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Optimization of Melting Process In Casting Industry Using GA and Reduction of Lead Time Using VSM

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Abstract

Value stream mapping is a kind of technique that helps to understand and streamline production processes. With a case study of a metal casting factory, the production process path is visualized by mapping the current state value stream. After tracking the production process of a order, problems affecting the lead time are identified and its causes analyzed. A future state value stream map is created and an optimization scheme is suggested, with which the production cycle of the order is expected to be shortened from 520 minutes to 287 minutes, representing a 44.8% reduction. Value stream mapping is proved as a useful technique to shorten delivery time and improve productivity.

Keywords: lead time, value stream mapping, production process, melting, and furnace optimization

Introduction

The increasingly fierce market competition has propelled product diversification and higher expectation of delivery from customers. The production sector is more and more characterized by multi-type, small batch and accelerated upgrading of products, which requires enterprises to react quickly to the fast-changing market and vigorously improve its capability of product development and technological innovation, as well as its production management [1]. Efficient production process coupled with reasonable quality control has become essence for manufacturing enterprises to guarantee on-time delivery and meet customers' satisfaction. Optimizing production process has become the key point which enterprises are desperately striving for. One useful way of improving processes successfully is to use a lean manufacturing technique called Value Stream Mapping [2].

Value Stream Mapping

A Value Stream is defined as all of the actions (both value added and non-value added) required to complete a product or service from beginning to end. The value stream often involves many processes and crosses numerous functions. It is vital to have all of the operators, users, and customers of the value stream involved in the improvement activity [3]. Value Stream Mapping is a method of visually mapping a product's production path. It can serve as a starting point to help management, engineers, production associates, schedulers, suppliers, and customers recognize waste and identify its causes [4]. The Value Stream Mapping method visually maps the flow of materials and information from the time products come in the back door as raw material, through all manufacturing process steps, and off the loading dock as finished products. Benefits of a value stream map include: (I) visualize material and associated information flow; (II) identify wasted efforts and practices; (III) improve all your processes from a systems perspective; (IV) prioritize activities to reach your future state goal [5]. A typical mapping process usually consists of the following steps:

1. Determining the value stream:
   The mapping effort starts with determining the value stream to be improved and involves extensive scoping efforts to identify the practical limits of the mapping activity.
2. Creating current state value stream map: the current state map that shows how things really work. This is the "as-is" condition with all of the problems, inefficiencies, and flaws displayed. It is crucial that the current state map be an honest depiction of what is really happening.
3. Creating future state value stream map: the future state value stream map improves the flow and reduces non-value added activities in the value stream. This future state must meet the customer requirements and includes the necessary process improvements to achieve the value stream vision.
4. Making improvement plan: the final step is to develop a detailed improvement plan that describes the necessary improvements to realize the future state. The mapping effort is simply a tool; implementing the plan is the key to success.

The Current State Value Stream Map

K.S.G casting and products is mainly specialized in Gray iron casting production. Currently it provides as many types of products like motor casing, automobile parts, printer rollers and etc., which are produced in multi-type and small batches. In order to analyze its production process, a 500kg batch was chosen to track, and collect data from its whole production process.

Production flow chart

The factory's production flow chart is as shown in Fig l.

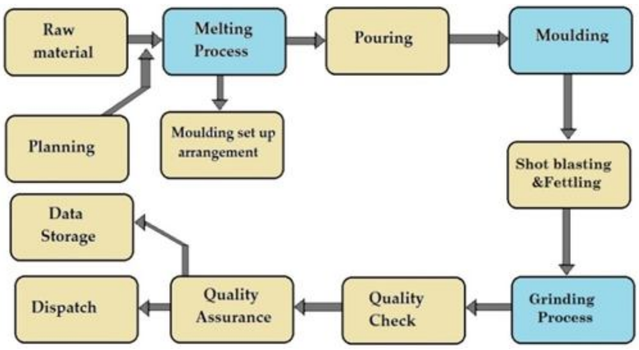


Figure 1: Production Flow Chat

The production plan

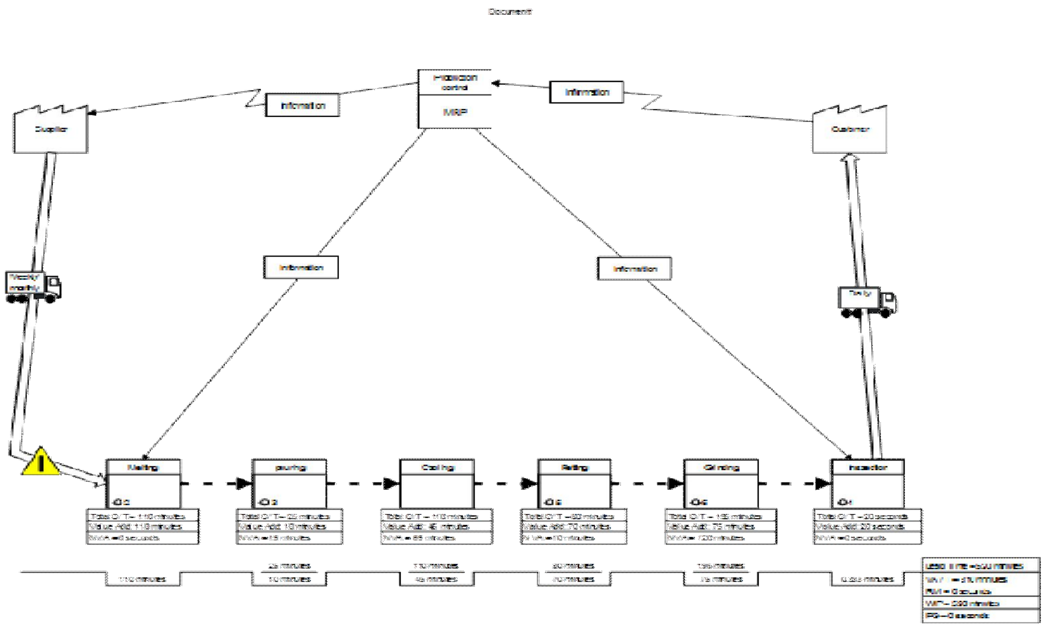
After receiving the order from customer for the production of motor casing, the production process was started and time study has been taken for each process are shown in table 1.

Table 1: Acutual time taken for production

Process	Cycle time(Mins)	Waiting Time (Mins)
Melting	110	0
Pouring	10	0
Cooling	45	15
Knockout	25	30
Shot Blasting	30	15
Grinding	75	10
Re-Short blasting	15	20
Inspection	20	120
Total Time	330	190

Current state value stream map

After tracking a production cycle the current state map is created and displayed in Fig 2.



Problem analysis

1) Problems affecting the production lead time are found in tracking the implementation of this order:
    - The main problem found in the production line is most of the process having waiting time even though the next consecutive process is still idle.
    - This caused a larger production lead time with waiting times between each stage.
    - The reason for this problem is analyzed and found that the root cause is melting time of the induction furnace.
    - The entire production depends on melting process so all other process has to wait for next batch of molten metal even though they completes the current cycle. This makes a process to work in a slow phase which causes large idle and waiting time.
2) Unreasonable movement of work-in-process: the movement of work-in-process along the processing line is randomly decided by the operator, usually following the principle of "first come, first processed". However, this is frequently disturbed by urgent processing.

The Future State Value Stream Map

Once the Current State Value Stream Map is created, it becomes the baseline for improvement and for the creation of the Future State Value Stream Map.

Creating future state

Based on the above analysis of problems affecting the production lead time and productivity, a future state value stream map is created as in Fig.3.

With the future state, production efficiency is significantly improved with the melting time reduced from 110 minutes to 67 minutes, representing a 39% reduction of production time.

Comparison of production performance

A comparison of production performances before and after the optimization is made as shown in Table 3.

Table 2: Comparison of performance

Item	**Before optimization**	**After optimization**	**Results(%)**
Melting time	110 mins	67 mins	36.8% Down
Lead time	520 mins	287 mins	44.8% Down
Production capacity	353.5 Kg	433.5 Kg	22.6% Up

Comparison of delivery time

From Fig.3, we can see that the overall waiting time is greatly reduced, with the production cycle being shortened from 520 minutes to 287 minutes, representing a 44.8% reduction. This helps to guarantee the productivity and on-time delivery. In the event of accidental events like melt leakage and furnace lining problem the theoretical production time may be affected. However, in the long run the production lead time will gradually become stable.

Optimization Scheme

The above analysis has shown that inefficient production process is the main cause affecting on-time delivery. Based on the future state value stream map, improvements can be made in the following areas to improve productivity and shorten delivery time.

Melting

From above analysis it is clear that the production cannot be speeded up without optimizing melting time. If the melting time is reduced the entire production process can be speeded up and unwanted waiting time can be reduced.

Response Surface Method Design

Response Surface Method Design (RSM) has developed a methodology for the application of designed experiments, including a practitioner handbook. This methodology has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. Contribution have also made the practitioner's work simpler by advocating the use of fewer experimental designs and providing a clear understanding of the variation in nature and the economic consequences of quality engineering in the world of manufacturing. RSM introduces his approach in using experimental design for,

1. Designing products and processes so as to be robust to environmental conditions.
2. Designing and developing products and processes so as to be robust to component variation.
3. Minimizing variation around a target value.

The philosophy of RSM is broadly applicable optimization of process parameters. It considers two stages in process development:

- System design
- Parameter design

System design is the process of applying scientific and engineering knowledge to produce a basic functional prototype design. Parameter design is an investigation conducted to identify the settings of design parameters that optimize the performance characteristics and reduce the sensitivity of engineering design to sources of variation (noise). Parameter design requires some form of experimentation for the evaluation of the effect of noise factors on the performance characteristics of the product defined by a given set of values for the design parameters. This experimentation aims to select the optimum levels for the controllable design parameters such that the system is functional, exhibits a high level of performance under a wide range of conditions and is robust to noise factors. Tolerance design is the process of determining tolerances around the nominal settings identified in the parameter design process. Tolerance design is required if robust design cannot produce the required performance without costly special components or high process accuracy. It involves the tightening of tolerances on parameters where their variability could have a large negative effect on the final system. Typically, tightening tolerances leads to higher cost. RSM recommends that statistical experiment design methods are employed to assist in quality improvement, particularly during parameter and tolerance design. Considerable quality advantages can be obtained by RSM technique implementation in the casting process. Casting is one of the most widely used manufacturing processes for producing parts that cannot be obtained through any other process. To date, a quite significant amount of research and development work has been done in order to optimize the casting process and improve the quality of the castings. It is also a well known fact that hardly nothing can happen in a Casting foundry without affecting the casting quality. The quality of a Casting is the result of a great number of parameters. Some of these parameters affecting quality are controllable, while others are noise factors. The most common method, which is, at the same time, the most easily applicable in the foundries environment, is the trial and error method. However, this demands extensive experimental work and causes losses in time and money for the gradual replacement or even substantial improvement of most Casting foundries. The RSM technique appears to be an ideal tool for continuous and rapid quality product design, and it becomes easier and more productive for today’s highly competitive international markets.

The focus of this paper is on the robustness of the Casting process. The basic steps for achieving the above target are summarized below

1. Lead time is selected as the most representative quality characteristics in the Casting process, as it is related to productivity. The target of the Casting process is to achieve high production.
2. To select the most significant parameters that causes variation of the productivity.
3. Make the Casting process under the experimental conditions dictated by the chosen orthogonal array (OA) and parameter levels. Based on the experimental conditions, collect the data.
4. Mathematical model is developed by using design of experiments. Response graphs are plotted to determine the preferred levels for each parameter.
5. Make decisions regarding optimum settings of the control parameters and predict the results of each of the parameters at their new optimum levels by using genetic algorithm.
6. Verify the optimum settings result in the predicted reduction in the casting lead time.

Process parameters of Castings

The most significant parameters are amount of metal (Kg), Input power to furnace (KW).The selected Casting process parameters, along with their ranges, are given in Table 3. and the output response is melting time.

Table 3: Process parameters with their ranges

Sno	Parameters Taken	Units	Range
1.	Amount of metal	(Kg)	460 - 500
2.	Input power	(KW)	260 - 300

The number of levels for each control parameter defines the experimental region. For each control factor, five levels are selected, out of which, one level is usually the starting level. The levels should be chosen sufficiently far apart to cover a wide experimental region because sensitivity to noise factors does not usually change with small changes in control factor settings. Also, by choosing a wide experimental region, we can identify good regions, as well as bad regions, for control factors.

Therefore, each parameter was analyzed at different levels based on the behavior of the process parameters. The process parameters, along with their ranges and values at three levels, are given in Table 3. From the selected parameters, the significant interaction between them is to be considered. As per the study conducted to know the parameter interactions, it is inferred that there are significant interactions of input power with melting time. Therefore, based on the input power, the melting time varies, and the amount of metal also affects the melting time.

Therefore, the L13 orthogonal array is selected; the array specifies 13 experimental runs. The various factors and their interactions are assigned in each column of the L13 orthogonal array shown in Table 4.

Table 4: Orthogonal array

Trail No	Melting Temp	Cooling Time
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-2	0
6	2	0
7	0	-2
8	0	2
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0

Experiments and analysis

Conducting the experiments

Once the parameters and parameter interactions are assigned to a particular column of the selected orthogonal array, the factors at different levels are assigned for each trial. The assigned experimental array is shown in Table 5. The casting of Grey iron was made against the trial conditions given in Table 5.

Table 5: Experimental Array

Amount of metal	Input power	Sample Code
470	270	TS1
490	270	TS2
470	290	TS3
490	290	TS4
460	280	TS5
500	280	TS6
480	260	TS7
480	300	TS8
480	280	TS9
480	280	TS10
480	280	TS11
480	280	TS12
480	280	TS13

After conducting time study, test results are shown in table 6.

Table 6: Time study results for Melting time

Sl. No	Sample code	Melting Time(Mins)
1	TS1	73
2	TS2	76
3	TS3	67
4	TS4	71
5	TS5	68
6	TS6	74
7	TS7	78
8	TS8	66
9	TS9	68
10	TS10	71
11	TS11	70
12	TS12	69
13	TS13	72

Direct and interaction effect of variables

Thus, this work experimentally investigates the effects of input power, amount of metal.

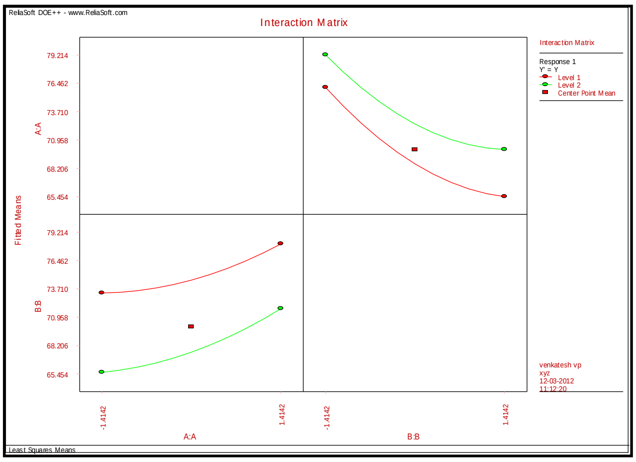


Figure 2: Interaction effect for melting time

This graph is used to analyze between combinations of parameters input power, amount of metal with respect to melting time.

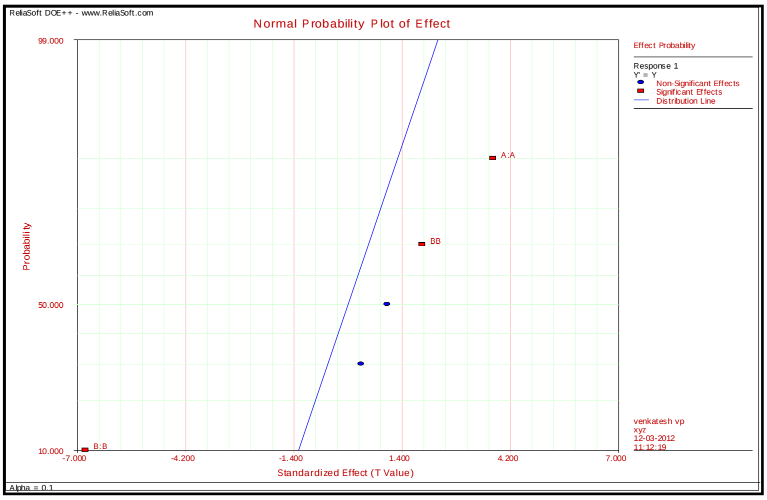


Figure 3: Normal probability plot Melting time

The normal probability plot shows that actual value which was experimentally obtained and optimum value for melting time for grey cast iron. It is a theoretical calculation in order to get optimum in straight line as shown in figure 2 and 3 for these output responses.

Mathematical Model

By the method of design of experiments mathematical model is developed for melting time. The mathematical relationship, obtained for analyzing the influences of the various dominant process parameters is given by:

For Melting Time

f(mt)=70+1.9357*A-3.4963*B+0.2500*A*B+ 0.5625*A2+ 1.0625*B2

The developed mathematical model can be used to analyze the effects of process parameters.

Optimization Using Genetic Algorithm

In this section the mathematical relationship between input power, amount of metal and the parameter set S = {A, I} is described, from which an explicit expression for fitness function can be constructed. The constraints based on machine limits are stated. Constrained optimization is used find out common optimized parameter for melting time. Melting time is chosen as objective function. By generation n number of offspring's, the best fitness value for melting time is obtained. Mean while optimum input parameters are obtained, by substituting these values in mathematical model f(mt),best fitness value for melting time is obtained.

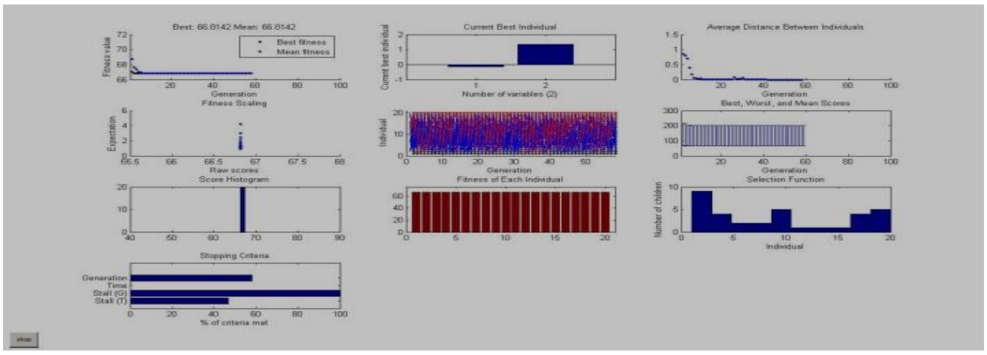


Figure 4: Output from Genetic Algorithm

The optimized input power, amount of metal and the optimum output melting time were shown in the table7. Based on optimum parameter, 5 consecutive time studies are conducted and the results are shown in table 8

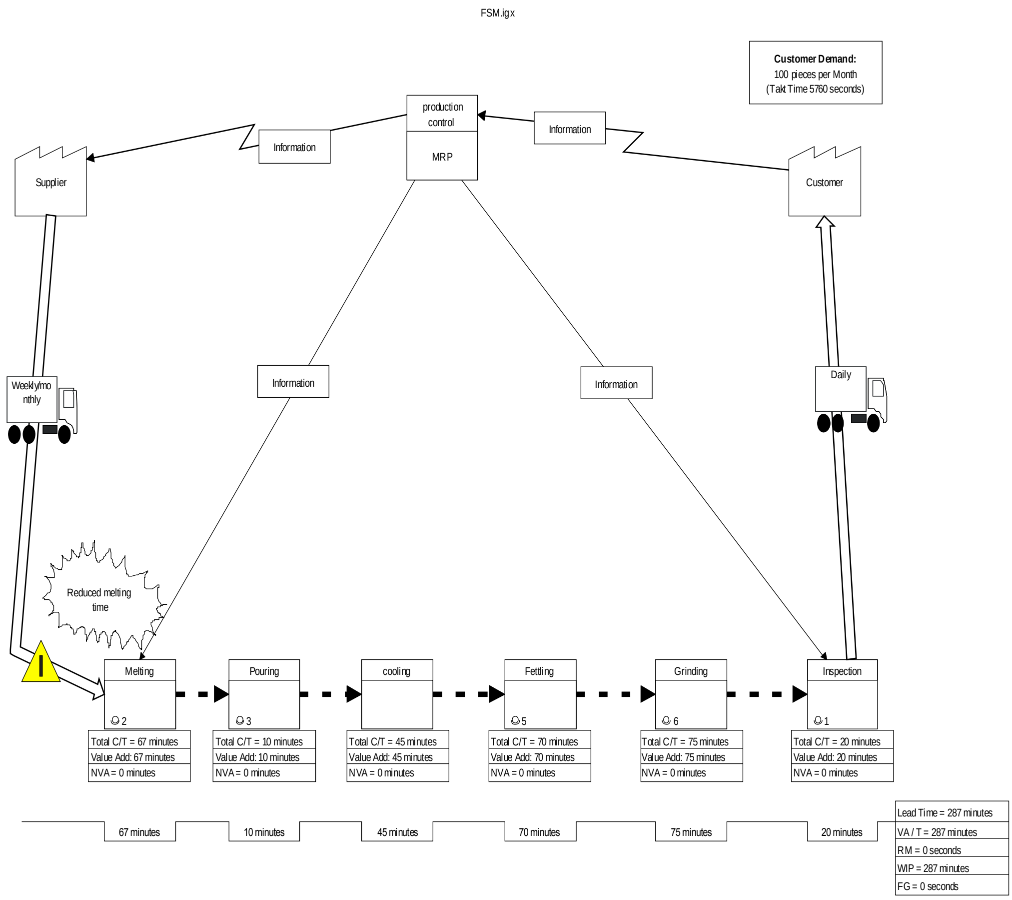
Table 7: Optimized input parameter and output response

Optimized Input Parameter		**Optimized Output**
Amount of metal (Kg)	**Input Power (KW)**	**Melting time (mins)**
293	478	67

Table 8: Comparison of results, existing samples Vs Optimized sample

Sl.no	Before optimization	After Optimization
1	84	68
2	83	67
3	84	68
4	85	68
5	86	67

Therefore, the selected parameter as well as their appropriate levels are significant enough to obtain the desired result



Conclusion

Value stream mapping, primary a communication tool, but also is used as a strategic planning tool, is a kind of technique that helps to understand and streamline production processes. The goal of it is to identify, demonstrate and decrease activities that add no value to the final product. By creating current state value stream map, the non-value added activities in the production process are visualized and identified. A future state value stream map is created with the waste activities eliminated. With the future state value stream map, the production cycle of casting is significantly shortened from 520 minutes to 287 minutes, representing a 44.8% reduction. This reduction in melting time makes all other process to operate in faster phase with no idle and waiting time which leads more production. Value stream mapping is proved as a useful technique to shorten delivery time and improve productivity

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