Logistics control
in lead-acid batteries production process

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ABSTRACT

Controlling inventory levels, logistics and production processes are a key role to the proper functioning of any supply chain.

The primordial aim of this Dissertation was the implementation of the IEP project towards the optimization of inventory levels to actual consumption and production needs of lead-acid batteries, to reduce the inventory value in 1 million euros comparing to the previous fiscal year. Therefore, different methods were used to build an inventory management system such as: ABC-XYZ analysis, low turnover inventory ratio identification, days-on-hand and cycle counting. So, by the end of the project implementation, it was achieved a reduction of the inventory value higher than the proposed one.

Subsequently, it was aimed the creation of an aggregate production plan for the assembly of batteries. Besides monitoring the assembly production by shift, this plan should also provide the needs of plates and raw materials to supply the assembly lines in their corresponding consumption shifts. By analysing the batteries BOM (bill of materials), it was created a detailed assembly production plan, which generated an MRP (material requirements planning) for both the preceding production process and the raw materials warehouse.

Finally, the Supply Chain KPI (key performance indicators) were studied to develop a solid daily control system of the logistics process. This task was crucial to restore the level of confidence with customers and the Group in which the Company operates. All these KPI, that evaluate the batteries flow from the assembly lines until the customer shipments, were improved and remained above its performance targets.

Keywords: inventory management; ABC-XYZ analysis; production plan; BOM, MRP, Supply Chain, KPI.

1. INTRODUCTION

The multinational group Exide Technologies is the global leader in lead-acid batteries production. The group operates worldwide within two different market segments: transportation and industrial. The first is related to automotive batteries used in vehicles and the latter is associated to motive and network batteries used in traction and stationary applications, respectively.

All described tasks hereafter took place at the Exide Technologies plant in Castanheira do Ribatejo, Portugal, which belongs to Exide's Industrial Energy Europe global business unit. In Castanheira plant there are three types of lead-acid batteries production: AGM, GEL and GROE. AGM and GEL batteries are VRLA (valve-regulated lead-acid batteries) where the electrolyte is fixed to allow oxygen recombination; while GROE batteries are flooded or vented ones with free electrolyte

Generally, the manufacturing process can be divided in plates (lead electrodes) production and in battery assembly, charging and finishing, sequentially. The plates are the electrodes of the lead-acid system and in assembly are combined with the separator to form a cell. The cells are placed in plastic boxes and covered with lids and double-lids. After filled with the acidic electrolyte the batteries proceed to the charging where they are electrochemically formed. Finally, when all testing is concluded and approved, the batteries are finished, palletized, packed and sent to expedition.

Then different materials are needed in each step of the production process, either raw materials or work-in-progress (WIP), until the batteries are ready to be shipped. To assure both the production flow doesn't have any rupture and the inventory level is not oversized, there must be a functional inventory management.

Besides the inventory management, it's essential to know what is the production plan for the key manufacturing area — assembly — and what are its material (and capacity) requirements by shift, given a load levelling (LL) production proposal and acceptance for a working week. This allows everyone in the structure to monitor the assembly production and to perform accordingly regarding the different planned batteries production by assembly line.

Exide Europe's supply chain links both business units (Transportation and Industrial) between its plants and distribution centres (DC). Generally, each plant operates in only one of the two segments and the different European distribution centres are supplied with finished batteries according to its needs. So, the distribution centres are internal customers of the plants. Therefore, there are a set of key performance indicators (KPI) that monitor the performance of this process in the supply chain, individually (plants and DC) and globally (European wide). Thus, it is essential that the targets by KPI are met to sustain the whole supply chain.

2. EXPERIMENTAL

2.1. Problem description

This study deals with three areas of Castanheira plant supply chain: (i) implementation of inventory management; (ii) development of the assembly production plan and its material needs; and (iii) comprehension of the supply chain KPI and consequent creation of a system to control them.

The initial objective of this Dissertation was the implementation of the Exide own IEP (inventory excellence program) project in the Castanheira plant, in order to optimize inventory levels to the actual consumption and production needs, reducing the inventory value in 1 million euros comparing to the previous fiscal year. This project was critical to improve the financial health of the group, especially in the United States, where the headquarters is based.

Using historical data from Exide's information system, *Phoenix/AS400*, and a consistent methodology (like the ABC-XYZ analysis) it was expected the creation of a full diagnostic, monitoring and prediction controlling tool in the controlling department to implement the inventory management throughout the plant.

With the acquired knowledge, the transition to the Production department had the purpose to develop the existing assembly production plan to a new level. This new aggregate production plan, besides monitoring the assembly, would trigger the needs of plates and raw-materials to be supplied to the assembly lines in their consumption shifts. This would be a practical information tool to everyone, mainly to the warehouse and the preceding production process to know what, when and where to supply the required materials, because it is impossible to parametrize a shift in *Phoenix/AS400*.

Unfolding the batteries BOM (bill of materials) in *Phoenix/AS400*, it was desired to have an integral aggregate assembly production plan for common use and to be used in parallel with the official information in *Phoenix/AS400*.

Finally, in the Planning department, the goal was to develop a solid control system of the logistics process using KPI. Most of the official supply chain KPI were only calculated weekly by Central Supply Chain team in Europe's headquarters; and in Castanheira plant the majority of these KPI measurements was unclear. Besides that, the KPI results were not satisfying for Castanheira plant, so it was highly imperative to the confidence with the customers and within the Exide Technologies group.

For that reason, it was important to have a monitoring and predictive KPI system to control the whole process from batteries assembly until its customer shipment.

The correct use of *Phoenix/AS400* data reports was fundamental to all parts of this Dissertation.

2.2. IEP project

Besides holding costs, high inventory levels also hide productivity issues —downtimes, overdue, scrap, obsolescence, oversized quantities, misfit layout— as it was the case in Castanheira's plant, where the reigning culture was set to satisfy the production objectives, like the OEE (overall equipment efficiency), without any relevant care concerning inventory levels. So, the IEP project also targeted that culture change, where the inventory management is seen as a key player in the whole operations system. That is why the focus of the project was on raw materials and work-in-progress, leaving finished goods out of the scope.

The first step towards the implementation of the inventory management system was the classification of stock keeping units (SKU) in Phoenix/AS400. As it is imaginable, given the size of the plant, there are thousands of items codified in the system. So, it would not be practical to classify the article by article. For that matter, using financial and accounting codes that are present in Phoenix/AS400 reports it was possible to create a database for all SKU, sort by IEP group —lead (main raw material, so treated individually) (LEAD); manufacturing raw materials (RM); logistics raw materials (RM L); work-in-progress (WIP); and finished goods (FG)— and IEP category (several classes of material that constitute a battery, such as: lead and lead alloys; grids; additives; plates; separators; boxes; lids and double lids; plugs, vents and valves; smelting parts, green batteries; labels; finished batteries; set of network accessories; others).

Afterwards, it was a built the value-stream mapping (VSM), which is a lean technique that visually represents the whole flow of materials and information in the logistics and manufacturing process. The VSM allows the identification of inventory allocation, generation and consumption in each step of the process, as well as the bottlenecks. Then, the VSM can be used as the basis of an implementation action plan with the identification of *kaizen* bursts (improvement opportunities) that reduce the total lead time of the process. Common symbols are used to identify inventory, production and other processes. The main information present in the VSM is: inventory value; days-on-hand (DOH); complexity (number of SKU per equipment); cycle time; and lead time. All these were calculated, but as the process is too big and complex to be confined into that visualisation, the VSM was only used as a mean to globally know the process and to identify improvement opportunities.

At the same, a much more used tool was built, the ABC-XYZ analysis, using Phoenix/AS400 stock and movement data reports. Not all items in stock have the same importance to Castanheira plant, so they must have different stock policies accordingly. The ABC-XYZ analysis categorizes the materials by importance (ABC) and variability of consumption (XYZ). The criteria used to this analysis can change from sector to sector and with the purpose of the results. For the IEP project the criteria was the value of consumption for ABC analysis and (volume of) consumption for XYZ analysis (Table 1).

Table 1 – ABC-XYZ criteria.

Class	Criteria
A	High value of consumption (80%) - minority of articles (5-10%)
B	Moderate value of consumption (15%) - moderate quantity of articles (10-30%)
C	Low value of consumption (5%) - majority of articles (60-80%)
X	Regular consumption variation (≤30%); high demand
Y	Great consumption variation (30-60%); medium demand
Z	Irregular consumption variation (>60%); sporadic demand

The inventory management policies that result from this dual classification are resumed in Table 2.

Table 2 – Inventory policies for the ABC-XYZ analysis.

Analysis	A	B	C
X	JIT	JIT	MTS
Y	JIT	MTS	MTS
Z	MTO	MTO	MTS

The just-in-time (JIT) approach is a based on producing and consuming what, when and where is needed, synchronizing flows and decreasing cycle times, in order to avoid waste, so minimizing inventory levels. Make/build-to-stock (MTS/BTS) is a strategy based on producing (or ordering) items to stock according to its demand. Whereas, make/build-to-order (MTO/BTO) is a strategy that only starts production after an order intake from the customer.

To build the analytical tool it had to be calculated the Pareto analysis (ABC) and the variation coefficient (XYZ) for all SKU. The ABC-XYZ analysis was updated on monthly basis and became a tool of excellence concerning inventory management, by prioritizing the material.

Another important task was the identification of low turnover stocks and obsolete materials. If it makes all sense to focus the majority of attention on the most important high-runners, low turnover stocks cannot be ignored. Each day these materials, so-called *monos*: occupy space, face the risk of obsolescence and require resources associated to holding stocks.

Using stock and movement data reports from *Phoenix/AS400* it was possible to create a tool able identify *monos* in the system. It is important to note that *Phoenix/AS400* is permeable to user mistakes, so sometimes there may be some situations where *monos* in system are not matched by *monos* in the shop floor. This way, it was important that a team of different departments analyzed the identified *monos* in system to confirm them or not. Once confirmed, the *monos* were: sent to scrap; stored until there new work or customer order; or sold to other plants within the Exide group.

The criteria used to identify *monos* was the absence of any kind of movement in *Phoenix/AS400* over the last two years.

One of the ways to control and monitor inventory levels was the creation of a common KPI for all plants all over Europe. This KPI, inventory ratio (IR) allowed to compare the available stock in days between same dimension and complexity plants.

$$IR\ (days) = \frac{Inventory\ value\ (€)}{Adjusted\ FMC\ (€)/30\ days}$$

As seen in the above equation the IR is based in the full manufacturing cost (FMC) adjusted to the actual lead cost during the fiscal year normalized for a month and the stock value. So it is similar to the traditional days-on-hand calculation, however, as it doesn't takes into account the actual consumption of an item, there is a bigger probability of deviation. Anyway, in terms of financial result, the IR is more close to the reality the reality. And that's why it was used in almost every developed tool, because it was the official metric for the IEP project.

The definition of this KPI allowed the creation of a daily inventory report by group of material IEP and by warehouse's bin locations. The report had clear objectives in terms of IR and stock value, using the forecasted adjusted FMC for the month. In the end of that period, already with the actual adjusted FMC the report would become official.

To control any logistics or production system it is required a high precision between what the records say and what is really in stock. According to Exide's own policy, every fiscal year quarter there was a general stock take for all warehouses.

Adding to that, under the actions taken during this Dissertation, based on the ABC-XYZ analysis and *monos* identification in *Phoenix/AS400* it was used the cycle counting technique. This is a method that counts frequently the stocks, instead of one, two, three or four times a year. The key point to this technique is to decide what materials should be counted and in what periodicity. That is why the ABC-XYZ is fundamental, as it shows the importance of each material. So, the most important materials must have a more rigorous control (for example, articles from class A).

With all tools and methodologies implemented it was fair to say there was a functional inventory management system in action. This, as well as the whole team (several departments) effort, led to achieving the target set by the IEP project managers, with a stock (Figure 1).

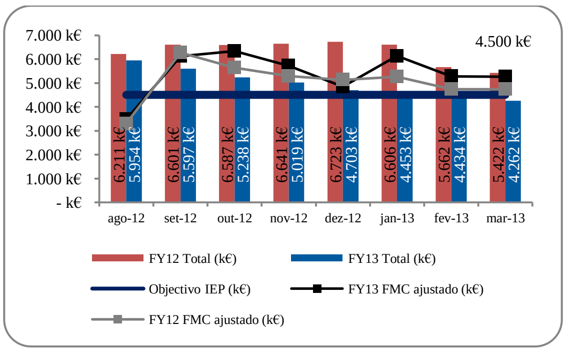

Figure 1- IEP inventory evolution during the project implementation; and comparison to the previous fiscal year.

The inventory value reduction in the end of the project IEP implementation was over 1 million euros, comparing to the end of the previous fiscal year. The result show the adaptation of inventory levels to actual consumption and production needs as the FMC during the implementation phase had a similar or higher value than the year before.

2.3. Assembly aggregate production plan

The assembly of batteries is the most important manufacturing area of Castanheira plant. This is verified all over European plants from Exide group. The budget, production proposals and labour, just to mention these, are all based on the number of batteries to be produced in the assembly process.

In Castanheira plant production process there is a push-pull strategy. The needs of the production processes before assembly are all successively dependent from the preceding process (pull); whereas for the finishing process, all batteries that have been assembled and charged are set to be finished (push). So, assembly is the decisive process, not only in the production process, but also in the whole supply chain, because every week Central Supply Chain team provides a load levelled production proposal per assembly line for week *n*+2, using *Manugistics* — software used by Exide to control the supply chain.

So, it was essential the development of the existing tool (simple production plan) to control the whole assembly area, in parallel with the information in the system. In *Phoenix/AS400* it is impossible to schedule or check a work order by shift. That way, everyone would benefit, not only the agents from the assembly process, but also the raw-materials warehouse and cutting process (process before assembly), would exactly know the material needs to supply by shift. In the past this was a bottleneck in what concerns the information flow.

Using the batteries BOM it was possible to improve the weekly assembly production plan with information that: facilitated the production declaration in *Phoenix/AS400*; monitored the performance by shift with planned, produced and capacity quantities, so it was possible to know the number of shifts and direct labour needed; provided the number of changeovers.

Once the assembly production for a week was planned shift by shift it would initiate the automatic calculations (BOM) for two dependent tools: cutting needs and production plan; and components (raw-materials) needs plan. Both of them were MRP.

Therefore, the assembly control and supply improved significantly, as all the developed tools became commonly used by everyone. The success of this set of tools was demonstrated by the fact that sometimes most departments considered those plans the official ones, when the only information data available is provided by *Phoenix/AS400*. Nonetheless, most of the whole assembly aggregate production plan is not available elsewhere. It should be noted that with number of shifts and workers needed by day, this plan also constitutes in a certain way a capacity requirements plan (CRP).

2.4. Logistics chain control

Key performance indicators are essential management tools in any industry, because they allow the success measurement of a company or process. There are several KPI for the different departments and for the whole Castanheira plant. From the supply chain point of view, all European plants from Exide group are evaluated in different stages of the chain: planning, production and expedition. The main KPI used for that matter are: committed manufacturing plan (CMP), manufacturing levelling compliance (MLC), build-to-schedule (BTS) and on time internal delivery (OTID). The fist of this KPI is applied to the plant, while the others measure the supply chain performance.

The majority of these KPI were not daily followed-up in Castanheira plant and in some cases its calculations were unknown. This reflected in poor results in those KPI (especially the supply chain ones) in the past, which made the customers and the Exide group distrust Castanheira plant agreed terms. That way, in order to create a solid daily controlling system of these KPI it was needed to understand its foundations.

All the supply chain KPI result from the Central Supply Chain software — *Manugistics* (MANU) — that manages manufacturing and logistics all over Europe for both plants and distribution centres. For plants, specifically for the Castanheira one, every Thursday MANU calculates a load levelled production proposal for assembly on week *n*+2. This load levelling results from the parameters plant provide to the software matrix, as well as customer orders intake and forecast at the distribution centres. The proposed planned must be accomplished on the respective week and afterwards, given the lead time until finishing the batteries, the customer shipments have to be done on time.

Then, the distribution centres are the internal customers of the plants. They can place two different types of orders: intercompany (IC) — through MANU; and direct shipments (DS) — directly at the plants. As the supply chain KPI only care about the MANU flowing process, the IC orders are the ones that count.

For the operations management of the Exide group, CMP is the KPI that allows measuring the production volumes per product family in every plant. This is monthly production plan must be totally fulfilled, that is why it is the reference KPI in Castanheira plant.

The conception of CMP is mainly based in the stock balance (days-on-hand) and demand forecast for all locations. Then, the CMP for each product family in Europe is built and subsequently is constituted the product mix per plant.

Knowing the product mix for a given month and its working days it is possible to follow the daily evolution of CMP, to predict it and to react accordingly. This was instituted under the developed tool for this Dissertation — production report — that also traces the MLC, BTS and all production in the different parts of the process.

Table 3 – Total CMP achievement for fiscal year 2016.

Family	CMP %
AGM MC blocs	**101%**
AGM MC blocs XP/XL	**98%**
AGM FT blocs	**94%**
AGM L2V cells	**107%**
Defence blocs	**99%**
Light vehicles (L3)	**91%**
Motorcycle	**86%**
GEL 01/A700 blocs (LQXs)	**225%**
GEL 07 blocs	**104%**
GROE	**96%**
Total	**99,90%**

The total CMP for fiscal year 2016 was around 99,9% of fulfilment (Table 3), but some battery families did not have such good result, especially the ones from assembly line A6. This is related to conflicts between the MANU production proposals, which do not take into account the product mix, but the costumer and forecast orders.

The MLC is related with the acceptance of the weekly LL assembly production plan proposed by MANU. Plants must confirm at least 85% of the proposed work orders (WO). For the calculation of this KPI, all extra work orders confirmed are not taken into account.

$$MLC_{WO}\ (\%) = \frac{Confirmed\ quantity\ (no\ extras)_{WO}}{Proposed\ quantity_{WO}} \times 100\%$$

Once the weekly assembly production plan is confirmed it must be fulfilled. BTS is the KPI that measures this. Like MLC, BTS as target of producing 85% of the work orders confirmed. Again, all extra production is not accounted for the KPI. However, all confirmed work orders, even those extra to the proposed plan, are considered.

$$BTS_{WO}\ (\%) = \frac{Produced\ quantity\ (confirmed\ WO\ with\ no\ extras)_{WO}}{Confirmed\ quantity_{WO}} \times 100\%$$

Finally, the last KPI of supply chain (perhaps the most important one) is related to shipping on time to the internal customers. After a declaration of production in assembly for an MANU proposed work order, automatically it is created an IC customer order with a defined delivery date given by the lead time from assembly until finishing per type of battery. This information is provided to MANU by plants.

The delivery date must be met on time and that is the scope of the OTID. This KPI evaluates the on time delivery to internal customers on a week. The foundation of the KPI is a bit different of the others. To begin with customers, the only ones that count are the European distribution centres, excluding the own (Portuguese) market. Then, the batteries produced under Transportation global business unit (bike and a type of defence batteries) also don't count for OTID. Lastly, OTID represents the fraction of shipments against backlog (overdue quantity) and these are considered differently. All shipments from the last five working days are considered daily, while the backlog from the last two weeks is considered, except the first three days of delay. This means that a customer order is only in backlog after three days of delay, so there is space to manage shipments.

$$OTID_{daily}\ (\%) = \frac{Shipments_{\sum last\ 5\ working\ days}}{Backlog_{>3\ days, \sum last\ 11\ days} + Shipments_{\sum last\ 5\ working\ days}} \times 100\%$$

$$OTID_{weekly}(\%) = \frac{\sum Shipments_{daily}}{\sum Backlog_{daily} + \sum Shipments_{daily}}$$

The OTID, as well as all customer orders (IC or not) were followed in the created OTID report.

On Table 4 it is summarized the supply chain KPI results from fiscal year 2015 to fiscal year 2016 (when the control was introduced). All KPI were above target over fiscal year 2016 and with less dispersion. That means the supply chain activities in Castanheira plant became controlled.

Table 4 – Supply chain KPI summary.

KPI	MLC	BTS	MLC x BTS	OTID
Target	**85%**	**85%**	**72,50%**	**90%**
FY15 average	86,90%	82,90%	74,40%	88,40%
FY15 standard-deviation	10,40%	7,90%	11,00%	5,20%
FY16 average	**89,10%**	**93,30%**	**83,20%**	**92,10%**
FY16 standard-deviation	4,00%	3,70%	4,60%	4,90%
Δ average	**2,20%**	**10,40%**	**8,80%**	**3,80%**
Δ standard-deviation	**-6,50%**	**-4,20%**	**-6,40%**	**-0,30%**

As noted that the MANU LL production proposal future vision was constantly changing for all assembly lines, it was decided to create an internal non-official KPI to measure that variation. So, this KPI measured the precision of the MANU proposal from week *n*-3 (forecast) with the one from week *n*-2 (actual proposal).

Table 5 – Manugistics precision for fiscal year 2016.

Assembly line	MANU average precision	Standard deviation
A2	45%	20%
A3	50%	18%
A4	47%	44%
A5	50%	20%
A6	71%	31%
A7	40%	27%
A8	43%	35%
Total	**47%**	**9%**

The result from Table 5 totally shows the imprecision of the MANU LL proposal regarding the forecast of the previous week. Therefore, some stock level is needed to face the constant wrong forecast.

By the end of the Dissertation tasks, Castanheira plant was using all developed tools, except the VSM, on a regular basis. This clearly shows the success of the implemented tools.

Conclusions

The study done within this Dissertation was important to the company’s strategy, because provided efficient diagnostic, control and forecast means of the logistics and manufacturing processes.

Regarding the inventory management, the targets were attained both locally and globally. In Castanheira plant it was introduced a methodology to control the inventory levels that is still in use in the present days. The Exide group emerged from the difficult financial situation with the good results from different reorganization strategies, in which the IEP project was included.

The assembly aggregate production plan enabled the Production department to react more efficiently, according to the plan’s data, to different situation it faces on a daily (shift) basis. For other departments, the plan became the way to follow the assembly productions and planning. The MRP features of the plan (raw-materials and plates) improved a lot the flow of materials in both ways. This set of tools is updated every shift, currently.

The discovery of the foundations of the supply chain KPI was essential to the construction of the whole solid system, which contributed to the improved results.

In the fiscal year 2016, Castanheira’s plant distrust from customers and the Exide group was completely changed. The plant achieved a whole year of BTS and MLC above the minimum target, which was a record never seen before. The OTID was also positive for the majority of the year, contrarily to what was observed in the previous year.

However, *Manugistics* precision, calculated internally, was quite low. It was very strange to realize that in just the proposal changes so much.

Regarding future prospects, the main opportunities are related with: the introduction of the economic order quantity models in a methodic way; programming Exide’s information system, Phoenix/AS400 to have more features; introducing some sort of target to *Manugistics* proposal or to define a better the proposal is generated globally.