Production optimization oriented to value-added: from conceptual to a simulation case study

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Abstract: Management in companies today faces a true paradigm shift, characterized by a growing optimization of global value-added structures. To pursue this goal, lean philosophy is used as it allows applying sustainable improvements to the processes of a company, focusing on the value of the process and eliminating if possible or minimizing all those activities or tasks that when executed are not beneficial, that is, they do not add value. The research pursues to design and apply a systematic methodology to improve efficiency of a manufacturing plant increasing the value-added towards the end-customer. With the development of this work, it is described how it is possible to analyze, assess and implement improvement tools in manufacturing systems with a long tradition and that to date have not needed to improve their processes significantly due to market dynamics such as manufacturing of detonators. Moreover, a work methodology for optimizing manufacturing plants based on the proposed tools can be applied to other sectors.

Keywords: Production Optimization, Lean Manufacturing, Theory of Constraints, Mining, Case Study.

1. Introduction
Management in companies today faces a true paradigm shift, characterized by a growing optimization of global value-added structures [1]. This need for innovation and optimization is relevant to all industries, and for the explosives manufacturing as well as reported by Karl Maslo, former EXSA (“Explosivos S.A.”) regional manager [2]. To pursue this goal, lean philosophy is used as it allows applying sustainable improvements to the processes of a company, focusing on the value of the process and eliminating if possible or minimizing all those activities or tasks that when executed are not beneficial, that is, they do not add value [3]. Once all the sources of waste have been identified, it is intended to obtain the maximum productivity of the plant and identify the configuration that provides a capacity more adapted to the demand, as well as achieving a reference framework of methodologies used in the improvement of processes that can be extrapolated to any other plant [4]. As a result, the research pursues to design and apply a systematic methodology to improve the efficiency of a manufacturing plant increasing its value-added towards the end-customer. In this research study, the methodology is applied to the manufacturing process of charged detonators.
2. State of the art and Methodology

First, a literature review is carried out with focus on the methods, tools and philosophies for the analysis and improvement of manufacturing processes as well as on the manufacturing challenges and the mining industry and explosives production. As a result, a search and analysis of bibliographic information regarding the analysis and improvement of manufacturing processes is carried out in the following fields:

- Manufacturing challenges
- Mining industry and explosives production
- Lean manufacturing
- Theory of constraints (TOC)
- Agile Manufacturing
- Quick Response Manufacturing (QRM)

The study of the different methodologies provides an approach to the possibilities of improvement of the process under study. All this allows the generation of a model for systematic optimization by applying the tools studied. The model is applied by evaluating the production process by mapping the production material flow and the planning processes. Later, the different improvement tools are implemented by trying to improve the current state. The related indicators are obtained based on average values. As this optimization is static, a simulation for variable demand inputs is performed. Then, the simulation results make possible to analyze the impact of the potential application of the improvement methods. The objective of this point is to assess how efficient the application of one chosen technique is on the process. Finally, recommendations of the proposed methodology are described.

2.1. Analysis and improvement of manufacturing processes

2.1.1. Lean manufacturing (LM): The goal of lean management is to concentrate efforts in added value and customer demand by reducing waste [5]. There are many lean manufacturing methods for reducing waste, however, a set of them was selected for its application in the case study and therefore described more in detail as follows:

- Value Stream Mapping (VSM) [6].
- Pull production systems [7].
- Single-Minute Exchange of Die (SMED) [8].
- Kanban [9].

2.1.2. Agile manufacturing (AM): was introduced in the early 1990s as a new management system to go well beyond lean production with concepts of highly efficient, adaptive, and flexible manufacturing enterprises thriving in a fast-moving competitive environment [10]. It offers enormous possibilities for increasing competitiveness in manufacturing [11].

2.1.3. Quick Response Manufacturing (QRM): A company-wide strategy based on reducing response times throughout the organization. Quick Response Manufacturing or Rapid Response Manufacturing is a company-wide strategy that is based on reducing response times throughout the organization [12]. Therefore, QRM takes Lean strategy to the next level, suitable for the 21st century [12].

2.1.4. Theory of Constraints (TOC). Identification and analysis of the bottleneck of a certain process for its improvement as a means of improving the overall process. The underlying process for implementing a TOC approach involves repeating applications of five key steps, ensuring on-going improvement [13]. A production system based on the TOC is characterised by the implementation of Drum-Buffer-Rope (DBR) [14].
2.2. Challenges in the mining industry and explosives production
The use of electric and non-electric detonators in mining is a system that has been developing since the mid-1940s. Market saturation implies that to remain competitive and, if possible, obtaining new customers, it is required to optimize production processes to reduce costs, also increasing customer satisfaction in terms of quality and delivery service. This need to innovate and optimize explosives manufacturing processes extends to all companies in the sector, as can be seen in the words of Karl Maslo, former EXSA regional manager: “Today, innovation is no longer an option, it is an obligation, for those organizations that are thinking of having a long-term validity” [2]. In the mining industry, at times the prices of mineral raw materials drop, this means that, on the one hand, ongoing projects are optimizing their costs and, on the other, that projects in the early stages of the life cycle are rethinking their situation. In this scenario, some mines close because they are not profitable, or because they have exhausted their reserves [15]. These fluctuations in the prices of minerals make it necessary to optimize the manufacture of the different elements that intervene in the exploitation of mining. To sum-up, the main challenges are:

- A short-list of dominant players in their corresponding markets.
- A high market maturity in which the product has not changed significantly in the last decades.
- A need to improve process efficiency to secure long-term viability by increasing its profitability.

![Figure 1. Methodological steps for systematic process optimization (own elaboration).](image)

3. Development of a conceptual model for systematic process optimization
The conceptual model pursues to describe the steps for systematic process optimization to answer the following questions:

- How can an optimization process of a manufacturing plant be designed to improve its efficiency in a systematic way?
- How can its application in a company increase the value-added towards the end-customer?

In this context, figure 1 represents and describes the steps that enable any manufacturing organization to improve in an iterative way. The systematic methodology pursues to improve the efficiency of a manufacturing plant increasing the value-added towards the end-customer.

4. Applying the Conceptual Model for the Detonator Manufacturing Process
4.1. Current state analysis
4.1.1. Representation of current state. The current production process is represented in figure 2. As it
is shown, there are three parallel production flows for the detonator’s shells, the relay containers, and the operculums, flows 1, 2 and 3 in figure 2. Then, the relay’s containers are charged in flow 4. Finally, detonator’s shells and operculums, charged relay’s containers, as well as the base charge and the initiator’s explosive are assembled into the end-product of charged detonators.

4.1.2. Gathering current indicators. All related indicators related to the manufacturing plant are collected: procurement lot sizes, production lead times, cycle times, replenishment times, number of employees, productivity, OEE (Overall Equipment Effectiveness), capacity per production step, etc.

4.1.3. Material flow analysis. The material flow for the different manufacturing processes from raw materials to semi-finished products as well as finished products is analysed. An extract is shown in figure 3.
4.1.4. Information flow analysis. The weekly planning process is depicted in figure 4.

4.2. Selection of improvement tools
After the analysis of the current state different improvement tools are selected for the different areas of the manufacturing plant as shown in table 1.

### Table 1. Selection of improvement tools by area (own elaboration).

| No. | Improvement approaches | Raw materials | Semi-finished Products | Finished Products |
|-----|------------------------|---------------|------------------------|-------------------|
| 1   | Lean Manufacturing (LM) | X (Kanban)    | X                      | X                 |
| 2   | Agile Manufacturing (AM)| X             |                        |                   |
| 3   | Theory of Constraints (TOC) | X  |                        | X                 |
| 4   | Quick Response Manufacturing (QRM) | X  |                      |                   |

4.3. Application of the improvement tools

4.3.1. Kanban application. It consists in the improvement of raw material procurement. An initial situation with its initial procurement lot size be adapted in the most optimal configuration for the current replenishment time from suppliers that counts for 30 days. As a result, consumption time is aligned to the replenishment time taking into consideration the minimum number of pallets or cans per procurement order, and then, the lot size can be determined. An overview is shown in table 2:

### Table 2. Kanban implementation results for raw material procurement (own elaboration).

| No. | Raw material         | Initial Procurement Lot Size (before optimization) | Kanban Procurement Lot Size (after optimization) |
|-----|----------------------|--------------------------------------------------|--------------------------------------------------|
|     |                      | Consumption time (days) | Lot size (kg) | Pallets per lot size (pallets) | Consumption time (days) | Lot size (kg) | Pallets per lot size (pallets) |
| 1   | Al Wire Type 1       | 45.4 | 4,500 | 6 | 30.2 | 3,000 | 4 |
| 2   | Cu Wire              | 23.4 | 6,000 | 15 | 31.1 | 8,000 | 20 |
| 3   | Al Wire Type 2       | 68.2 | 4,500 | 15 | 31.8 | 2,100 | 7 |
| 4   | Zn Wire              | 45.6 | 6,000 | 20 | 31.9 | 4,200 | 14 |
| 5   | Al Band              | 166.7 | 1,500 | 6 | 55.6 | 500 | 2 |
| 6   | Delay charge         | 37.1 | 1.5 | 5 cans | 37.1 | 1.5 | 5 cans |
| 7   | Base charge          | 61.7 | 1.5 | 5 cans | 37.0 | 0.9 | 3 cans |
| 8   | Initiating explosive | 66.7 | 0.5 | 5 cans | 40.0 | 0.3 | 3 cans |

4.3.2. Pull-system application. Calculation of minimum intermediate stock for each reference of semi-finished products. The intermediate target inventory is calculated based on the lot size and on the consumption rate required. An overview is shown in table 3:

### Table 3. Pull-system implementation results for semi-finished material (own elaboration).

| No. | Semi-finished material | Consumption (units / min) | Lead time (min / lot size) | Minimum Lot size (units) | Replenishment time (min) | Target Inventory (units) | Target Inventory (# lot sizes) |
|-----|------------------------|---------------------------|----------------------------|--------------------------|--------------------------|---------------------------|------------------------------|
| 1   | Detonator’s shells     | 62.5 | 320 | 20,000 | 620 | 38,750 | 2 |
| 2   | Relay                  | 93.9 | 213 | 20,000 | 850 | 79,812 | 4 |
| 3   | Operculum              | 62.5 | 480 | 30,000 | 690 | 43,125 | 2 |

4.3.3. SMED application. For the number of lot sizes determined for the pull-system implementation, the number of changeovers is optimized accordingly. An overview is shown table 4.
Table 4. SMED implementation results for semi-finished material (own elaboration).

| No. | Semi-finished material | Initial Situation (before optimization) | With pull-system (after optimization) |
|-----|------------------------|-----------------------------------------|----------------------------------------|
|     |                        | Production Lot Size (units / min) | Time between changeovers (min) | Production Lot Size (units / min) | Time between changeovers (min) |
| 1   | Detonator’s shells     | 150,000                               | 1.800                                 | 40,000                               | 480                                |
| 2   | Relay                  | 150,000                               | 1.800                                 | 80,000                               | 960                                |
| 3   | Operculum              | 180,000                               | 2.880                                 | 60,000                               | 960                                |

4.3.4. **TOC application.** The five TOC steps are applied to the whole production process. The relay charged manufacturing is the bottleneck as it needs 811 minutes for the minimum lot size of 20,000 units. Based on that, two options can be used for expanding the bottleneck. In case of applying the first option is the optimization of the machine cycle for the scratching process, the lead time for the minimum lot size reduces to 611 minutes. As a result, in the fifth step the operculum manufacturing arises as the new bottleneck as it needs more time for the minimum lot size. An overview is shown in Figure 5.

Relay charged manufacturing = 811 minutes

1. Bottleneck identification

Operculum manufacturing = 630 minutes

5. Re-examination of the bottlenecks

Option 1: Scratching machine cycle time from 400 min to 200 min

2. Optimal use of the bottleneck

Relay charged = 611 minutes

4. Expansion of the bottleneck

Option 2: Production lot size from 20,000 to 10,000 units

3. Bottleneck-oriented management

Relay charged = 441 minutes

Figure 5. TOC implementation results (own elaboration).

4.4. **Simulation for variable demand scenario**

A simulation of the implementation was also performed by applying the different optimization measures for different demand scenarios per month. Results for raw material and semi-finished stock, changeovers, and production capacity are compared with the values of the simulation before and after the optimization. The following results were obtained as shown in Table 5.

4.5. **Results**

With the application of the designed methodology the following benefits for manufacturing companies and for the manufacture of detonators are obtained and are shown in Table 6.
| No. | Optimization measure          | Optimization element                        | Simulation before Optimization | Simulation after Optimization | Improvement (%) |
|-----|-------------------------------|---------------------------------------------|--------------------------------|-------------------------------|-----------------|
| 1   | Kanban                        | Stock (raw material) (kg)                   | 12,728 kg                      | 10,031 kg                     | 21%             |
| 2   | Pull-System for non-electric  | Stock (semi-finished) (units)               | 171,750 units                  | 97,500 units                  | 43%             |
|     | detonator’s shells            |                                             |                                |                               |                 |
| 3   | Pull-System for electric      | Stock (semi-finished) (units)               | 222,000 units                  | 97,500 units                  | 44%             |
|     | detonator’s shells            |                                             |                                |                               |                 |
| 4   | Pull-System for non-electric  | Stock (semi-finished) (units)               | 96,750 units                   | 57,500 units                  | 41%             |
|     | relay’s containers            |                                             |                                |                               |                 |
| 5   | Pull-System for electric      | Stock (semi-finished) (units)               | 139,500 units                  | 72,500 units                  | 48%             |
|     | relay’s containers            |                                             |                                |                               |                 |
| 6   | Pull-System for operculums    | Stock (semi-finished) (units)               | 236,250 units                  | 130,000 units                 | 45%             |
| 7   | SMED                          | Changeover (min)                            | 2,340 min                      | 480 min                       | 79%             |
| 8   | TOC                           | Capacity (units)                            | Detonator’s Shells 60,000 units Relay’s Shells 80,000 units | Detonator’s Shells 60,000 units Relay’s Shells 80,000 units | 79%             |
|     |                               |                                             | 40,000 units                   | 90,000 units                  | 79%             |
|     |                               |                                             | 125%                          |                               |                 |
|     |                               |                                             | 0%                            |                               |                 |

5. Discussion

Based on the results, managers can decide for one or other technique to be implemented depending on the improvement area they want to optimize according to their strategies:

- Get a constant flow of materials along the production process.
- Reduction of waiting times.
- Reduction of stocks along the production process.
- Correct leveling of the intermediate products and warehouses.
- Reduction of the numbers of changes.
- Improvement of information flows.
- Avoiding overproduction.
- Improve quality.

By considering which objectives the company is pursuing, then the best-fit tools for this strategy can be selected. These actions, accompanied by other methodologies such as the standardization of positions and other tools, not only have an impact on the improvement of the manufacturing process, but also generate a better understanding of the process by both technical personnel and factory workers.

Finally, based on the case study a work methodology is derived with the potential to be extrapolated to other detonators manufacturers in the sector and to companies from other sectors considering the production system characteristics.
6. Conclusions
After completion of the research work, the following points can be successfully concluded:

- The challenges of mining and explosive manufacturing organizations were described.
- A systematic methodological approach for continuous optimization of manufacturing plants was developed.
- A guide was described to develop optimization programs based on improvement tools selection.
- A discussion of the related potentials of the improvement tools for manufacturing companies was stated to help managers in their decision-making processes.

For the case study, a manufacturing of detonators has been chosen. The results of the case study for the detonator manufacturing process have provided significant improvements in the following areas:

- Average stock levels.
- Production leveling.
- Manufacturing batches of each of the components and the production mix.
- Response flexibility to customer demands.
- Quality rate.

With the data obtained in the application of the different tools, it can be concluded that the market for manufacturing explosives initiation systems and, specifically, the manufacturing process for charged detonators is capable of being improved by applying the improvement techniques analysed. These techniques, which have already been proven in other industries, are perfectly suited to the explosives
field. Moreover, a work methodology for optimizing manufacturing plants based on the proposed tools can be applied to other sectors. Finally, it is important to point out that a future line of research may be the consideration of quality control processes, the implementation of these tools in real organizations as well as to standardize the developed analysis and process optimization methodology for the different sectors.

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