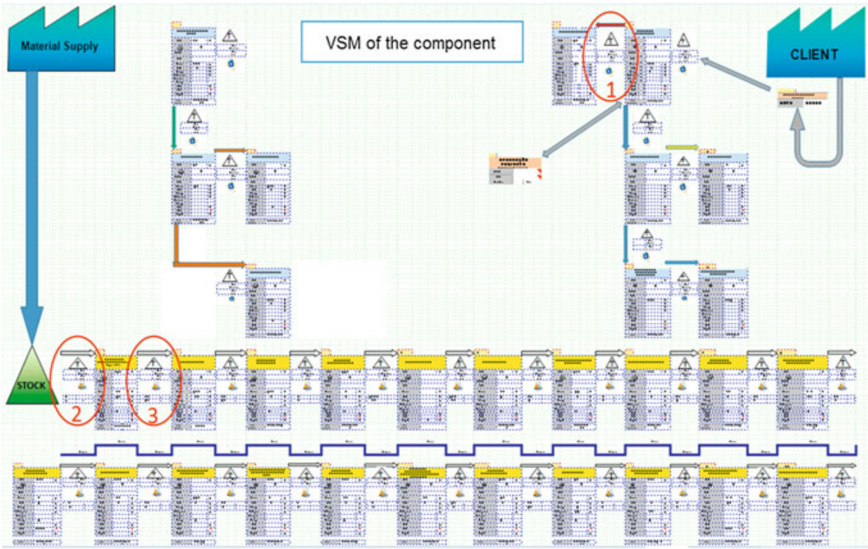


**Fig. 4** Overview of the VSM automatically generated with pictorial and quantitative information (to print in A1 paper format)

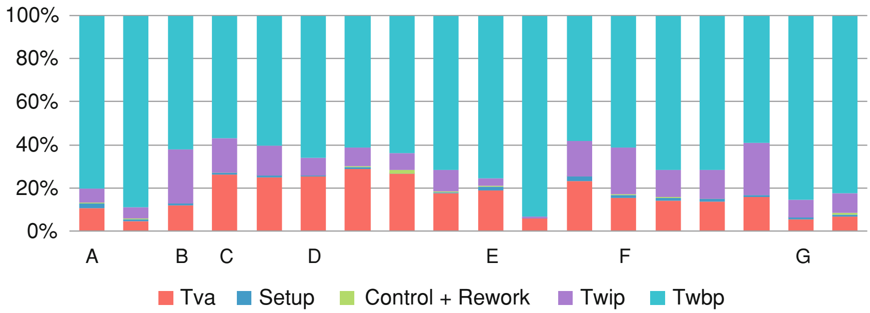


**Fig. 5** Lead time distribution of the moulds core components. Study developed in 7 mould making companies (A–G)

## 6 Study of Benchmarking

The waiting time between process steps of the mould critical component emerged as a critical issue that significantly increases the total lead time. As shown in Fig. 5, depending on the company, the waiting time between (Twbp) and within (Twip) process steps can go from near 70 % to more than 90 % of the total lead time. Reasons for that rely on lacks of synchronism between the mould core components and the remaining (not so critical) mould components; a high workload in the whole system and uncontrolled bottlenecks; and poor look ahead

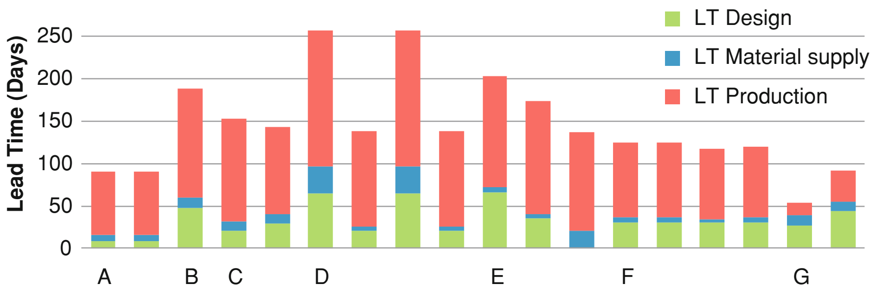


**Fig. 6** Lead times of design versus production

planning capabilities. In fact from the workshops in the companies, missing information, the work queues, urgent last minute jobs, and even long delays in initially not critical components of the same mould appeared as the most frequent reasons for the inefficient stop and go process of the mould most critical component.

One should note that the shop-floor production steps take most part of the total lead time (Fig. 6). However, in some cases the design is also very long, going together, in an intermittent way, with the production. The material supply lead time is quite similar in the studied cases, and quite constant among the different moulds in the same companies.

It's clear that the shop-floor production time is the most important part of all the mould process. Because of that, production starts just after the materials arrival, even if the design is not finished yet. However, all companies keep spending a lot of time waiting inside and between the production steps. That time can go from 30 to 90 % of the production lead time (Fig. 7). Reasons for this high percentage of waiting rely on lack of planning, machine waiting for available operators, equipment failure, the need to process rush jobs (frequently from rework needs in other almost ended moulds). Frequently, the waiting time is concentrated in initial steps, meaning that low control is provided when the mould is still far from its delivery date. So different causes deserve a deeper analysis but the understanding

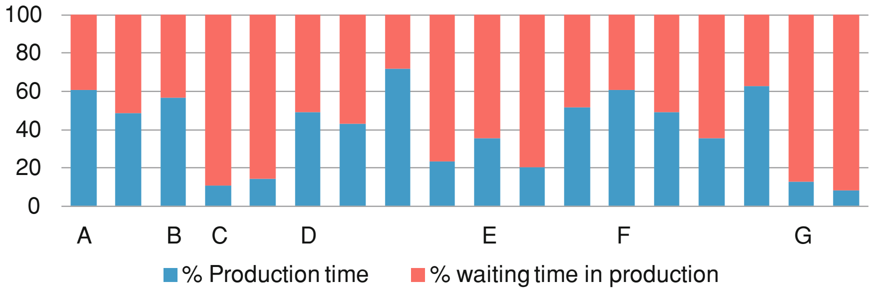


**Fig. 7** Production lead time distribution

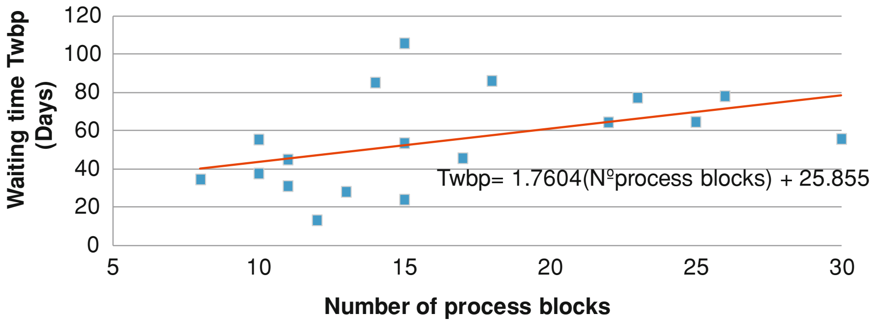


**Fig. 8** Number of process steps versus waiting time analysis

of the whole process pushes the involved stakeholders to design the appropriated actions to improve the global performance.

Another relevant result is that the waiting time tends to grow with the number of process steps (Fig. 8). Apart from some exceptions the tendency is very perceptible, process with a small number of steps use to wait less than "more broken" processes with twenty or thirty steps.

## 7 Conclusions

Mould makers keep relying must more on the technology performance than on the global improvement of the manufacturing management organization and procedures. Aiming to contribute to change this attitude, this paper intended to understand the potential of VSM techniques to facilitate, organize and take a better advantage of improvement practices in the one-of-a-kind processes of mould making industry. With the use of the VSM, it's possible to punctually and periodically represent in a simple but effective way the manufacturing process of critical components of a set of few moulds. The representation does not intend to define a standard process, even because that standard process does not exist. In industrial terms its benefits were recognized as regards to making the process visible, recognize the problems and opportunities, establish relative references to evaluate the effects of potential improvement actions. However, due to the high variety nature of mould making processes, one cannot assume that the performance of one process can be stated as an absolute baseline to really evaluate the effect of any implemented improvement actions. This is indeed a major drawback when compared to VSM application in repetitive industry.

Finally, one should say that to create a value stream map of the process does not by itself solve or point out solutions to the process improvement, but it is an efficient and effective way to identify inefficiencies and diagnose important problems of the process. Real time collected quantitative and qualitative data and the visual representation of the process that a critical component went through provides a solid ground to establish a sound analysis of what needs to be improved, aligning operators, designers, and supervisors in the vision for a better future process.

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