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Optimisation of reordering points considering purchasing, storing and service breakdown costs

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Abstract

This paper focuses on the problem of the optimisation of reordering points through the usage of an educational version of a commercial Discrete Event Simulation software. A product for the optimisation of reordering points has been developed and successfully tested. After that, it has been used to optimise the reordering points of a plastic manufacturing company. The satisfactory results obtained have been useful not only to reduce the storage and backorder costs, but to train the purchasers of different plants.

Most companies implement lean production principles. These are related to the minimisation of waste due to unneeded and inefficient operations, such as excessive buffering operations to serve the client or backorders (Narasimhan, Swink, & Wook Kim 2006). These two inefficiency types can be faced by defining a proper reordering point, as too low reordering points may worsen service rates whereas excessively high reordering points increase the storage costs.

The optimisation of the reordering point of raw materials and maintenance spare parts is a problem extensively studied in the academic field, but poorly solved in the context of plant management. Thus, several authors (i.e. Namit & Chen 2007; Namit & Chen 2005; Taskin Gumus & Fuat Guneria 2009) study the problem of determining optimal reordering points. As a result, several tools for the development of reordering policies have been launched to the market; i.e. NSI developed a freeware tool (NSI 2004) for the optimisation of the reordering point of a single reference: to do that it is necessary to bring the monthly consumption of the reference during the last year, its lead time and the items per order of the element. As a result it offers different options of reordering points, each one with a determined expected service and confidence levels. Concerning the non freeware utilities, for example, Lokad (2008) offer its safety stock calculator, capable of interacting with the database of the company to determine proper safety stock levels. Nevertheless, practitioners state that most academical solutions developed do not reach SMEs. Tools as Lokad's must

deal with the severe resource restrictions SMEs deal with, whereas freeware tools are normally close-source utilities that may not respond properly to the needs of the companies.

Previous experiences of the research team involved in the project have been useful to detect abnormal situations in the implementation of reordering policies; for example, the company where the tool has been tested, Tajo S. Coop. (Tajo), has six productive plants spread around the world, but did not have defined reordering point policies until this project was launched. Thus, each of the six purchasers of the six plants had determined a particular policy, so that there were two moderately risky, two moderately conservative, two risky and one very conservative purchase. This situation was too expensive to be afforded: in some cases the storage costs were excessive, whereas in others the lack of raw material delayed the products to be delivered to the clients.

Having tested that this problem is relatively common within the companies the research team works with, this work aims at presenting the results of the design, development and implementation of a tool that calculates optimal reordering points considering purchasing, holding and backorder costs. Specifically, the software tool can jointly optimise the reordering point levels and transportation types of elements, by combining Discrete Event Simulation with optimisation algorithms. The tool has been successfully used for a preliminary study in Tajo, a plastic component manufacturer who serves products to the automotive auxiliary and domestic appliance sectors.

Specifically, the software tool jointly optimises the reordering point levels and transportation types of elements, by combining the educational version of commercial Discrete Event Simulation software with a pseudo brute-force algorithm. Thus, a product for the optimisation of reordering points has been developed and successfully tested. After that, it has been used to optimise the reordering points of a plastic manufacturing company. The satisfactory results obtained have been useful not only to reduce the storage and breakdown costs, but to train the purchasers of different plants.

It is worth noting that the development presented herein has been considered as a case of success in the European Manunet platform (see the following link for further information (The Manunet platform 2010)). The Manunet platform is a joint effort for the promotion of research and development in manufacturing; the platform comprises 22 contractor partners, representing 13 regions and 5 countries, plus 10 extra associated partners, based on a shared view for Europe.

1. Optimisation problem

The optimisation problem studied herein consider several input variables, constant variables, assumptions and output objectives, whose overall context is described in Fig. 1 (input and output data) and 2 (representation of the model), and described below.

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X |
|----|---------------------|---------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|-----------|---------------------|--------------------------------|-------------------------|---|--------------------------------|--------------------------------|------------------------------------|--------------------|---------------------------------|
| 1 | | Consumption (units/month) | | | | | | | | | | | | Time to serve (days, normal distribution) | | Batch order size | Cost of storage/ Holding | Reord ering costs | Backorder or service breakdown costs | Minimum reordering point | Maximum reordering point | Jumps between min and max | Pseudo- Optimal | Minimum Cost (Optimal Costs) |
| 2 | Reference (name) | 1 (January) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Average | Deviation | Units | euro\$/ye ar | euro\$/ order | euro\$/hour | Units | Units | Units | Units | Euros |
| 3 | A | 150 | 200 | 260 | 152 | 100 | 72 | 89 | 12 | 124 | 126 | 170 | 160 | 3 | 1.2 | 50 | 150 | 2 | 70 | 100 | 300 | 100 | 100 | 64.6385756 |
| 4 | B | 366 | 211 | 40 | 281 | 185 | 14 | 40 | 350 | 443 | 255 | 396 | 137 | 3 | 1.2 | 100 | 150 | 2 | 70 | 100 | 200 | 100 | 200 | 54.41838981 |
| 5 | C | 303 | 443 | 224 | 358 | 388 | 265 | 462 | 441 | 253 | 36 | 463 | 369 | 5 | 1.2 | 200 | 150 | 2 | 70 | 100 | 300 | 100 | 200 | 40.11650545 |
| 6 | D | 445 | 160 | 332 | 185 | 123 | 15 | 86 | 217 | 235 | 227 | 134 | 150 | 3 | 1.2 | 100 | 150 | 2 | 70 | 100 | 300 | 100 | 100 | 46.27393906 |
| 7 | E | 263 | 142 | 292 | 425 | 90 | 70 | 322 | 114 | 367 | 343 | 377 | 198 | 3 | 1.2 | 50 | 150 | 2 | 70 | 100 | 200 | 100 | 100 | 120.0769025 |
| 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 9 | | | | | | | | | | | | | | | | | | | | | | | | |
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| 28 | | | | | | | | | | | | | | | | | | | | | | | | |

Fig. 1. Input (in black) and output (in red) data of the problem to be solved in the optimisation interface

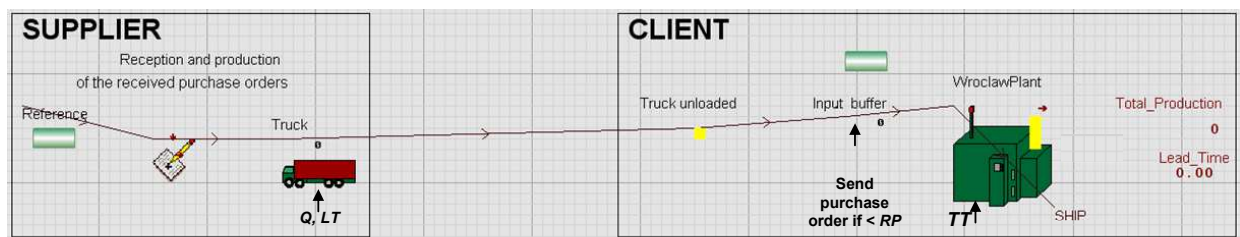


Fig. 2. Graphical description of the problem to be solved

The problem deals jointly with 5 references for the following two input variables (of each of these references):

- The product comes in Q size batches.
- The reordering point (RP).

Concerning the constant values and assumptions to be modeled it is supposed that;

- The logistic lead-time (LT), the time taken from a purchase order is submitted to the arrival of the products related to that order, is variable but known (historical data is available, so that information can be fitted to a known distribution).
- The customer demand rate of client TT , thus is, the speed the client consumes buffered products is known (historical data is available, so that information can be fitted to a known distribution).
- The buffer containing the arriving products has an infinite capacity.
- Each batch of products jointly bought has a fixed purchasing order cost (C_e).

- Each product has a fixed cost per unit of time for being stored in a buffer (C_s).
- A fixed backorder cost (C_b) is assigned each time a client needs to take a product from the buffer and does not find any products within.

Finally, the outcomes to be optimised may consider the joint optimisation of the following costs:

- The minimisation of the total cost spent on submitting purchase orders (C_{et}).
- The minimisation of the total holding cost for elements in the buffer (C_{st}).
- The minimisation of the total cost of not serving the client because the buffer is empty (C_{bt}).

Each one of these cost will be calculated by multiplying the times an event related to the above mentioned costs happen by its concept of cost. So, being n_e and n_b respectively the amount of purchasing orders submitted and the amount of non-served products in the studied period, C_{bt} and C_{et} are calculated as follows:

$$C_{bt} = n_b \cdot C_b \quad (1)$$

$$C_{et} = n_e \cdot C_e \quad (2)$$

While for the calculation of C_{st} is performed taking into account C_s and the amount of time each of the m products is stored in the buffer (t_s), as it is shown in Equation (3):

$$C_{st} = C_s \cdot \sum_{i=1}^m t_{s_i} \quad (3)$$

2. Problem formulation

Optimisation of Q and RP variables considering C_{bt} , C_{st} and C_{et} criteria can be formulated as Single-Objective Problem (SOP) or a Multi-objective Optimisation Problem (MOP). A SOP could be presented summing all purchasing, buffering and backorder costs, while MOP would be formulated to optimise a vector of functions of the form (Martorell et al. 2004):

$$f = (f_1, f_2, \dots, f_n) \quad (4)$$

where f are functions which depend on the decision variables, Q and RP . The optimisation proposed in this paper considers the total costs detailed in Equation (5) as a SOP problem:

$$f(Q, RP) = C_{st} + C_{et} + C_{bt} \quad (5)$$

Additionally, and although the software application is prepared to deal with different values of Q , the application cases tested with the collaboration of Tajo considered only RP as

decision variable, so that for the case the function shown in Equation (5) is modified as follows:

$$f(RP) = C_{st} + C_{et} + C_{bt}$$

(6)

3. Modeling and optimisation techniques:

3.1 System DES model

DES concerns the modeling of a system as it evolves over time by a representation in which variable states change suddenly at separate points in time. These changes happened in the system are considered events. Systems do not change between events, so DES considers that it is not necessary to analyse what happens in a system in periods taken place between two events.

A single traffic light is an example of the concept of ‘variable time between consecutive events’ (Fig. 2). In the example shown below, the states of a traffic light are shown based on the DES technique. As can be appreciated in the figure, consecutive events do not occur after the same periods of time. While $\Delta t=15s$ when changing the state of the traffic light from red to green, it varies to $\Delta t=50s$ and $\Delta t=100s$ when changing the state from red to green and green to yellow, respectively.

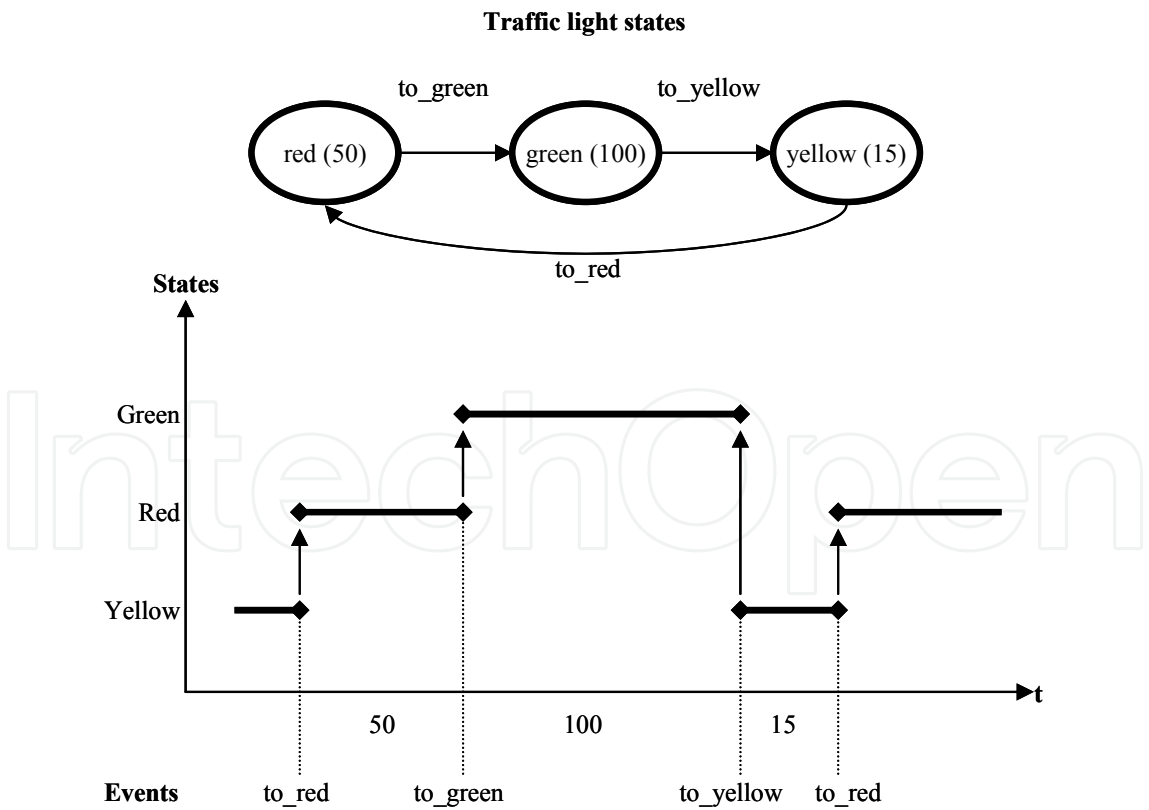


Fig. 3. States and events graph in a traffic light using DES (Oyarbide-Zubillaga 2003)

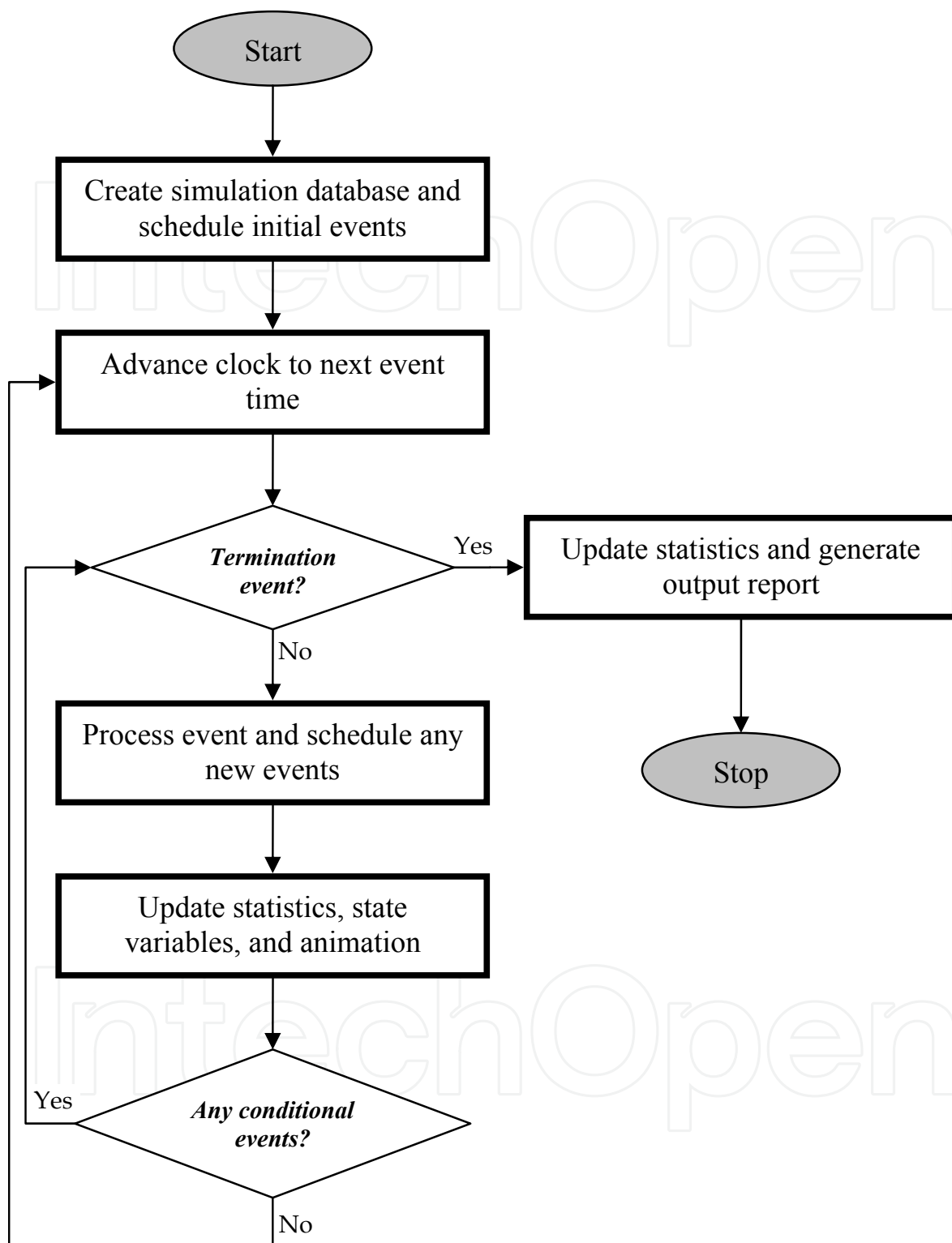


Fig. 4. Diagram of Discrete Event Simulation process (Harrell et al., 2000)

The main advantages of DES are two (Goti, Oyarbide-Zubillaga, & Sánchez 2007; Law & Kelton 1991; Oyarbide-Zubillaga, Goti, & Sánchez 2008): i) standard DES-based tools provide capabilities of modeling or modifying complex system models easily, and ii) DES is

closely related to stochastic systems so they are appropriate when simulating real-world phenomena, since there are few situations where the actions of the entities within the system under study can be completely predicted in advance. In order to generate stochastic events, simulation packages generate pseudo-random numbers to select a particular value for a given distribution. Thus, using pseudo-random numbers it is possible to implement the stochastic nature of real models in DES models. Therefore, DES was used as modeling technique for the modeling tool to be developed. The running mechanism of DES, extracted from Ref. (Harrell, Ghosh, & Bowden 2000) is shown in Fig. 3.

Specifically, the development of the model was performed using an educational version of Witness (Lanner 2008). This was a collaboration between the authors and Tajo, so that they could experience the potential benefits of a DES approach for addressing real-world situation, which are to a certain extent different from those that can be found in text books. The study focused on some references using the data available at that moment in time. Indeed, Tajo was very satisfied with the proposed approach and stated that values obtained from the study were very reliable and would be implemented.

The authors are very confident that Tajo will rely on the future in DES approaches for both this type of analysis and for other ones. As to reordering point studies they may end up acquiring some software to recalculate values (as data change overtime) and to extend the analysis to other references and, even more, carry on analysis when setting policies for references in combination (for example, it may be interesting to launch a reordering order for a product although for a particular reference the reordering point has not been reached if for other reference it has, and simultaneous ordering saves some money).

3.2 Brute-force as a pseudo optimisation algorithm

Depending on the complexity and the characteristics of the optimisation problem different techniques can be used. For instance, if the problem is faced as a MOP a Multiobjective Evolutionary Algorithm (MOEA) (i.e. the Non-Dominated Sorting Genetic Algorithm NSGA-II, by Deb et al. 2002) can be used. In case as a SOP (minimisation of overall cost as the unique objective) is presented, a single objective optimisation algorithm is enough to solve the problem. In this case, as the exploratory space of many of the references was not wide in many cases, these cases were optimised using the brute force (test of all the range of choices) technique.

More specifically, the brute force technique was applied, but not testing all the reordering point choices of all references. For each case, a minimum and a maximum reordering point and a 'jump' step scale were defined (see Fig. 1, columns T, U and V): Thus, the optimisation process will start by analysing the minimum reordering point (100 in file 3 of Fig. 1), to then try the minimum plus the jump value (Fig. 1, minimum 100, jump value of 100, 200), increase again the tested amount with the step value (300), until the maximum value is achieved (300 in file 3 of Fig. 1).

4. Implementation case

As it was previously stated, the set of modeling plus optimisation techniques was applied to optimise the reordering points of several references of Tajo. Tajo is part of the Mondragon

Group (known until last year as “Mondragon Corporación Cooperativa”, the seventh largest corporation in Spain). Tajo has produced and supplied plastic sub-assemblies and components since 1963 for the automotive auxiliary and domestic appliance sectors, consisting of six manufacturing plants, two in Spain, two in Poland and one in the Czech Republic.

There are some elements of special interest to be optimised, as they are sub-products supplied to the six plants by Spanish dealers. Additionally, these references are not stocked in the dealer’s warehouse, and the total LT value can round the 21 days. This means that, for these cases, the reordering point must consider not only the amount of elements within the client plant buffer (the storage location at the beginning of the client plant of Poland or the Czech Republic), but also the already ordered elements which have not arrived the client plant.

The implementation case uses the data shown in Fig. 1, who are referred to 5 raw material and consumable references. Finally, it is need to be said that the warm-up period and the simulation period values are of 5 and 229 days respectively, and have been calculated considering the suggestions provided by the theory of the simulation, compiled in Ref. (Goti 2007)

5. Results

The overall results obtained after the optimisation process using the previously shown values are specified in Fig. 1. For each one of the references, the optimisator presents the input and output values for each simulation; the results of one reference are shown in Fig. 4:

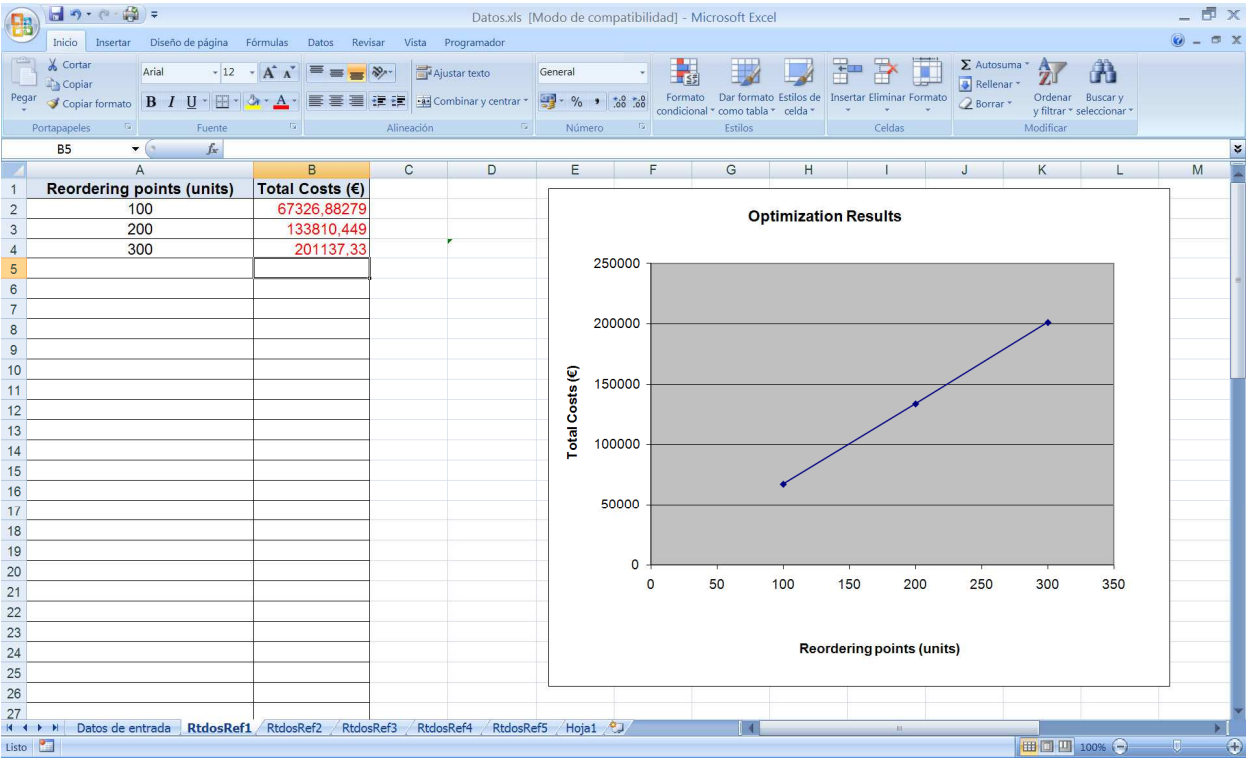


Fig. 4. Optimisation results

The consolidation of the results obtained has been considered successful, and as a consequence, several plants within the Mondragon Group are testing the initiative to optimise production raw materials and maintenance spare parts, but considering both RP and Q values.

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Considered by many authors as a technique for modelling stochastic, dynamic and discretely evolving systems, this technique has gained widespread acceptance among the practitioners who want to represent and improve complex systems. Since DES is a technique applied in incredibly different areas, this book reflects many different points of view about DES, thus, all authors describe how it is understood and applied within their context of work, providing an extensive understanding of what DES is. It can be said that the name of the book itself reflects the plurality that these points of view represent. The book embraces a number of topics covering theory, methods and applications to a wide range of sectors and problem areas that have been categorised into five groups. As well as the previously explained variety of points of view concerning DES, there is one additional thing to remark about this book: its richness when talking about actual data or actual data based analysis. When most academic areas are lacking application cases, roughly the half part of the chapters included in this book deal with actual problems or at least are based on actual data. Thus, the editor firmly believes that this book will be interesting for both beginners and practitioners in the area of DES.

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