

Spreadsheets to teach the (RP,Q) model in an Inventory Management Course

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Abstract

The use of spreadsheets to support learning processes has become a common practice used by teachers in Operations Management courses. This paper shows a predesigned spreadsheet used in an Inventory Management course to explain the model (RP,Q) using the decision rule based in the Units Service Level (USL).

Keywords: Inventory Management, Learning Processes, Education, Spreadsheets

Introduction

In recent years, inventory management and control at enterprises has become an important area that requires a higher attention by directors and managers. For one hand a suitable management of inventories can drive toward competitive advantages as cost reduction, improving the service levels, fast and reliable deliveries, and/or increase the flexibility of the business (Ketchen, 2008). On the other hand, inventories are current assets, which according with some studies represent on average 25% of GDP (Gross Domestic Product) of a country, and thereof about 50% are from logistics costs (Silver et al, 1998, Rey, 2008).

The process of the management and control of the inventories at any company, no matters if these are in the manufacturing or in the service sector, have the responsibility to give answer of three issues or problems: 1) how often the status of the inventory should be revised; 2) when an order should be placed and 3) how much should be ordered (Silver et al, 1998). These three questions must be faced in a regular basis for many industrial and production engineers, when they work at professional level as inventories coordinators, vendor management, production managers or plant directors (only to mention some roles in the companies) not matter if the company has a commercial information system (as SAP, Oracle or Dynamics) or if it is a customized information system or if it was developed at home, because in any case the definition of the control policy, the selection of the models and mainly, the technical calculations of its parameters, are the core of the inventory management (Shehab, 2004; Moon, 2007; Gutierrez, 2009).

In order that future professionals can achieve with higher probability of success the objectives and goals in the inventory area at the companies they will work, it is important that in the inventory management courses (at undergraduate and graduate levels) the students can

develop the competences that they will need to cope adequately the challenges that it implies. It can be accomplished with an appropriate teaching of subjects mentioned above related with inventory management and control, which begins with a deep understanding of the basis and foundations of the topic, that will allow to comprise, analyze, interpret, develop, implement and measure the performance of the inventory management models in a company.

Spreadsheets have been used for years in teaching and training students in many areas of knowledge, including a wide variety of subjects related to Operations Managements and Logistics (OM&L) because with them is easy to represent, model and analyze many administrative situations, that can support the decision making process at different levels into a company (Baker, 2003). Some topics that were found in literature related to the OM&L teaching and training included control quality and statistical process control (Rajalingham, 2000), forecasting of demand (Dawood, 1995; Segura, 2001, Castro, 2012), management and analysis of supply chain management (Chwif, 2002) and simulation (Evans, 2000), just for mention only some of the huge quantity of spreadsheets developed with educational purposes.

One of the most practical ways to teach the inventory management models, including parameters definition, sensibility analysis, policies simulations, etc., it is through the use of spreadsheets, because electronic spreadsheets have two main advantages: 1) at educational level, there is an utilization and knowledge almost generalized of this kind of computational tools by students and 2) at industrial level, many manufacturing and service industries (mainly small and medium enterprises) use spreadsheet to control and management the inventories (Silver, 1998; Gutierrez, 2008,2009).

One of the main challenges that have current professors, at graduate and undergraduate levels of industrial and production engineering is trying to reduce the gab that historically has existed between theory and practice, and working to improve the quality of teaching in the underlying topics of OM&L, including the subject of inventory management and control. This paper presents the developed of electronic spreadsheets in Microsoft Excel®, which are used to teach the inventory management models, focusing in the model of continuous review, known in the academic literature as reorder point, fixed quantity (RP, Q), using the decision rule based on the units service level (USL) or fill rate. The rest of the paper is organized in four sections. This introduction is followed by section two, where are showed fundamentals, concepts and an overview about inventory management and control and of the ($PR; Q$) model. In section 3 is presented a numerical example with the pre-designed spreadsheets used in the graduate course Warehousing and Inventory Management of the Master in Operations Management and Logistics at Eafit University, to teach the model described in section 2, which includes both mathematical and Excel formulations, the results of the process and the verifications of it. Finally in section four there is a summary of the paper, some recommendations for its uses and future work.

An Inventory Management Overview

As it was mentioned in previous section, inventory management and control has the liability of give answer, for a large numbers of supplies, raw materials and/or finish products, three main questions. The first one is related to the frequency that the inventory of the whole stock keeping unit (*sku's*) should be reviewed, this means defining if it must be done continuously or periodically. The second question consists in determining when an order should be placed, which depends of the policy of review defined in the first question. If the frequency is continuous, the

model requires establishing a quantity that triggers the generations of the orders (that is to set the reorder point RP). Moreover, if the orders are placed every T units of time fixed, is because had been defined a frequency of reviewing periodically. Finally, issue three is related to the quantity that should be ordered, called order quantity (Q), which can be an economic order quantity (EOQ), a finite replenishment economic order quantity ($FREOQ$ or EPQ) or a quantity constrained by the suppliers or by the processes.

In order to illustrate the use of electronic spreadsheets in teaching concepts related to inventory management, the (PR, Q) policy is used to calculate the parameters of the model, based on the decision rule for a specified fraction of demand satisfied directly from shelf, which is a rule of service level known as Units Service Level (USL) or Fill Rate. It is recommended to use this control policy to start the analysis of the models of inventory control, since it is easy to comprise by the students and also because that allows to show and develop the underlying concepts of inventory models that can be understood and applied over others more complex models (Silver et al, 1998). Below there is a more detailed description of the model.

The policy for inventory management and control (PR, Q)

The policy for inventory management and control (PR, Q) it is an inventory control system of continuous or perpetual review used generally in inventory management with probabilistic or stochastic demand, where always the on-hand stock and the inventory position are known. In this system a fix quantity is ordered every time that the inventory position drops to the Reorder Point (RP) or lower. The inventory position is defined by the on-hand inventory (shelf inventory) plus on transit inventory or the orders in the pipeline. So, the inventory position is the key quantity that activate the system (that is, when put an order), because every time this values is equal or under RP , should be ordered a fix quantity that increases the value of the inventory position above RP .

Figure 1 illustrates how the (RP, Q) system operates. As it is shown in the figure, the parameters of the model are the Reorder Point (RP) and the Fixed Quantity (Q), which are the core of the model. Both values should be defined technically in order to obtain the desire results in terms of service levels and/or costs. According to the graph, before the point of time A , the net inventory and inventory position are equal. At time A , inventory drops under RP , so a fixed quantity Q should be ordered, ensuring that inventory position increases above the RP . The time that elapses between when an order is placed and that it arrives physically is called lead time (L); therefore the quantity ordered at time A , arrives at time B , making that net inventory rises again above RP , guaranteeing that almost all demand could be satisfied until the next order cycle.

The good performance of the model (that is, obtain the service levels and/or expected costs) will depend if the parameters of it are correct, which is one of the objectives with the use of pre-designed electronic spreadsheets, that will be explain in the next section, where is presented a numerical example used in the graduate course Warehousing and Inventory Management of the Master in Operations Management and Logistics at Eafit University, in Medellin, Colombia.

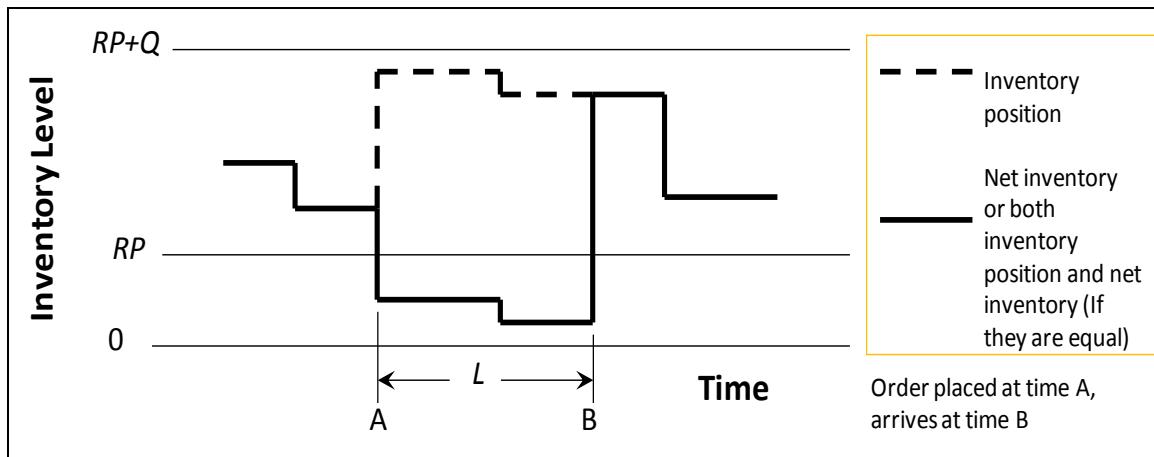


Figure 1. Continuous Review System (PR, Q) (Adapted from Silver et al, 1998)

Numerical example of (PR,Q) model using pre-designed spreadsheets

Many inventory management models are based on expressions and mathematical models that require intensive use of computational aids when those are applied to hundreds (and sometimes thousands) of items that should be controlled within a company. As was mentioned previously, the expected results in terms of service levels and cost when a model is implemented, depend that the parameters were calculated correctly according with the selected decision rule, the characteristics and some key information of the items. To do this well, is necessary that the person in charge of inventory management has on the one hand a good understanding about the inputs, processes, outputs and sensibility of the models, and on the other hand the experience, knowledge and capability of analysis of the business. Both issues affect (positively or negatively) the results. The experience in inventories is achieved through constant contact with the area over the time, but knowledge, understanding and the analysis skills of inventories should be developed from undergraduate courses of inventory management, followed by graduate and master courses.

The use of spreadsheets for teaching and training of students at graduate and undergraduate levels at inventory management topics, should allow validating the knowledge that students have acquired in the classroom or with personal readings, and to improve its analysis skills, key features that an inventory manager should have in order to develop, deploy, implement and make decisions related to inventory management and control.

An additional advantage of using predesigned spreadsheets in the courses, is that with these a topic can be explained in a most general and quick way, compared when each student has to design, develop and fill his own spreadsheet, because the teacher can use the time more efficiently, focusing on the core of the course and not in the form.

Predesigned spreadsheets: Notation and Formulation of System (RP,Q)

The control inventory policy (RP, Q) can be used as the first probabilistic model to be explained in an inventory management course, because its principles can be applied (or these can be modified easily) to others existing inventory control policies.

The calculation of the parameters of this model, that is, the definition of the reorder point and the fixed quantity to order, can be found using different decision rules. For example, the order quantity can be calculated with the economic order quantity (EOQ) or with the finite replenishment economic order quantity (FREOQ) when there are capacity constraints. Also this quantity can be calculated considering quantity discounts, the inflation, the sizes of the products, etc, or simply because there are constraints of suppliers or processes (that is called technical lots). Moreover, the reorder point can be calculated based on minimizing costs, on customer service or on aggregate considerations (Silver et al, 1998). Because of this there are a lot of possibilities and therefore the use of electronics spreadsheet becomes critical, since no matter the type of considerations or models used, these can be developed easily, quickly and accurately, three characteristics necessary in any inventory management model.

Figure 2 shows the predesigned electronic spreadsheet used by students in the inventory management course to calculate the parameters of the (RP, Q) model as well the performance measures, using one of the decision rule based on customer service, known as Units Service Level (USL) or Fill Rate. In this worksheet are shown two scenarios: (1) without variability in the lead time (column E) and (2) with variability in the lead time (column F). In both cases, the order quantity is calculated as the EOQ and we supposed that we have 12-month of historical demand with a random behavior of data and that the errors of forecasting should have a normal distribution. In this example, the expected demand is obtained with the average of the 12 months (which suppose a high stability of data) and the standard deviation of errors of forecasts is calculated using model of forecasting mean.

| A | B | C | D | E | F |
|---|--------------|---------------|------------------------------------|----------------------------------|-------------------------------|
| MODEL (PR, Q) WITH DECISION RULE BASED IN USL | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | Month | Demand | Data | Without Variability in LT | With Variability in LT |
| 7 | 1 | 210 | D | | |
| 8 | 2 | 270 | LT | | |
| 9 | 3 | 260 | VAR LT | | |
| 10 | 4 | 370 | MONTH | | |
| 11 | 5 | 450 | A | | |
| 12 | 6 | 500 | v | | |
| 13 | 7 | 450 | r | | |
| 14 | 8 | 470 | B2 | | |
| 15 | 9 | 490 | P2 or USL | | |
| 16 | 10 | 480 | Q | | |
| 17 | 11 | 520 | XI | | |
| 18 | 12 | 420 | Dd | | |
| 19 | | | XLT | | |
| 20 | | | σ_l | | |
| 21 | | | σ_L | | |
| 22 | | | | | |
| 23 | | | Gu (k) Rule | | |
| 24 | | | k | | |
| 25 | | | $pu > (k)$ | | |
| 26 | | | ss (security stock) | | |
| 27 | | | PR (reorder point) | | |
| 28 | | | | | |
| 29 | | | Co (Order Cost) | | |
| 30 | | | $Cm Q/2$ (Carrying Cost of $Q/2$) | | |
| 31 | | | $Cm ss$ (Carrying Cost of ss) | | |
| 33 | | | Cf (Stockout Cost) | | |
| 34 | | | CTR (Total Relevant Cost) | | |
| 35 | | | CT (Total Cost) | | |
| 36 | | | | | |
| 37 | | | % VARIATION OF CTR | | |
| 38 | | | % VARIATION OF CT | | |
| 39 | | | | | |
| 40 | | | P1 | | |
| 41 | | | | | |

Figure 2. Initial Predesigned Worksheet

The input data, that is the initial information required to solve the problem in the predesigned worksheet, it is shown in Table 1. It is important that each student understand the importance of this information be linked with the appropriated cells in the sheet, in order to be able to develop multiple scenarios. Alike, is important to alert the students that they do not forget to type a zero (0) in cell E9, because this cell is used for the case where does not exist variability in the lead time ($VAR\ LT=0$). Finally, it is important to stand out that most of the notation used in this paper is based on the text of Silver et al, Inventory Management and Production Planning and Scheduling, so it must be changed and adapted according with the text used in the course.

Table 1. Input Data for the pre-designed worksheet of Figure 1.

| Notation | Definition | Units | Cells |
|-----------|--------------------------------------|-------------|-----------|
| D_i | Demand of periods 1 to 12 | Units/month | B7:B18 |
| LT | Lead Time | days | E8 y F8 |
| $VAR\ LT$ | Variance of Lead Time | days | E9 y F9 |
| $MONTH$ | Number of days of the month | days | E10 y F10 |
| A | Ordering or setup cost | \$/order | E11 y F11 |
| v | Unit variable Cost | \$/unit | E12 y F12 |
| r | Carrying charge | \$/\$/year | E13 y F13 |
| B_2 | Fractional charge per unit stock out | % | E14 y F14 |
| USL | Expected Unit Service Level | % | E15 y F15 |

Table 3 shows the notations and the cells that should be formulated in the worksheet with their respective formulations, both mathematical and in excel, in order to get the parameters and the performance measures of the model, represented by the costs and service levels expected. Students should first enter the input data listed in Table1 and after that, formulate the cells referred in Table 2, in the same order as they are shown.

Table 2. Formulation of the pre-designed worksheet.

| Cell in Sheet | Notation | Definition | Mathematical Formulation | Excel 2007 Formulation* |
|---------------|------------|--|-------------------------------------|-------------------------------|
| E7 – F7 | D | Annual Demand | $\sum D_i$ | =SUM (B7:B18) |
| E16 – F16 | Q | Economic Order Quantity | $\sqrt{\frac{2AD}{vr}}$ | = SQRT ((2*E11*E7)/(E12*E13)) |
| E17 – F17 | Xl | Average Demand per Month | $\frac{\sum D_i}{n}$ | =AVERAGE(B7:B18) |
| E18 – F18 | Dd | Daily Demand | $\frac{Xl}{mes}$ | =E17/E10 |
| E19 – F19 | XLT | Forecast or expected demand over the lead time | $Dd * TS$ | =E18*E8 |
| E20 – F20 | σ_l | Standard Deviation of Forecast Errors | $\sqrt{\frac{(D_i - Xl)^2}{n - 1}}$ | =DESVEST(B7:B18) |

| Cell in Sheet | Notation | Definition | Mathematical Formulation | Excel 2007 Formulation* |
|---------------|------------|--|---|-------------------------------------|
| E21-F21 | σ_L | Standard Deviation of Forecast Errors over the lead time | $\sqrt{E(TS) \times VAR(D) + [E(D)]^2 \times VAR(L)}$ | =SQRT(((E8/E10)*E20^2)+(E18^2)*E9)) |
| E23-F23 | $G_u(k)$ | Decision Rule for USL based on lost sales | $\frac{Q}{\sigma_L} \times (1 - USL)$ | =((E16*(1-E15))/E21 |
| E24-F24 | k | Safety factor | Find in normal distribution tables | Find in normal distribution tables |
| E25-F25 | $pu(k)$ | Probability of have stock outs | $\int_s^{\infty} f_x(x_0) dx_0$ | =1-DIST.NORM.ESTAND(E24) |
| E26-F26 | ss | Safety stock | $k \times \sigma_L$ | =E24*E21 |
| E27-F27 | RP | Reorder Point | $XTS + ss$ | =E19+E26 |
| E29-F29 | Co | Expected Ordering Cost | $\frac{AD}{Q}$ | =(E11*E7)/E16 |
| E30-F30 | Cm Q/2 | Expected Holding Cost of Q/2 | $\frac{Q}{2} vr$ | =(E16*E12*E13)/2 |
| E31-F31 | Cm ss | Expected Holding Cost of ss | $ss \times v \times r$ | =E26*E12*E13 |
| E33-F33 | Cf | Expected Stockout Cost | $\frac{DB_2 v G_u(k) \sigma_L}{Q}$ | =(E7*E14*E12*E23*E21)/E16 |
| E34-F34 | CTR | Total Relevant Cost | C_f | =E33 |
| E35-F35 | CT | Total Cost | $C_o + C_m + C_f$ | =(E29+E30+E31+E33) |
| E40-F40 | P1 | Order Service Level | $1 - pu(k)$ | =1-E25 |

According to Table 2, from the calculations of standard deviation of forecast errors over the lead time (cells E21 and F21) the values of all others cells for both scenarios change, so it is necessary typing the formulas of columns E and F, relating them only to their respective column.

The decision rule used in this example is based on unit service level for the case of lost sales (cells E23 and F23). To find the value of the safety factor (k) it is necessary that students use a lookup table of the unit normal distribution that contains the special function $G_u(k)$ to calculate the expected shortage per replenishment cycle, which can be found in almost any textbook of inventory management (Silver, 1998, pp724-734). Thus, the students must select of the table the value of k that satisfies (for each scenario) the value found in cells E23 and F23. Alternatively, rational approximations can be developed in Excel to get the value of k (Ballou, 2004; Silver et al, 1998), but such approach is not shown in this paper.

Figure 3 shows the final spreadsheet with the two scenarios proposed above, where students make a parallel of the model when exist or not variability in the lead time. In cells E37 and E38 are the percentages of variation of the total relevant costs and of the total costs of the model, which are calculated as the relation when it has variability in the lead time with respect

when it does not exist. With this kind of comparison, students can understand for example, the economic effects that imply for a company to have suppliers or unreliable processes in terms of the variability of the lead time. In addition, the calculations of the performance measures allow that students comprise the impact and implications that an specific decision rule have on the expected costs (cells E29 to F35) and on the expected order service levels (cells E40 and F40), so they can determine when a decision rule or even a control policy should be changed.

| A | B | C | D | E | F |
|----|--|---------------|-------------------------------|----------------------------------|-------------------------------|
| 1 | MODEL (PR, Q) WITH DECISION RULE BASED IN USL | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | Month | Demand | Data | Without Variability in LT | With Variability in LT |
| 7 | 1 | 210 | D | 4890 | 4890 |
| 8 | 2 | 270 | LT | 7 | 7 |
| 9 | 3 | 260 | VAR LT | 0 | 3,5 |
| 10 | 4 | 370 | MONTH | 30 | 30 |
| 11 | 5 | 450 | A | 3000 | 3000 |
| 12 | 6 | 500 | v | 6000 | 6000 |
| 13 | 7 | 450 | r | 0,25 | 0,25 |
| 14 | 8 | 470 | B2 | 0,55 | 0,55 |
| 15 | 9 | 490 | P2 or USL | 0,95 | 0,95 |
| 16 | 10 | 480 | Q | 139,8570699 | 139,8570699 |
| 17 | 11 | 520 | XI | 407,50 | 407,50 |
| 18 | 12 | 420 | Dd | 13,583333333 | 13,583333333 |
| 19 | | | XLT | 95,083333333 | 95,083333333 |
| 20 | | | σl | 105,32 | 105,32 |
| 21 | | | σL | 50,87640996 | 56,86988128 |
| 22 | | | | | |
| 23 | | | Gu (k) Rule | 0,137447856 | 0,122962337 |
| 24 | | | k | 0,721091579 | 0,787003197 |
| 25 | | | pu>(k) | 0,235426586 | 0,215639997 |
| 26 | | | ss (security stock) | 36,68655078 | 44,75677836 |
| 27 | | | PR (reorder point) | 131,7698841 | 139,8401117 |
| 28 | | | | | |
| 29 | | | Co (Order Cost) | \$ 104.893 | \$ 104.893 |
| 30 | | | Cm Q/2 (Carrying Cost of Q/2) | \$ 104.893 | \$ 104.893 |
| 31 | | | Cm ss (Carrying Cost of ss) | \$ 55.030 | \$ 67.135 |
| 33 | | | Cf (Stockout Cost) | \$ 806.850 | \$ 806.850 |
| 34 | | | CTR(Total Relevant Cost) | \$ 55.030 | \$ 67.135 |
| 35 | | | CT (Total Cost) | \$ 1.071.666 | \$ 1.083.771 |
| 36 | | | | | |
| 37 | | | % VARIATION OF CTR | 21,9978% | |
| 38 | | | % VARIATION OF CT | 1,1296% | |
| 39 | | | | | |
| 40 | | | P1 | 0,764573414 | 0,784360003 |
| 41 | | | | | |

Figure 3. Final Predesigned Worksheet

An important feature of the use of predesigned spreadsheets is that they can be modified to teach or to evaluate other decision rules (for example based on minimizing costs) or for other systems of inventory management (for example for periodic review systems). In such practices, students must make the changes in the initial spreadsheet to implement other decision rules or models, so the teacher can identify the degree of comprehension, the analytical skills and the

proficiency that have been acquired by students to implement inventory management models. Equally, it is important to highlight the possibility that the spreadsheets provided to make comparisons, because, in addition to understand the running and features of each model or decision rule, when some scenarios are evaluated there are more information to make the better decision.

Finally, through the use of spreadsheets, students can make sensibility analyzes, varying the initial parameters that affect the performance of the models such as: the ordering cost, the carrying cost, the stockout cost, deviations (both of the forecast of demand as of the lead time), service levels, etc., so they can understand the robustness of the models, analyze the effects of change the parameters, learn to parameterize a model using some decision rules and develop and implement different inventory management policies, which are all essential competences that should be achieved by students in a inventory management course.

Summary and Future work

The electronic spreadsheets used to support the teaching and learning processes in different topics of Operations Management and Logistics (OM&L), it is a practice increasingly used by teachers and instructors at graduate and undergraduate levels, mainly in those courses that require handling large volumes of information, demand a high use of mathematical models and where the precision is necessary for a big quantities of calculations, as in the case of a course of Inventory Management.

This paper presents an example of predesigned spreadsheet developed in Excel® used in the graduate course Warehousing and Inventory Management of the Master in Operations Management and Logistics at Eafit University, in Medellin, Colombia, to teach and explain the model of reorder point, fixed quantity (RP, Q) using the decision rule based in the Units Service Level (USL), emphasizing in both mathematical and Excel formulations, which could be used as a guide for teachers and instructors, after making the necessary changes and adjustments according to the models, books and notation used in their inventory management courses.

The spreadsheet displayed is not restricted to the explained model. This can be easily modified to explain other inventory models and decision rules, as well as include other relevant factors in inventory management such as the forecasting models and the variability of the lead time. The development of this kind of spreadsheets, the use of these in the classroom and the measurement of the impact of it in the teaching and learning process of the students are a part of the future work of this research.

Acknowledgements

I am grateful with Eafit University for its funding and support. I also thank everyone whom helped me with their comments and suggestions that resulted in a substantial improvement of this manuscript.

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