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Applying a Markov approach as a Lean Thinking analysis of waste elimination in a Rice Production Process

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ABSTRACT

The Markov Chains Model was proposed to analyze stochastic events when recursive cycles occur; for example, when rework in a continuous flow production affects the overall performance. Typically, the analysis of rework and scrap is done through a wasted material cost perspective and not from the perspective of waste capacity that reduces throughput and economic value added (EVA). Also, we can not find many cases of this application in agro-industrial production in Latin America, given the complexity of the calculations and the need for robust applications. This scientific work presents the results of a quasi-experimental research approach in order to explain how to apply DOE methods and Markov analysis in a rice production process located in Central America, evaluating the global effects of a single reduction in rework and scrap in a part of the whole line. The results show that in this case it is possible to evaluate benefits from Global Throughput and EVA perspective and not only from the saving costs perspective, finding a relationship between operational indicators and corporate performance. However, it was found that it is necessary to analyze the markov chains configuration with many rework points, also it is still relevant to take into account the effects on takt time and not only scrap´s costs

Keywords: Rice, Lean Manufacturing, Statistical Thinking, Markov Chains, Costa Rica

1 Introduction

This research focuses on the study of how to make more efficient and effective the implementation of lean production systems using statistical thinking as the core and based on the relationship between operational indicators and enterprise performance (Bain R., 2012). There is a relation between the value stream of a process and the rate of cash generation and, therefore, with the economic value added (EVA). In addition, waste and rework decrease the outflow but its effect is typically analyzed from a cost perspective and not from an economic throughput approach (George Michael, 2013) using robust statistical techniques like Markov chains.

This paper presents partial findings of a research on optimization models of agro-industrial processes which seek the development of generic strategies for statistical analysis of the operational effects of reducing rework and scrap. At the same time, taking into account the effects on economic value added (as a way to link the tactical level indicators with indicators at a strategic level), a framework is proposed making a contribution to change typical deterministic and fragmented way for analysis.

First, critical concepts and the most important advances in similar research published are described. Then, the results of the application of a quasi-experimental methodological strategy based on the simulation of a real case of Central America are described. Finally, conclusions and recommendations are provided to give a contribution to the theme of markovian and DOE statistical models applied to agro-industrial sectors in the context of lean manufacturing implementation processes.

2 Literature Review

Lean manufacturing systems have their genesis on the automotive industry in Japan, after the World War II. However, it is not until the eighties that throughout the world, particularly in the West, a boom about the practices that helped the Japanese industry take a leadership position in very competitive markets such as the U.S. (Hamilton Bruce, 2007). In 1990, J. Womack, D. Jones and J. Roos (three researchers from the Massachusetts Institute of Technology), published the findings of an investigation which revealed that the production system called "lean" was to dominate the world in the nineties, and the 21st century (Wang Y.P., Gao L., Shi Z.M., Bi K.X., Ge J.H., 2014), as opposed to traditional systems (craft manufacturing system and mass production) .

A classic goal of continuous improvement programs and strategies guided by lean thinking is the reduction of waste and rework. This objective is usually associated with the costs of internal failures and external failures of quality, which decrease when investment in preventive programs to improve the quality increases (Liker Jeffrey, 2012). However, particularly in agro-industrial processes it is not common to link this goal with economic throughput.

The Value Chain of any industrial operation has two main streams: the flow of materials from the supply of raw materials to delivery and after-sales processes and the flow of information (Caldwell E., 2013). These essential flows are linked with EVA because "profit" depends on production orders delivery (Liker Jeffrey, 2012) and the basic paradigm says that a good decision is characterized by cost reduction because it obviously increases profit. However, figure 1 shows that clearly EVA depends on three variables: profit, investment and capital cost (K); this mean that better decisions suppose a combined positive effect of three indicators related with EVA, not only one.

Theory of Constraints (TOC), developed during the seventies of the last century, proposes an approach based on three indicators: throughput (gross margin of contribution), operational expenses and inventory (Goldratt Eliyahu & Fox Robert,1989). According with this theory, EVA is calculated as ROI minus cost of equity. "Throughput", as operational indicator, is the new"King" in TOC´s model and is calculated from bottlenecks. This key process indicator (KPI) relates EVA with operational cycle times, productivity and production capacity; because the throughput velocity directly affects ROI (Return of Investment).

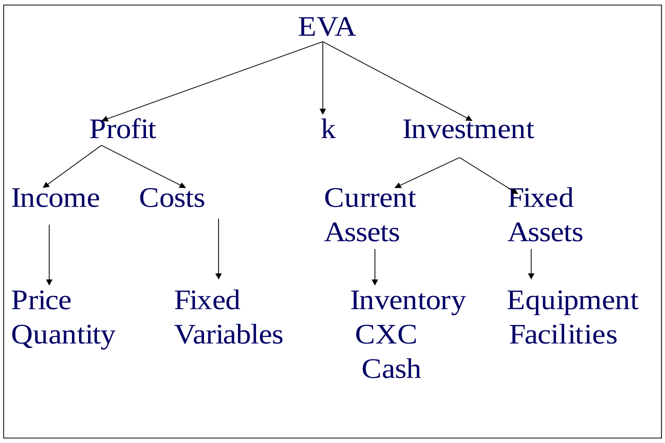

Figure 1. Economic Value Added Model**.**

Parallel to the theory of constraints (in the early years of the 21st century) a global movement is growing in the productive sectors wich establishes the need to achieve three operational goals: eliminate the hidden costs of quality, build more flexible processes and eliminate waste. That is, remove everything that does not allow smooth movement and synchronized flow of material and information within the value chain from the perspective of external and internal customer (Modrak V. and Pandian S., 2010). This approach is called "Lean Thinking" and it becomes a "World Class" characteristic (Wang Y.P., Gao L., Shi Z.M., Bi K.X., Ge J.H., 2014). For example, many publications conclude that 100 best profitable worldwide enterprises typically apply this principles (Liker Jeffrey, 2012). However, companies do not necessarily associate their tactical improvement decisions with financial results and, if they do, it is also common to find that they do not consider randomness of the variables that affect performance (Shuli Zhang, 2013).

Statistical Thinking, according with the American Society for Quality (ASQ), is defined as "philosophy and learning-action approach (both, individual and corporate level)" based on three principles (George Michael, 2013): (a) work takes place in a system of interconnected processes; (b) variation exists in all processes and thread; and, (c) understanding and reducing variation is critical to continuous improvement. According to this definition, the contribution of "statistical thinking" to decision making is strategic because it subverts the paradigm of static measurement both at operational and corporate level. However, the philosophy that rules our age does not include the integration of three key principles explained in last paragraphs, which may cause the underestimation or overestimation of global effect of operational actions on measures of corporate performance.

3 Markov Analysis: Linking Rework and Eva

Figure 2 shows a generic strategy for statistical analysis of EVA, related with the implementation of actions for rework and scrap reduction. This strategy begins with an assessment of key processes in order to set improvement opportunities. These opportunities can be based on process characterization in order to define critical variables phase by phase. Then, rework and scrap causes can be studied with an Ishikawa Diagram or a Current Reality Tree. In addition, target levels of scrap and rework can be defined.

After scrap and rework level calculation, the next step is to calculate cycle time and capacity with a stochastic. If rework level is too small, cycle time with scrap adjustment can be calculated using a Vi factor:

$V_i = \prod_{i=n}^{1} ai$ where a is the probability of a part that entries in the operation i and it is converted into finished good. Then, the cycle time is calculated as the ratio between the standard time for the operation i and the factor Vi.

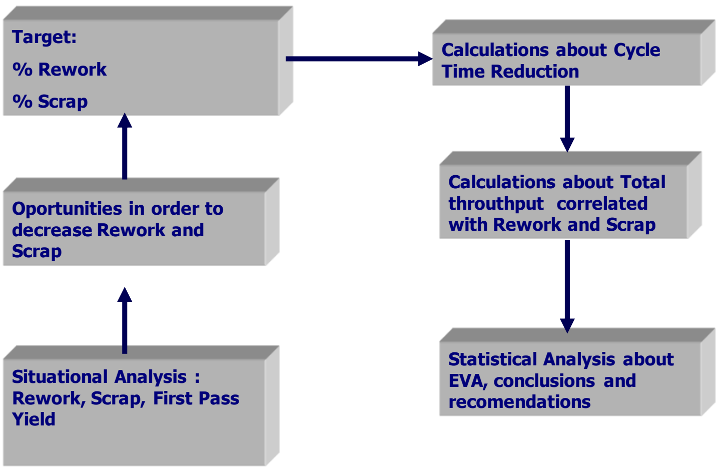

Figure 2. Strategy for EVA statistical analysis based on scrap and rework.

If rework level is high, cycle time can be calculated with a Markov Chains approach, where a transition matrix is defined with the probabilities about parts changing their phase into the process. Thus, Markov set adjustment factors from two matrix models: A X MINVERSE (I-N) and MINVERSE (I-N), where A is a matrix with absorbent states and N is a matrix with non-absorbent states or phases. The next step is the calculation of production capacity deviation; then, changes in costs can be set and changes in gross margin of contribution, operational expenses, investment and throughput. As last phase, EVA is calculated, taking into account the cost of equity and, therefore, the data can be analyzed to answer two fundamental questions: which statistical parameters describe EVA and Economic Throughput? ; is it possible to statistically predict EVA change related with a change in scrap and rework levels?

This methodological strategy was applied in an enterprise engaged in the production and sale of rice located in Central America with the following characteristics:

a. Founded in 1974 and put on the market all of their production during 2012-2013.
b. 4 brands: Rice G-80-20, Pre-Cooked Rice I-97-3, Rice and Rice 99/1-leader, J-75-5, economic brand

c. Operates with 3 production plants, 750 employees; 4928 hours of annual operation
d. Current capacity of rice: 112 000 tons per year; 2 shifts of 8 hours per day; Monday to Saturday
e. Cost of equity: 12%; Total Investment: $ 250 million
f. Annual Operating Expenses: $ 15 million. Weighted average price per kilogram: $ 0.9; Raw material cost calculated without waste adjustment: $ 0.3 per kilogram
g. Recovery of the waste (animal feed): $ 0.25 per kilogram

There are three facilities for storing and drying grain located in Zone 1, Zone 2 and Zone 3. These facilities supply the peeled plant located in zone 3, which takes the grain and gives a specific pre-treatment drying: (a) drying tower and (b) aeration.

Grain is received from plantations wet and dirty, then, first processes refer to drying and cleaning respectively. Zone 1 and Zone 3 have drying towers but Zone 2 has aeration drying system with a stabilization of humidity without temperature shock, reducing the % of cracked grain. Peeled process is where waste and rework have been reduced. As shown in figure 3; rice process has two automatic inspections where grain is selected and one part goes to scrap (treated as animal food) and the other part goes on across the flow.

However, grain can be reworked at peeled process or at polished grain selection process. Furthermore, rice supplied from farms can´t be selected before their income to peeled process. Competition is aggressive at the time of harvest, and it is common for producers seeking centers nearby plantations. Then, zone of origin of rice is an independent factor because some producers prefer to travel more distance in order to get a delivery in places where grain is paid better, even though it is further away.

4 Results and Discussion

Figure 3 shows that there is scrap just before the first process called Scalper. This is because from silos, rice enters broken or stained due to thermal shocks or due to transport via augers. Then the grain is peeled and the shell is placed in bags for later use as fuel and rice is classified according to different dimensions.

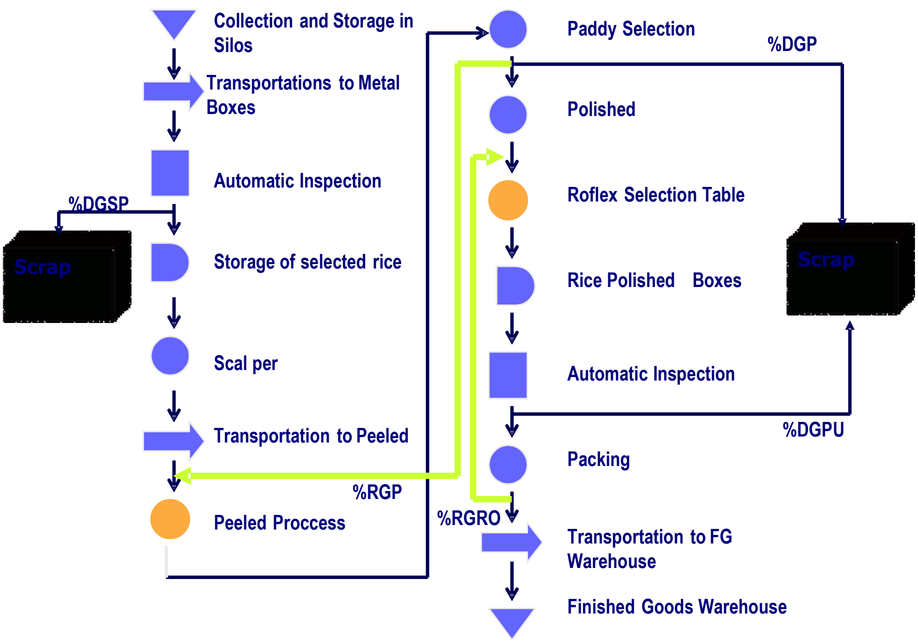

Figure 3. Process diagram with scrap and rework mapping.

Bottleneck of main process is located on peeled phase (22500 kg/hr aprox.). To carry out this investigation, 110 batches produced in 2012 were collected, in which it was found that waste and rework occurred.

Five study variables were initially found:

a) %DGSP: Scrap of rice not peeled.
b) %DGP: Scrap of peeled rice.
c) %DGPU: Scrap of polished rice.
d) %RGP: Rework of peeled rice.
e) %RGRO: Rework of selected rice that goes to polished (Roflex machine to polishing)

Using STATISTICA Software, an exploratory study was realized and a normality behavior of data was found (95% of significance). It was determined that the initial waste and rework global levels were between 0.12% and 11.44%. Comparing these data with typical indicators of the Central American industry, it was determined to be attractive to work on reducing these waste and rework rates; then, a graph of causes and effects (also called Ishikawa diagram) was made. It was defined that managers can take action with a better criterion of use of pre-drying treatment, depending on the area from which the grain and with the same type of roller used in peeled tables. This allowed the development of an experimental design, in order to establish criteria for the use of rollers and types of pre-drying, depending on the origin farm of rice (see Table 1 for factors and levels definition).

Table 1.
Factors and experimental levels

Factor	Level 1	Level 2	Level 3
Zone	1	2	3
Roller	Soft Rubber	Hard Rubber	
Type of Drying Process	Drying Tower	Aeration	

In this mixed experimental design (Ghosh Subir, 2011), the dependent variables are described above (DGSP%; DGP%; % DGPU; RGP%). 5 samples of the dependent variables for each combination of factors were taking, for a total of 60 samples. The data analysis shows that for each variable, normality fit (Gauss Model) occur in the differences (values between -2 and 2) and factors that affect with more significance were identified according with the dependent variables studied. When significant incidence was found, in the case of the areas of origin of rice, an analysis of multiple means comparison was made. Subsequently the corresponding models for the factors and levels studied were obtained.

About DGSP%, differences in average by area, the roller and the type of drying were found (DOE assumptions were tested). There are also significant differences in the roller-type drying interaction; the comparison analysis of multiple means, according with Scheffe test, Newman-Keuls test and Duncan and Tukey test, found significant differences in DGSP% for all zones. Then, it can be deduced that when the grain comes from zone 1 and the soft rubber roller is used, there is no difference in using the drying tower or aeration.

However, if the rice comes from zone 1 and the hard rubber roller is used, it is best to dry with aeration in order to get less scrap. Likewise, when the rice comes from the zone 2 and the soft roll is used is better to dry with aeration and when the soft roller is used, is relatively the same using a drying tower or other. Furthermore, when the rice comes from zone 3, and a soft roller is used, it is best to use aeration, but if the hard roll is used, the type of drying is indifferent.

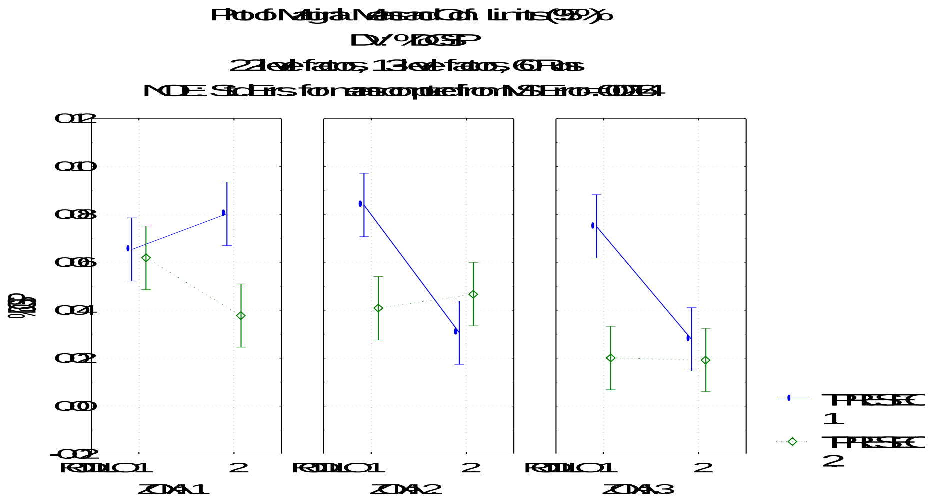

Figure 4. Differences in %DGSP by zone, roller type and pre-drying process

By a similar analysis, it was found that regardless of the type of roller, when the rice comes from Zone 1 should be drying by aeration for lower% DGP. When the rice comes from zone 2 and soft rubber roller is used, again aeration is recommended, but when the roller is hard drying should be in towers. When rice comes from Zone 3 and the soft rubber roller is used, the drying process should be in towers but if hard rubber roller is used, then drying process cause no difference. In the case of %DGPU, according with Duncan Test, no significant difference (p-value 0.05) was found in the type of drying process when rice comes from Zone 1 and hard rubber roller is used; but if soft rubber roller is used, then aeration process is better in order to get less %DGPU. When rice comes from Zone 2, drying process is indifferent when soft rubber roller is used, but when hard rubber roller is the choice, drying towers are going to be better. When rice comes from Zone 3, drying process is indifferent when soft rubber roller is used, but when hard rubber roller is used, aeration process is better. %RGP and RGRO are not influenced by Zone, type of drying process and type of rubber.

Therefore, from DOE analysis, it was decided to implement the following policies for scheduling operations in order to reduce waste and rework:

a) If the rice comes from Zone 1, then the hard rubber roller with pre-drying by aeration is used.
b) If the rice comes from Zone 2, then the hard rubber roller with pre-drying towers is used.
c) If the rice comes from Zone 3, hard rubber roller with pre-drying by aeration is used.

Since the implementation of these policies in the production of 2013, new data was collected coming from 110 processed batches. It was found, again, that the data fit a normal frequency model (Gaussian distribution) with a significance of 95%. Obviously, these levels of scrap and rework were lower than 2012 giving confirmation about the DOE analysis effectiveness. Scrap levels of not peeled rice and peeled grain decrease on 50% aprox. However, the methodological strategy proposed in this research, seeks to study the effect of these reductions in productive capacity, and therefore the levels of ROI. This was accomplished using Markov analysis, whereby adjustment factors were calculated, considering the overall process waste and taking into account the two rework points described before.

For each sample n, considering the data of batch records (110 of 2012 and 110 of 2013), the matrices of factors and probabilities were calculated, deploying global grain yields (p) and overall waste markov probabilities (1-p), as shown in Table 2 for a specific case of waste and rework rates. 110 tables like Table 2 were calculated using a specific software program designed with this objetive (using the Java IDE platform). The next step was to simulate these factors and generate 2000 iterations with random Monte Carlo model for types of batch and Normal Distribution for scrap and rework levels (using RISK Pallisade).

Related with each sample of a production batch, a factor was taken from the peeling process (phase 2), because this is the bottleneck of the whole process (theory of constraints approach), and the associated global scrap, either. A critical change on global scrap levels was found with the operational policies applied. A hypothesis test confirmed a significant difference between means (95% of significance).

The same was found related with cycle time rates in peeling process and, therefore, the Global Economic

Throughput and EVA, finding an association with scrap and rework reduction. In this way, it was possible to study the deviations on throughput and EVA, taking into account the global operational expenses and the global investment.

Table 2.

Transition Markov Matrix for Peeled Rice Process.

	%DGSP	**%DGP**	**%DGPU**	**%RGP**	**%RGRO**				
	0.0279	0.0425	0.00748	0.0771	0.007				
PHASE		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Electronic Inspection	**1**		0.9721						0.027
Peeling process	**2**			1.0000					
Selection 1	**3**		0.0772		0.8803				0.042
Polishing	**4**					1.0			
Selection 2	**5**						1.0		
Electronic Inspection	**6**							0.9925	0.007
Packing and Packaging	**7**							1.0	
Scrap	**8**								1.000

Related with each sample of a production batch, a factor was taken from the peeling process (phase 2), because this is the bottleneck of the whole process (theory of constraints approach), and the associated global scrap, either. A critical change on global scrap levels was found with the operational policies applied. A hypothesis test confirmed a significant difference between means (95% of significance).

The same was found related with cycle time rates in peeling process and, therefore, the Global Economic Throughput and EVA, finding an association with scrap and rework reduction. In this way, it was possible to study the deviations on throughput and EVA, taking into account the global operational expenses and the global investment. Average of global Scrap (Markov´s results) decreases from 14.37% to 7.97% and this change causes a positive change on Throughput (from 9449.345$/hr and std-dev 489.16 in 2012 to 10858.8 $/hr with std-dev 626.15 in 2013) and EVA, increasing from 0.6265% (with std-dev 0.096%) to 2.15 (with a std-dev. 0.23); giving a real impact of a scrap and rework reduction program program (as the result of a hypothesis test for a difference between means of EVA calculated by Markov Method (see Table 3).

Table 3.

Hypothesis test for a difference between means of EVA calculated by Markov Analysis.

Grouping: AÑO: =v0 (arrozi~2.sta)						
Group 1: G_1:2012						
Group 2: G_2:2013						
	Mean G_1:2012	Mean G_2:2013	t-value	P	Std.Dev. G_1:201	Std.Dev. G_2:201
EVAESP	0.006265	0.021482	-10.216260	2.8437E-20	0.000964	0.0022908

Finally, a prediction models for EVA and Throughput were found using regression techniques. Pearson coefficient for EVA model was 0.9998 and 0.9999 for Throughput. These models are:

EVA= 0.05906 - 0.458307 (%DGSP)-0.5035 (%DGP)-0.4471 (%DGPU)

Throughput= 12873.198 – 23316.302 (%DGSP)-0.25607.66 (%DGP) - 22737.428 (%DGPU)

5 Conclusion

Statistical Thinking can be integrated with Lean Thinking processes in order to find a relationship between operational indicators and corporate performance indicators like EVA and Global Throughput. The analysis of process capacity using Markov chains and DOE strengthens the integration of statistical thinking to lean thinking because it is necessary to calculate the variability in overall yields and hence on the adjustment factors that provide solutions to the loops generated by reworks. For the specific case of the rice production plant studied in this research, these techniques gave critical information in order to reduce scrap and rework, because helped to find a systemic solution to the problem of how to reduce the sources of variability in processes.

In addition, this research preliminarily supports the convenience, for agro in general, of a comprehensive analysis of the performance and not only the change in costs as a way to assess the operational and strategic decisions, in particular, finding sources of variability and working. With the evidence generated in this study, the need for more research about factors associated with statistical thinking is strong, specially related with Constant Work in Process (CONWIP) techniques, Pull from Bottleneck systems (PFB systems) or Drum Buffer Rope Systems (DBR). However, it is recommendable to include different types of processes, not only continuous flow, so the application of the findings can hold more general and theoretical conclusions.

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