

Study of measures to monitorize operational performance

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Abstract

This thesis describes how IBEROL - Sociedade Ibérica de Biocombustíveis e Oleaginosas, S.A., henceforth referred to as IBEROL, was able to minimize its information flow global lead time, by developing Microsoft Excel tools, along with Visual Basic for Applications (VBA) scripts, which automatize the calculation process of Key Performance Indicators (KPI). This work's objectives were to improve IBEROL's information process's efficiency, eliminate waste and reduce its global information lead time, and were aligned with the company's Kaizen methodology. The duration of each process step was measured, following a Critical Path Method (CPM) methodology. Gantt charts were generated, before and after these changes were implemented, representing the duration of all process steps that belong to the global information flow. Results show that IBEROL's global information flow lead time was reduced by 40,1% (62 minutes), and there was a 64% reduction on the number of non value-added activities. The number of Microsoft Excel files, paper documents, rework steps, manual calculation steps and general waste were reduced on the intervened company units - Biodiesel Production Unit, Preparation/Extraction, Silos and Warehouses, Laboratory and Electrical Maintenance. A statistical study was made, in order to obtain better correlations for the estimation of rapeseed and soybean stocks in the silos, based on their geometry and dimensions. Two equations were obtained, one for each type of seed, that validate the empirical/heuristic equations already in use. Also, four other equations were obtained, two for each type of seed, one to be applied to the top section of the silo, and the other to its pyramidal bottom section.

Keywords: Kaizen, Lean Methodology, KPI, biodiesel, soybean meal

1. Introduction

IBEROL - Sociedade Ibérica de Biocombustíveis e Oleaginosas, S.A. was established in 1967, in Alhandra, Portugal, producing rapeseed meal and soybean meal for the animal feed industry. From 2004, it is, also, the leader of Portuguese biodiesel market, producing it from raw oil extracted from rapeseed and soybean seeds. Today, IBEROL produces roughly 450 thousand tons of rapeseed meal, 170 thousand tons of soybean meal, and 110 thousand tons of biodiesel, mainly to Iberian customers[1].

After arriving at IBEROL, rapeseed and soybean seeds are pre-treated, in order to enhance oil extraction by mechanical pressing (Preparation Unit). Then, the remaining raw oil is extracted by contact with liquid hexane, and physically degummed (Extraction Unit). Then, the oil is transferred to the Biodiesel Production Unit, where it is mixed with other types of degummed oil. Here, it goes through a chemical refining process (Neutralization) and, then, is converted to biodiesel by a transesterifi-

cation reaction, with a mixture of methanol and methylate acting as catalyst [1].

This work is integrated on a Kaizen methodology [2] Lean culture, recently embraced by IBEROL, which encompasses key concepts like "continuous improvement" [3], waste elimination [4], task standardization and KPI analysis. It began in September 2015 and ended in April 2016.

It focuses on the reduction of IBEROL's information flow lead time, waste elimination and overall increase of information processes' efficiency. For this to be achieved, KPI's need to be rapidly obtained and distributed to IBEROL's multiple production units, in order to minimize daily information lead time, that is, the time that goes from the beginning of each day, to the moment process data (consumptions, productions) is inserted in the Enterprise Resource Planning (ERP), SAGE X3. This would enable faster access to process KPI's by each production unit team members, as well as improving the efficiency of the invoicing system. Consequently, it provides more free time to be allocated to KPI

analysis by production teams, problem identification and solving and process improvement brainstorming activities, instead of wasting it on non value-added activities, such as manual calculations and transporting paper documents.

2. Background

Overall, production units were still very dependent on manual process steps and paper documents. Reworking, loop-backing for missing information or input/calculation errors were very common and time consuming. Therefore, multiple Microsoft Excel templates (hereinafter referred to as "Excel mask") were developed, in which raw material consumption, products production and KPI's were calculated and displayed; some inputs are manually inserted, and others exported from each units control computers, via Industrial Data Bridge (IDB), a Siemens add-in for WinCC[5]. These Excel masks are supported by macros developed in VBA scripting language, which ran in the background, allowing for a simpler, cleaner and user friendly interface.

2.1. Utilities Production Unit

These unit is responsible for the production of high pressure and medium pressure steam from its three natural gas boilers. It supplies cooling water and steam to Biodiesel Production Unit, Preparation/Extraction and also to external clients.

This was the first production unit to have an Excel mask, in September 2015. It automatically calculates natural gas consumption, purified (by osmosis) water and steam production, and the unit's specific KPI's. However, it was not being frequently used in this unit, because employee training was not yet been given. Therefore, the employees still had to do manual calculations on a paper sheet in order to obtain the necessary KPI's.

By January 2016, the mask was fully implemented and basic training has been given to all team members. Yet, it still coexisted with the former method of calculations.

A lot more of specific training was deemed necessary for the old method to be finally dropped off, because employees were lacking Microsoft Excel knowledge and, thus, were not sufficiently qualified and confident with operating this software.

2.2. Laboratory

In this unit, rapeseed and soybean seeds are analyzed, as well as rapeseed meal and soybean meal, full-fat soybean, biodiesel and other byproducts. The analysis results are subsequently distributed, by internal e-mail, to all business units within IBEROL.

This unit's employees are highly qualified, holding engineering degrees and, thus, are well famil-

iarized with intermediate-level Microsoft Excel utilization. Indeed, the analysis results bulletins were made in Microsoft Excel templates developed by them.

Yet, in order to achieve the main objective (reducing global information lead time), a faster issuing of report bulletins was needed. Thus, the automatic exportation of these bulletins to PDF and Excel format were required.

2.3. Biodiesel Production Unit (BPU)

In this unit, almost all process data are obtained through a software installed on its supervisory control computer, WinCC. Tank levels, process counters, temperatures and pressures, were all exported to a standardized log sheet, which was printed at the end of each labor shift. Then, the operators had to add some information which was missing from it (three process counters which have no connection to the supervisory computer, changes in biodiesel formulation proportions, etc.).

Then, his log sheet is delivered to the unit's team leader, around 9 A.M.. Then, he had to input all these data into a Microsoft Excel template ("Stocks Control"). Here, degummed oil (rapeseed, soybean, sunflower oils) consumption was calculated based on the product formulation and process counters; biodiesel production is calculated based on process counters; byproducts (glycerin and fatty acids) production and catalyst consumption were also calculated. However, the consumption of raw oil, per type of oil used in the neutralization process, as well as the consumption of each type of chemically degummed oil converted to biodiesel (transesterification), was manually calculated, requiring both the exported process data (process counters) and inputs by operators (intermediate reading of each process counter, at the moment of changing product formulation).

The daily outputs of this tool were inserted in another Microsoft Excel file, "Biodiesel Production Unit Daily Bulletin", which encompassed accumulated monthly and annual process data. Also, biodiesel and other products intakes and outlets (this information comes from the Weighbridge unit) were inputted here. Yet, the daily bulletin only is completed when missing information arrives from Silos and Warehouses unit (power and cooling water consumption), by telephone. Although this data is gathered at Utilities Central unit, it is distributed to other units by Silos and Warehouses unit leader, because he combined two functions: his unit's control and monitoring, and the company's information management.

Then, the process data is entered by the unit's team leader, in IBEROL's ERP, SAGE X3. This software has specific standard templates for inputs.

Therefore, product data is entered as Production Declaration (on for each product), and byproducts or raw materials are entered as Manufacturing Tracking.

KPI's were simultaneously calculated, by the operators, from another Microsoft Excel file, "Daily Kaizen". They were automatically printed in the form of column and line charts. Objectives and goals were not represented in these charts.

The Near-infrared spectroscopy (NIRS) results of analyzed biodiesel samples were only stored in BPU's local network. Likewise, biodiesel and degummed oil report bulletin from the Laboratory were not available in Microsoft Excel format. Therefore, both data sets could not be subjected to further analysis or benchmarked against established objectives, goals or specification limits.

2.4. Preparation/Extraction

As of the beginning of this study, this unit had no access to either Microsoft Excel, or IBEROL's internal network. Every calculation step (rapeseed and soybean oil extracted and meal; rapeseed and soybean meal and full-fat soybean production; hexane and steam consumption; effluents production) were done manually, with a calculator, and then written on a paper sheet. Unlike BPU (Section 2.3), Preparation/Extraction has very little process data coming from its supervisory computer system, with just steam and effluent production, and the oil transferred to BPU obtained in this way. All other data (hexane and raw oil tank levels) had to be manually gathered by the operators.

Then, as this data were not exported or printed, it had to be manually inserted in a daily paper sheet ("Preparation/Extraction Daily Bulletin"), where the results of manual calculations were also written. Input and calculation errors were common, leading to frequent rework by the Silos and Warehouses team leader (also, information manager.)

The biggest constraint this unit faces is that, due to the absence of a weighing scale, the real consumption of rapeseed and soybean is unknown. Thus, it is estimated, by the information manager at Silos and Warehouses, when shipping information of rapeseed and soybean meals (by applying an estimated process yield) is made available by the Weighbridge unit.

KPI's were represented in manually crafted charts, by the operators, based on data coming from Silos and Warehouses unit.

Rapeseed meal, soybean meal and full-fat soybean are analyzed every hour in the unit's NIRS equipment. Then, the results were written on a paper sheet. There were no automatic comparison with acceptance limits or digital database.

Likewise, the results of rapeseed and soybean

seeds, rapeseed and soybean meals, and full-fat soybean analysis were sent, in PDF format, by the Laboratory, deeming further results analysis and benchmarking impossible.

2.5. Silos and Warehouses

This unit acted as an information distribution center, receiving daily bulletins from all other production units, because its team leader was also the company's information manager.

Here, other production units' daily bulletins are verified and corrected, and the consumption of rapeseed and soybean is calculated. This is done manually, on a paper sheet. The only Microsoft Excel files used here were utilized to generate graphical representation of KPI's.

After calculating consumption and production relating to the Preparation/Extraction unit, the team leader enters these data into another Microsoft Excel file, "Control an Operations Map" and, then, also inserts Production Declarations and Manufacturing Tracking into SAGE X3 (because of his double job as team leader and information manager).

2.6. Control and Operations Map (COM)

This tool, at first developed on Quattro Pro, was fully replicated into an Microsoft Excel version by September 2015. It is operated by the information manager/Silos and Warehouses team leader.

Essentially, it acts as a repository of all process data gathered from IBEROL's production units, requiring manual input of raw material consumption and products production data. Then, it automatically allocates some products production (for example, steam, cooling water and power) to each unit. This is also an Excel mask, in the sense that has, on its background, a program code developed in VBA language, with the macros activated by buttons. There is a button that activates the importing of yesterday's daily bulletin. With it, and today's bulletin, the mask can calculate raw material and product stocks on tanks, silos and warehouses.

2.7. SAGE X3

Here, the final process data are entered, in the form of Production Declarations and Manufacturing Tracking. These inputs were all manually inserted, and the process data needed to be allocated to production batches, depending on each product client, or each raw material supplier.

The data was inserted in SAGE X3 by the team leaders of BPU and Silos and Warehouses.

3. Implementation

On this section, the implementation procedure is described, in respect to each production unit. The modifications and innovations introduced in each unit are described.

For Biodiesel Production, Preparation/Extraction and Silos and Warehouses units, Excel masks were developed, to allow automatic calculation of product production, raw materials consumption, process yields and KPI's. The masks were developed in VBA language, assigning each macro to a specific button.

An "Autonomous Maintenance" tool (AM) was integrated on Utilities Production, Biodiesel Production, Preparation/Extraction and Silos and Warehouses Units' masks. These tool, developed by a fellow author [6] between September 2015 and April 2016, was created to allow each unit's operators to record equipment breakdowns and malfunctions, and which periodical maintenance circuits were performed. These were developed based on each equipment fault frequency.

In order to integrate all the mask's outputs on Control and Operations Map and, then, on SAGE X3, it was necessary to create specific folders (one for each unit) on IBEROL's IT network. Thus, the information manager has access to all process data on its computer.

There was, also, some work developed on non-production units, for example Electric Maintenance. Here, an Excel mask was developed for Android operating system, that allows the operator to input electrical power consumption measured by all existing counters. Therefore, process data is inserted in the mask, and readily available on IBEROL's network, no longer being inserted on a paper sheet.

For the Biodiesel Production and Preparation/Extraction units, two IndustrialDataBridge (IDB) projects had to be developed, that enable the export of process data from WinCC to Microsoft Excel format[5]. Two subroutines were developed in Visual Basic Script language, and each unit's set of process data to be exported (tank levels, process counters, temperatures and pressures) had to be carefully selected in each project, as there is a limit of 128 process parameters that can be exported, per project. Process data is exported three times a day, at the end of each labor shift.

3.1. Utilities Production Unit

The work done on this production unit focused on improving the already existing Microsoft Excel mask (Section 2.1), making it more user friendly and easier to operate, as well as providing adequate training to its users. Also, the Excel mask's front page was redesigned, and the AM tool was integrated into it. Some calculation errors were corrected, KPI charts were revised and their printing was automatized.

After input and output verification, process data is exported, from UPU's Excel mask to a specific folder on IBEROL's network, from where it can be

imported to SAGE X3 (Section 3.7).

3.2. Laboratory

In this section, no Excel mask was developed. Instead, the already existing Microsoft Excel templates, used to create chemical analysis report bulletins(section ??), were automatized. Thus, these bulletins are converted to PDF format by a specific action button. Each PDF file is automatically stored in this section local network folders; a copy is stored in the respective production unit folder on IBEROL's network.

In order to allow other unit's Excel masks to import their report bulletins, these is exported to another Microsoft Excel file, in which confidential or sensitive data is omitted (because IBEROL's other units are, in fact, the Laboratory's internal clients). The PDF file is the official report bulletin, and is the one that IBEROL's team leaders consult; the Excel file is only for the import process. Therefore, another set of action buttons had to be created, and VBA macros were assigned to them.

3.3. Biodiesel Production Unit

This unit has the grand majority of its process data available on WinCC. The IDB project developed enables the export of almost 90 process values per labor shift, to Microsoft Excel format. Then, this data set is imported to BPU's Excel mask by an action button activated by the operators. However, there are still some manual inputs (section 2.3) tho this Excel mask. When all the inputs are filled in, outputs such as biodiesel and degummed oil production are automatically calculated. Then, KPI charts are generated and printed. Goals and objective values for each KPI were added to these charts.

The allocation of the consumption of each type of degummed oil to each batch of biodiesel is automatic, after the required input is made.

Now that the parameter values of report bulletins from the Laboratory are available in Microsoft Excel format (Section 3.2), they are imported to BPU's Excel mask, and benchmarked against the specification limits set by each biodiesel client.

NIRS results are also imported to BPU's Excel mask, and benchmarked against established limit ranges.

The Microsoft Excel files "Stocks Control" and "Biodiesel Production Unit Daily Bulletin" were, thus, terminated, as their outputs are now obtained from the Excel mask.

Now, the team leader can input the remaining process data directly in the Excel mask (no longer needing to write it on a printed log sheet), on his computer, because it is also connected to IBEROL's network, where all Microsoft Excel files are stored. Then, after checking inputs and outputs, the Excel

mask is completed and process data is exported to a specific folder on IBEROL's network. It is always available on BPU's computer, allowing the operators a chance to actively analyze its outputs, and input NIRS and laboratory results.

3.4. Preparation/Extraction

Unlike BPU, most of these unit's process data is obtained from analogical process counters, which are not connected to the WinCC supervisory system (section 2.4). Nevertheless, an IDB project was developed to, at least, export the available data from WinCC (steam, effluents and transferred oil counters).

These data are imported to Preparation/Extraction's Excel mask by activating a button with a macro assigned to it. Then, analogical process data must be manually inserted in the mask. When it is completed, outputs are automatically calculated and KPI charts are generated and printed.

The lacking information necessary to the completion of the mask is imported from Silos and Warehouses Excel mask (Section 3.5), as both are available on IBEROL's network. That way, there is no longer a need for the paper sheet in which KPI's (such as oil yield, rapeseed and soybean consumption) were written (Section 2.4).

Just like in BPU, the parameter values of report bulletins from the Laboratory are imported to the Excel mask, and benchmarked against the defined specification limit.

Rapeseed meal, soybean meal and full-fat soybean are analyzed in a NIRS equipment, and its results are, now, exported to Microsoft Excel format, imported to the Excel mask, and benchmarked against the acceptance range. In order to enable the export of data at the end of each labor shift, modifications to the existing NIRS software projects were made. Thus, each time a NIRS analysis is performed, its results are automatically exported to Microsoft Excel format and imported to the Excel mask by activating a button.

Likewise, rapeseed and soybean analysis results are, now, sent in Microsoft Excel format, by the Laboratory, enabling its import to the Excel mask, where its parameters are benchmarked against acceptance limits; rapeseed meal, soybean meal and full-fat soybean analysis results are benchmarked against NIRS results, defined goals/objectives and specification limits.

3.5. Silos and Warehouses

This unit's team leader is no longer accumulating two functions, the unit's team leader and the company's information manager, retaining only the former (section 2.5).

This unit's Excel mask integrates all the scattered

Microsoft Excel files and paper documents that had been used in it. Therefore, its main purpose is to enable rapeseed and soybean stocks calculation. Formerly, this was achieved by two empirical equations, one for each component. The independent variable to this equations, the seed pile height, is now measured with a laser measuring device. This input must be manually inserted in a table, which then calculates rapeseed and soybean daily consumption. Raw materials enters the Preparation/Extraction process from the 37th Silo. Therefore, the outlet quantity from it is the consumption quantity. This silos's initial stock is imported from the previous day worksheet, final stock is obtained from the aforementioned equations, and the intake quantity is obtained by manually inputting how much was transferred to it, from other silos.

Some process data is imported from the Preparation/Extraction Excel mask (laboring times, rapeseed meal, soybean meal and full-fat soybean production), other from the BPU mask, which is possible because they are always available in IBEROL's network.

Additionally, six theoretical equations for calculating rapeseed and soybean stocks were obtained, based on the silo's engineering design documents and their geometry. Two global equations were obtained, one for each component, which validate the empirical ones (section 2.5). Four other local equations were also obtained, two for each component. Each one of this is applied to a specific, geometrically different, section of the silo. The top section is rectangular parallelepiped, while the bottom section is pyramidal.

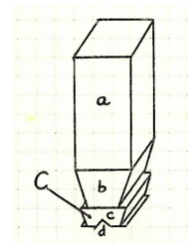


Figure 1: The different sections of the silos.

Referring to Figure 1, section A is associated with pile height measures ranging from 0-27,5 meters; section B ranges from 27,6-29,2 meters; section C ranges from 29,3-29,9 meters. Most frequently, pile height measures fall on section A range.

Instead of applying the same empirical equation to these two sections, the obtained equations are less prone to error in calculating the output, because the variation of stock with the pile height is not linear along the silo.

The empirical equations used to estimate rapeseed and soybean stocks are as follows:

$$y(x) = -18,0x + 540 \quad (1)$$

Soybean

$$y(x) = -16,3x + 490 \quad (2)$$

Rapeseed

where y is the seed stock in tons, x is the pile height in meters, and the intercept value is the maximum capacity of the silo, in tons.

3.6. Control and Operations Map

The first modification realized on this Excel mask focused on integrating BPU's process data because, formerly, this unit's daily bulletin was completed in an Microsoft Excel file, by its team leader (Section 2.6) and, then, copied to Control and Operations Map (COM) by the information manager/Silos and Warehouses team leader. Now, daily bulletins of all production unit's are generated in COM.

A large set of VBA routines were developed for COM. The already existing routines focused just on importing the previous day bulletins and printing worksheets. The newly added routines enable the information manager to import process data from BPU's, Preparation/Extraction's, Silos and Warehouses and UPU Excel masks, as all these files are always available on IBEROL's network.

No changes were made to the calculation procedures running on the background. However, a mechanism to export COM's outputs as Production Declarations and Manufacturing Tracking was developed, based on VBA routines that assemble the necessary process data from COM and rearrange them in predefined tables. These specific layout allows for these data to be exported in a format that is recognizable by SAGE X3 (Section 2.7). Two buttons, assigned to VBA routines, activate this export to CSV format.

3.7. SAGE X3

No changes were made in SAGE X3, because it already has default templates for importing data. However, the data in COM had to be rearranged to meet this templates (Section 3.6).

The import of process data from CSV files was successfully tested and implemented.

The import process is managed by the information manager, and no longer by Silos and Warehouses or BPU's team leaders.

4. Results

Every process step included in each unit's information flow was measured in respect of its duration, requiring the author to closely follow and understand each unit's daily routine. Then, activities belonging to the information flow were listed in

a Gantt Chart, along with its duration time. This parameter was calculated assuming a Beta time distribution [7], taking into account not only the most probable time, but also the optimistic and pessimist times (see Equation(3)). This is based on a Critical Path (CPM) methodology[8].

$$T(m, o, p) = \frac{o + 4 \times m + p}{6} \quad (3)$$

with m being the most probable duration, o the most optimistic duration, and p the most pessimist duration.

The global lead time of the previous situation were compared to that of the present situation, already benefiting from the development of Excel masks and other improvements.

The implementation of the modifications described in Section 3 led to a reduction of 40,1% (or 62 minutes) of the global information flow lead time. The lead time of BPU's information flow was reduced by 40,5% (51 minutes); by 66,8% (139 minutes) on Preparation/Extraction and by 56,6% (88 minutes) on Silos and Warehouses.

The number of total non value-added activities, in the global information flow, was reduced by 64%, from fourteen to five.

In general, for all the intervened units, the number of Microsoft Excel files was reduced, because most of them on integrated into the unit's Excel mask; paper documents, rework and total number of process steps were also reduced.

Three equations were obtained for each type of seed (rapeseed and soybean), one global (applied to both sections of the silos) and two local (applied to each section) (see Section 3.5 and Figure 1).

The two global equations obtained are:

$$y(x) = -17,6x + 538 \quad (4)$$

Soybean

$$y(x) = -15,8x + 484 \quad (5)$$

Rapeseed

where Equation 5 relates to Equation 2, and Equation 4 relates to Equation 1.

The local equations applied to section A of the silos, are:

$$y(x) = -17,8x + 540 \quad (6)$$

Soybean

$$y(x) = -16,2x + 490 \quad (7)$$

Rapeseed

The local equations applied to sections B/C of the

silos, are:

$$y(x) = -10,1x + 328 \quad (8)$$

Soybean

$$y(x) = -9,2x + 297 \quad (9)$$

Rapeseed

Therefore, we can infer that, not only are the intercepts (maximum capacity of the silo/section) significantly different, but also the slopes. This is because sections A and B/C have different geometry and volume. Thus, if empirical (Equations 2 and 1) or global (Equations 5 and 4) correlations are applied for the range of pile heights corresponding to sections B or C, the estimated seed stock would be significantly different from the output generated by the local correlation (Equations 8 and 9), because the latter takes into account the correct geometry and non-linear relation to the independent variable. On the contrary, the local correlations for section A (Equations 7 and 6), and the global and empirical equations are expected to give similar results.

This reasoning is evidenced in Table 1.

Table 1: Mean absolute error (MAE), for soybean data, between empirical and local correlations, and between empirical and global correlations.

Silo Section	Empirical vs Local (Ton)	Empirical vs Global (Ton)
A	2,5	3,7
B	12,0	9,0
C	21,5	9,5

A statistical *t-test* was performed in order to verify if the mean results obtained by empirical and global correlations, and between empirical and local correlations, were statistically different. A *p-value* $\geq 0,05$ indicates that the means are not statistically different [9]. This was the case with empirical vs. global correlations, but not with empirical vs. local correlations. This supports the aforementioned reasoning.

5. Conclusions

The Excel masks and tools developed or improved are already contributing to facilitate consumption, production, stocks and KPI calculation; and eliminating reworking, error-checking and manual calculation process steps.

The IndustrialDataBridge projects were successfully implemented in BPU and Preparation/Extraction and are being used routinely, providing inputs to the masks. This success cases already motivated IBEROL to consider the creation of another IDB project, this time for UPU.

The Laboratory already creates all of its report bulletins using the developed VBA macros, and a third-party software to converting them to PDF is no longer needed.

Production daily bulletins can be emitted on a daily basis by the information manager on COM, as the network structure that supports the importing features is now well established, functioning and stable.

The COM-to-SAGE X3 process step has been successfully tested once, although it requires more tests in order to be considered viable.

In summary, the global information flow lead time was reduced by 40,1%. Also, the number of Excel files, paper documents and reworking process steps was reduced.

Overall, the information flow efficiency has improved, the propagation of input and calculation errors to downstream units was minimized.

The global and local correlations to estimate rapeseed and soybean stock in the silos were considered viable. The former was considered not statistically different from the existing empirical correlation, thus, supporting and validating it. Likewise, the local correlation for section A of the silo was considered not statistically different from its empirical counterpart. However, the means obtained from empirical and local for section B of the silo were considered statistically different[9]. Therefore, it is suggested that the local correlations should be used.

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