

Waste Reduction Applying Lean Thinking and Six Sigma Tools in Steel Industry

Vinicius de Souza Moura

Mechanical Engineering Department
PUCRS

Porto Alegre, Rio Grande do Sul, Brazil

mouravini1988@gmail.com

Carlos Alexandre dos Santos

Dean, School of Engineering
PUCRS

Porto Alegre, Rio Grande do Sul, Brazil

carlos.santos@pucrs.br

Daniel Luiz de Mattos Nascimento

Civil and Environmental Engineering Department
PUC-Rio

Rio de Janeiro, Rio de Janeiro, Brazil

danielmn@puc-rio.br

Rodrigo Goyannes Gusmão Caiado

Industrial Engineering Department

Federal Fluminense University

Niterói, Rio de Janeiro, Brazil

rodrigoggcaiado@gmail.com

Abstract

This study presents an operational interruption analysis in bars and profiles rolling mills, developed with the support of a steel company. The study was performed by analyzing the operational interruption records related to guidance equipment in order to identify the fundamental causes of the interruptions, helping in their subsequent minimization or even elimination. The analysis included the equipment assembly and maintenance parameter, physical conditions and performance during operation. The equipment assembly and maintenance cell has undergone a layout change aiming higher functionality, the equipment was standardized, and the employees were trained by the manufacturers. The applied solutions have been proven to be effective with superior results than 35% of reduction and tending to stabilize the process.

Keywords

Lean Thinking, Six Sigma, Kaizen, Operational disruptions; Rolling mills.

1. Introduction

The competitive landscape of the industrial sector, with the need to reduce operating costs to maximize profit, fundamentally prioritizing efforts that aggregate value for customer can be a lean way to operations management in steel industry. In fact, the implementation of Lean Production principles and practices can be generating a competitive advantage within global market (James et al. 2014). By means of synergisms between tools of Lean Production System and Six Sigma, applying these practices in the operations management can be a critical success factor to achieve real gains in lead-time, cost, rework and waste (Dombrowski and Mielke, 2014; Franchetti, 2015; Kumar et al. 2016; León and Calvo-Amodio, 2017).

Maleyeff et al. (2012) inform that Lean Production emerged under the leadership of Taiichi Ohno in the Toyota Motor Company, in the nineteen fifties, with the goal of reducing waste, achieve an involving approach in the relationship between employees, suppliers and clients. Moreover, this mental model promotes the practice of kaizen events, defined as a process for continuous and incremental improvement starting from the mapping of problems and their root causes in these organizations, while Six Sigma (created by Bill Smith at the Motorola Corporation in the nineteen eighties) aims to reduce errors and defects by applying DMAIC (Define, Measure, Analyze, Improve and Control) methodology. Outlined as they are, the synergism of these concepts becomes an unprecedented, vital measure that can reduce costs and maximize profit in organizations developing high-quality services or products.

According to Kumar (2016) Lean is focused on waste and its elimination and Six Sigma focuses on the continuous improvement of quality of products and services in an organisation by minimising the defects. In this context, manufacturing processes necessity of bettering the process of continuous improvement provided by Lean Thinking and Six Sigma (MUSTAPHA et al. 2015) stands out. These are globally used methodologies in the industry, especially in manufacturing; however, in the scientific literature there are few examples of these principles being applied, from both Lean Production as well as Six Sigma.

In this way, the research aims to answer the following central question:

How to reduce waste and rework in the manufacturing of rolling mills by means synergies between concepts and tools of Lean Thinking, Six Sigma and Kaizen?

The contributions of this paper include: (2) making a literature background of Lean Thinking, Six Sigma and kaizen; (3) describe research methodology; (4) presenting synergies of Lean and Six sigma in steel industry through a real-world case study; and (5) conclusions. In addition, this paper demonstrates a real gains in pursuance of linking the gap in the effective operations management.

2. Literature Background

The purpose of the literature is to collect synergies between principles and practices to support the application of Lean Thinking and Six Sigma concepts in favor of Kaizen in the case study.

2.1 Lean thinking and Kaizen

For Aziz and Hafes (2013), since the 50's, lean principles of the Toyota production system have evolved, and have been implemented successfully by the Toyota Motor Company. They were formed by two main conceptions: Just-in-Time flow (producing according to the demand) and Jidoka automation (man-machine separation, in which a single operator manages several machines).

Lean Thinking offers a unique methodology, which is to do more with less – less human effort, less equipment, less staff and less space – in order to achieve the real needs of its clients. It results in the elimination of waste through more efficient processes, and that generates the essential capabilities a customer values (Comm and Mathaisel 2006).

As stated by James *et al.* (2014), Lean and the use of Kaizen or Japanese continuous improvement practices in total quality management (TQM) can have a significant and positive impact on improving safety and productivity, as it can also reduce the waste and risk of constructions. The authors present a study in which engineering management at

one modular homebuilder decided to implement a Lean approach to individual workstations through a series of Kaizen events (Japanese word for “change for better”) to improve the overall performance and the cycle time. As defined by the Productivity Press Development (2002), the Kaizen events are divided into three phases:

- Phase 1—planning, preparation, baseline data collection, and brainstorming of solutions;
- Phase 2—implementation of solutions and follow-up data collection; and
- Phase 3—presentation of results.

The Kaizen has the potential to affect both technical (i.e., work area performance) and social (i.e., participating employees and work area employees) systems. Kaizen practices are common on the shop floor, but some Kaizen methods, including 5S and small group activities, are applicable to nonproduction activities, such as R&D activities (Machikita *et al.* 2016).

Conforming to Taghizadegan (2006), Lean and Kaizen are strategic problem-solving techniques in the industrial world, and the integration of these quality methods will bring powerful tools to eliminate waste and improve productivity and profitability. In addition, the Kaizen strategies are based on several rules that may differ from one organization to another, depending on their application. They are shaped from the following action-based processes:

- a. Keep a positive attitude.
- b. Be open-minded.
- c. Get involved in teamwork and challenges.
- d. No excuses--look for solutions.
- e. Ask the five whys rule.
- f. Apply ideas immediately with available resources and do not wait for perfection.
- g. Treat and implement all the team members' opinions equally. Ignore member ranking;
- h. Apply 5S improvement rules that comes from the following five initials of Japanese terms: seiri (sort), seiton (set), seiso (shine), seiketsu (standardize), and shitsuke (sustain);
- i. Apply just-in-time (JIT) concepts.

Moreover, a Sustainable Continuously Improving (CIP) organization is a key element of lean leadership, because it undermines the necessity to improve all processes, and because it also imposes new requirements for leaders and employees. The basic elements of lean leadership are: the improvement culture, the self-development and qualification (that should be supported with standardized problem-solving routines that aim on systematic and ritualized use of Plan-Do-Check-Act), the Gemba (go and see yourself), and the Hoshin Kanri (Dombrowski and Mielke, 2014).

2.2 The Synergisms of Lean and Six Sigma methods

Six Sigma was created in the 1980's by Bill Smith at the Motorola Corporation, and seeks to reduce errors and defects by applying the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology. Popa *et al.* (2005) argue that Six Sigma is a highly disciplined process that helps organizations focus on delivering lower-cost products with improved quality and reduced cycle time, where Sigma represents a statistical term that measures the extent to which a given process deviates from perfection and Lean Six Sigma is a methodology of process improvement used in organizations of international standard in order to eliminate waste in the processes and deliver products and services with extreme quality to its clients.

According to Franchetti (2015), Six Sigma can help in developing skills, improving knowledge and employee morale and the ability to use a wide range of tools, techniques and has the following advantages over total quality management: Establishing zero defaults targets, creating the DMAIC process improvement cycle, and intensive use of statistics and data to make managerial decisions and reduce process variation. The main difference between Lean and DMAIC is that Lean projects can use qualitative and quantitative analysis of root cause analysis, such as the five whys, cause and effect diagrams, Failure mode and effects analysis (FMEA) (Voehl *et al.* 2010). However, by focusing on process improvement and variability reduction, Six Sigma programs do not guarantee a sustainable competitive advantage, and mechanisms need to be developed that address innovation and product differentiation, the pattern of change in the customer base, and uncertainty Environmental, while improving organizational processes, considering radical changes and the formation of new markets and / or customers (Parast 2011). George (2002) states that it is essential to merge the two methodologies to reduce cost and complexity. Just as Lean can not statistically control a process, Six Sigma alone can not dramatically improve process speed or reduce invested capital (George 2003).

Six Sigma helps connect business leaders and key project teams in a potent two-way fact-based dialogue, which is considered a blind spot of lean thinking (Voehl *et al.*, 2010). For Voehl *et al.* (2010), in the appropriate situation,

approaches to process improvement, Lean and DMAIC, can be integrated in order to form a more powerful tool than any other is alone, since practically all Lean concepts integrate well with any project DMAIC, regardless of size or scope, and root cause analysis is the common cross-point between these approaches.

The Lean Six Sigma (LSS) methodology has expanded the seven original wastes (Ohno 1997) and recognizes nine forms of waste - defects, overproduction, transport, waiting, inventory, movement, overprocessing, underutilized employees and behavior - showing more emphasis on waste reduction than reduction Of variability (Voehl et al. 2010). Thus, the authors suggest that this methodology seeks to eliminate the nine wastes and provide goods and services at a rate of 3.4 defects per million opportunities (DPMO). Thus, the LSS incorporates the principles of speed and immediate action of the Lean with the vision Six Sigma of quality without defect and reduction of the impact of the variation in the times of queue. From this, Lean Six Sigma attacks the hidden costs of complexity and is a mechanism that seeks the engagement of all for joint reach and without trade-offs of quality, speed and cost (George 2003).

3. Research Methodology

The approach of this paper is exploratory because it aims on bringing up the most relevant information of Lean and Six Sigma in order to reducing waste of steel manufacturing in the PDCA cycle. It is also descriptive because it seeks to reveal real gains from Lean Production implementation. Therefore, it is also qualitative and quantitative because of the way of empirical study is conducted, in which performance data is analyzed.

The research study applied a triangulated methodology with qualitative and quantitative data collection mechanisms. Data were collected using three mechanisms:

- (1) a literature review
- (2) a documentary analysis of corporate reports;
- (3) empirical study

It is noticed that the research has multiple sources of information and iteration with the constructs developed from the literature, which allows greater constructive validity (Eisenhardt 1989). For Miguel (2005), the use of multiple sources allows to support the constructs, propositions or hypotheses, that is, the use of the triangulation technique helps in the iteration and convergence between the several sources of evidence.

4. Case Study

As a research strategy, the exploration and theory-testing case study method is used according to Voss et al. (2002) and Childe (2011) based on new avenue of research from the application Lean, Six Sigma and Kaizen in steel manufacturing company.

4.1 Company Description

The company in which the study was conducted requests that it not be identified. It is a company in the steel industry and has similar processes in other plants, which makes the study even more interesting in the sense of replicating the gains generated. Financial resources were made available for the implementation of the improvements foreseen in the action plan, as well as access to the historical data of the process. It was possible for the study to be performed during office hours and with the support of production.

The work began in February 2015, at the Laminador Support Workshop located in Vale dos Sinos, under the guidance of the engineers responsible for the cell. The research is a study on the performance of guidance equipment, and is part of a project of the Problem Solving Group (GSP). From this initial contact with the equipment and the operation of the support cell, it was verified that there were many opportunities for improvement, both in the technical knowledge of the equipment and in the management of the cell itself to be deepened and better understood, the following Work problem: How to increase plant productivity by reducing downtime while minimizing failures due to guiding equipment? In order to better respond to this questioning and guide the research, the following steps were outlined:

- (1) Identify which are the most problematic guides, in which cages they laminate, which are the materials that when they are produced have a greater index of failures by equipment of guidance, which failures are these and which of them are more common;

- (2) Investigate how the process flow of the guides workshop and the main difficulties of the cell have been organized;
- (3) Understand the company's failure treatment procedure;
- (4) Raise opportunities for improvement;
- (5) Reduce stopping times.

4.2 Methods and tools

The method applied in order to reduce the rolling mills interruption variability was DMAIC. In details, Figure 1 shows the scope and steps exploration of Lean Six Sigma.

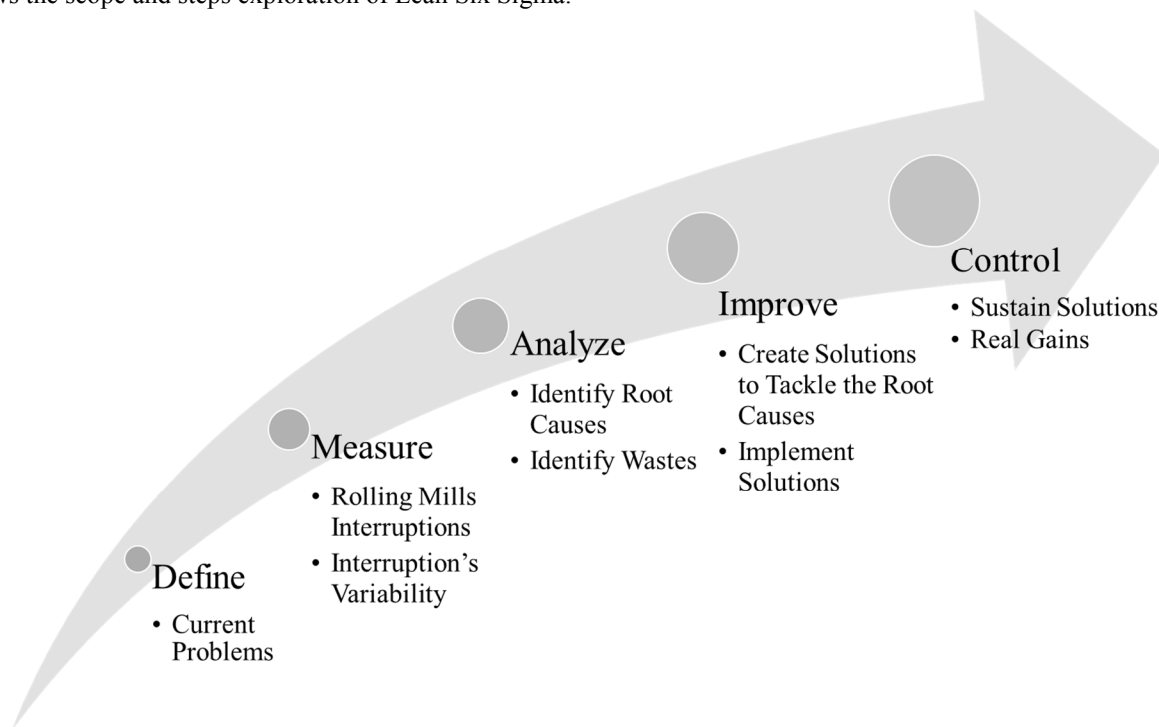


Figure 1. DMAIC applied in order to reduce the interruption's variability and waste.

The present study takes into account how the work of the guide office is organized and structured. Specifically, we turn to the analysis of the events related to the problems of guiding equipment present from the sixth thinning pass, contemplating every intermediate train and the final train of the mill, disregarding the guides of the trio cage responsible for the first five thinning passes and problems related to refrigeration.

In step of operations programs deployment with focus in the Lean Thinking and DMAIC concepts into PDCA cycle by using exploration and comparison case study methodology according to (Voss et al. 2002). As planning, an analysis of the interruption records was carried out followed by the mapping of the operating equipment during each stop, observations of the equipment in operation, definition of the goal through analysis of the best historical value, calculation of the gain for the feasibility of the project, observation by Pareto analysis, and after this analysis the area of action was defined. A Brainstorming was done to begin the assembly of a cause and effect diagram, in which the possible root causes were defined and a GUT matrix was set up, in which the causes with greater relevance in the questions, gravity (severity), urgency and tendency.

For execution was set up a team with eight people. Each member was responsible for a portion of the planned actions, deadlines and weekly meetings were established in which the progress of the actions was verified, the main difficulties to accomplish them and their respective results, aiming at creating a support network and avoiding actions in arrears. After the completion of the actions, the period of verification of the defined goal and maintenance of the results began. Finally, the results were documented and standardized.

The first records analyzed were related to the period from July 2014 to February 2015. During the month of March, the problem was identified. In the first fortnight of April, the observation occurred. For the next forty-five days, the data were analyzed. In the first half of June the action plan was drawn up, from the beginning of the second fortnight of the same month until the end of July, the deadline for completing the actions was granted. August, September and October were the months of verification and in November the results were standardized. It should be noted that all planning was carried out in accordance with the previously defined steps.

4.3 Results

Based on the analysis of production interruption records in the period between July 2014 and February 2015 (as shown in Figure 2, a total of 3.881 minutes of interruptions were observed due to problems with rolling mills, on average 485.18 minutes/month which represents 1.45% of the total scheduled time of the plant in the month, that is to say, approximately 275 tons of steel were left unprocessed throughout the month.

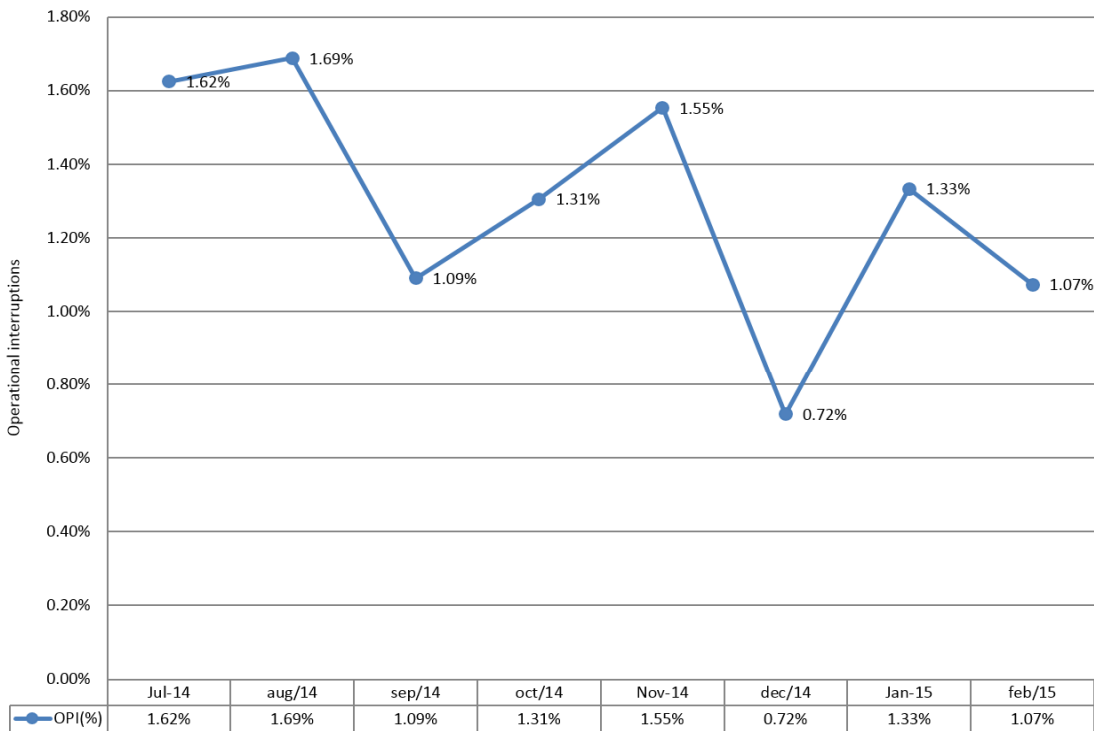


Figure 2. Percentage of the total scheduled time of interruptions during the months in which the records were analyzed.

In order to define the goal, an average of the historical results (1.30% of the total time programmed) was performed, and this value was taken as the basis for the monitoring until the months of verification in which a reduction of 35% of the average value was proposed (Approximately 0.85% of the total time programmed) according to Figure 3. That is the half of the worst historical value (approximately 1.7% of the total time programmed).

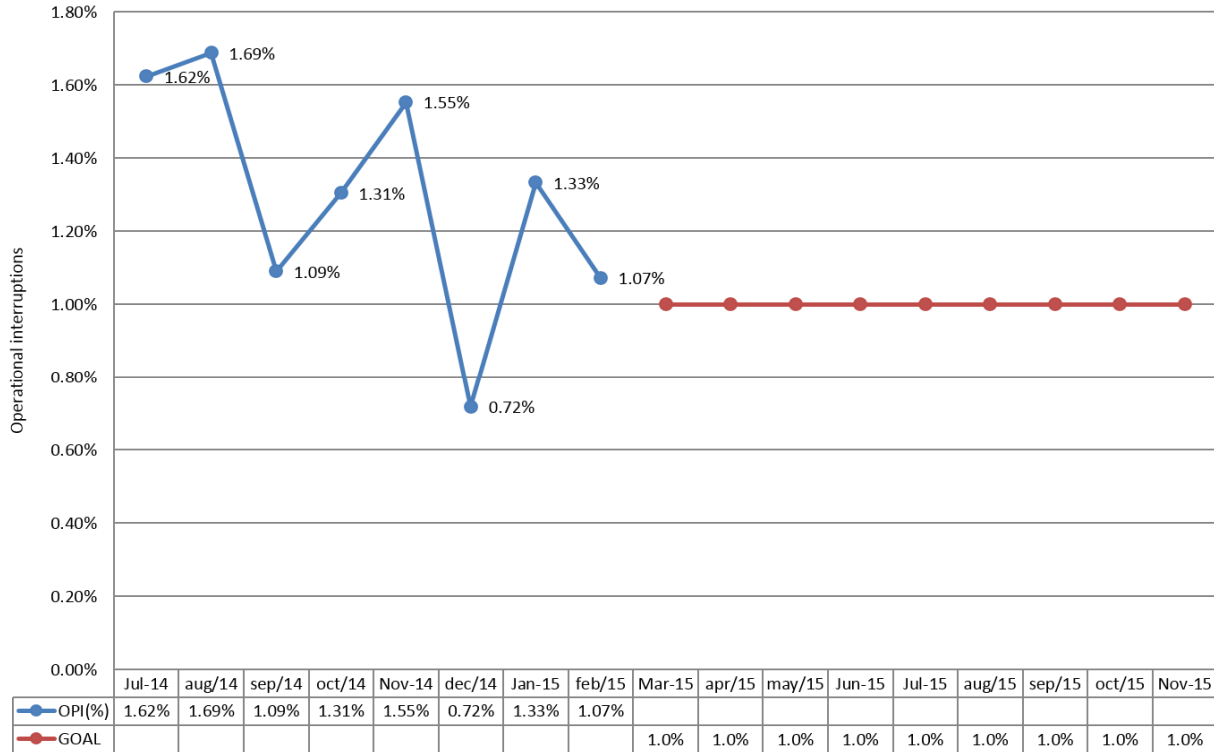


Figure 3. Percentage of the total scheduled time of interruptions during the months in which the records were analyzed.

After analyzing the interruptions and goal setting, the next step was to calculate the projection of the financial return that the project implementation would cause. According to Eq. (2), was obtained an annualized result of \$320.884,74 dollars.

$$GAIN = \left(\left(\frac{100 - OIP_{REAL}}{100 - OIP_{BASE}} \right) - 1 \right) (CM)(PR)(12\ months)$$

Eq.(2)

Where:

- GAIN = Gain calculated by cost (R \$ / year)
- OIPREAL = Averages of actual interruption (%)
- OIPBASE = Average of Bases interruption (%)
- MC = Average of contribution margin (R \$ / t)
- PR = Average of production (t / month)

Then, a total of 237 guides were observed and analyzed, being 39 different models through a Pareto diagram, as shown in Figure 3 where the area of action was defined.

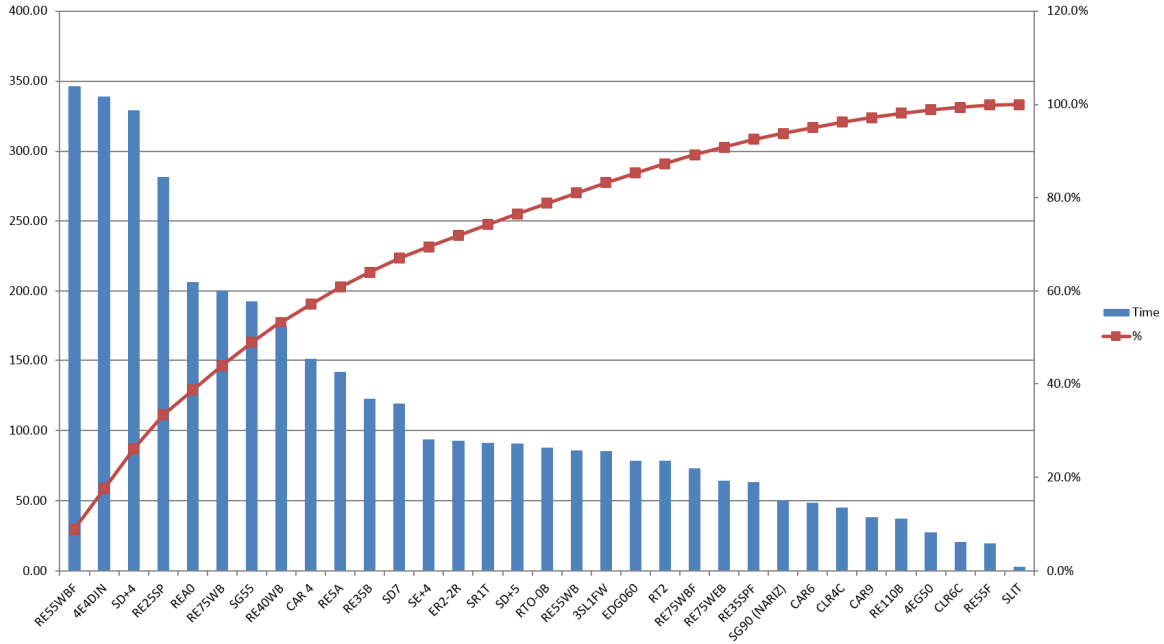


Figure 3. Pareto diagram used in the definition of the project area.

The project focused on eight critical models, which represent 53.3% of the total interruptions per guide in the analysis period, according to Figure 4.

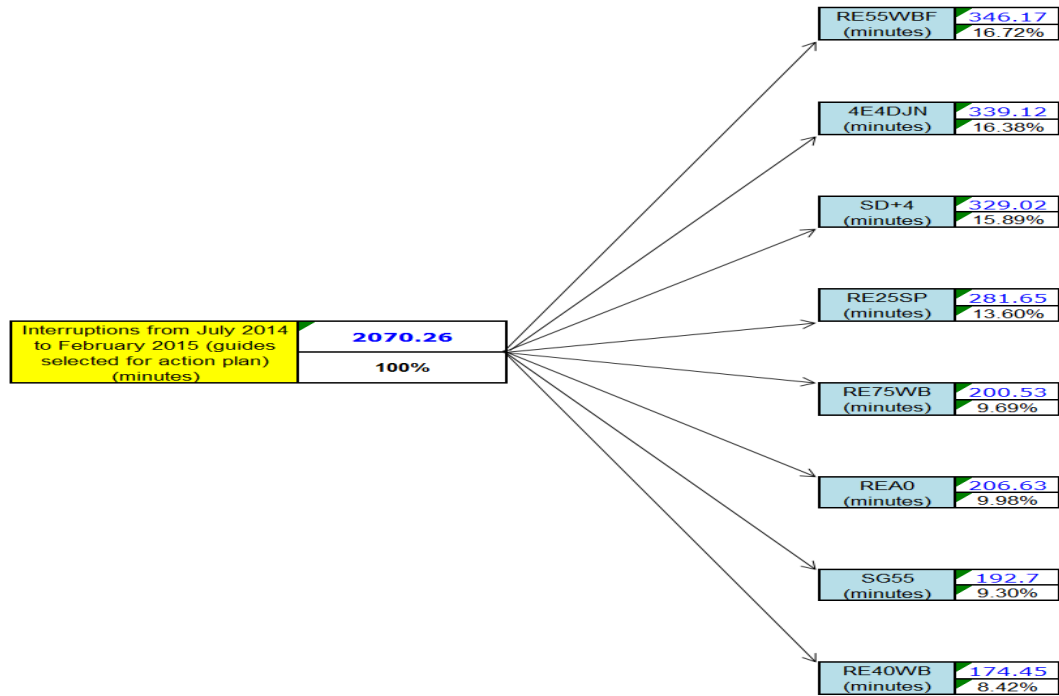


Figure 4. Schematic with the eight guide templates on which the project focused.

After defining the equipment with the highest incidence of problems, another Pareto diagram was made to define in which cages these eight selected models present a higher failure rate, as shown in Figure 5, where it can be observed that the highest failure rate occurred in the last finishing cage.

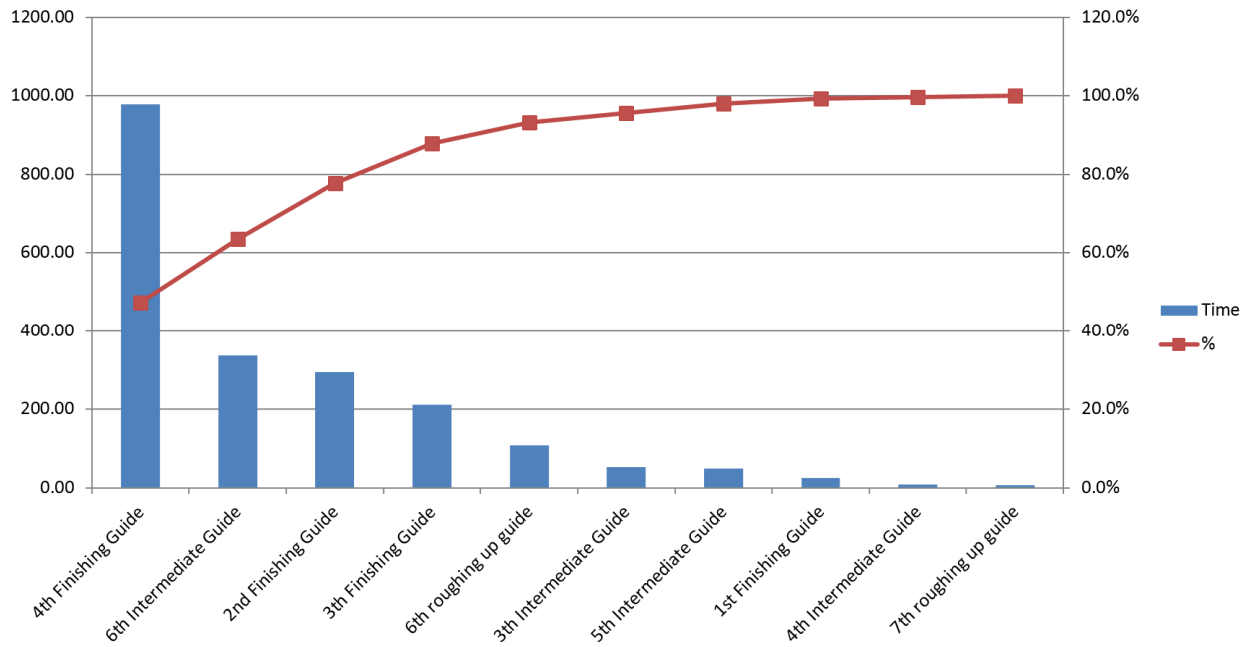


Figure 5. Pareto diagram defining in which cages these eight models of selected guides present a greater index of failures.

A third diagram was then given to identify the main problems reported. According to Figure 6, it is evident that the alignment problems stand out from the others.

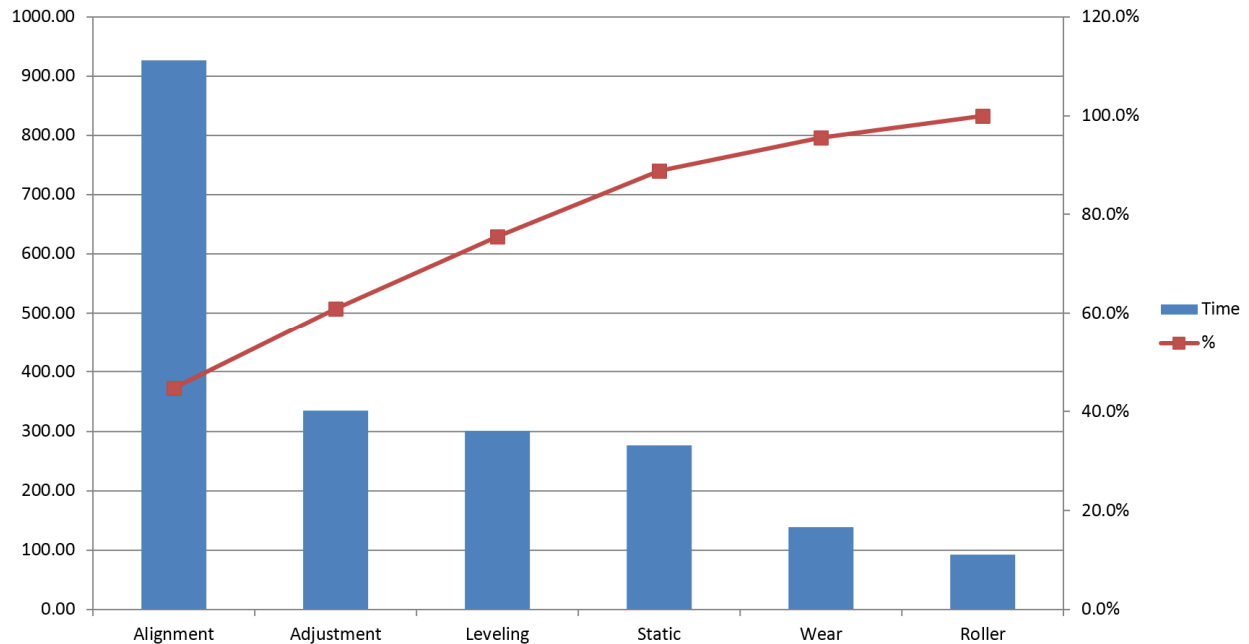


Figure 6. Pareto diagram defining what are the main problems presented by the eight models selected for actuation

Finally, a fourth Pareto was used to define which profile these eight models of selected guides presents greater difficulty in producing. Figure 7 shows that 60% of the stops occurred during the production of the profiles, rebar and round.

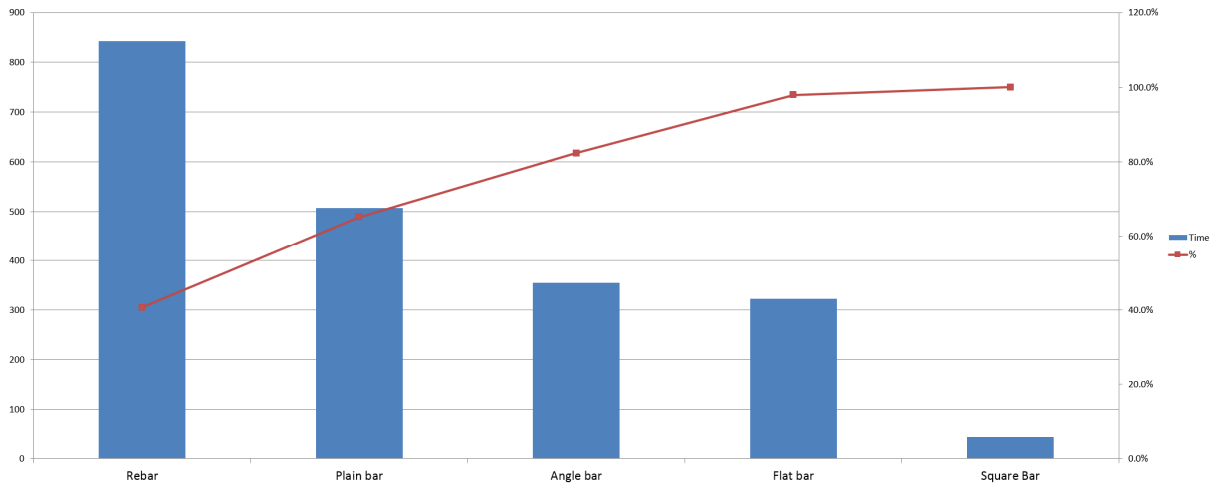


Figure 7. Pareto diagram used to define in which profile of these eight models of selected guides presents greater difficulty in producing

After the Pareto analysis, a project presentation meeting was held with the operation. To take advantage of the meeting, a Brainstorming was conducted, which served as the basis for separately mounting an Ishikawa diagram for each of the eight guide templates selected for performance. After the assembly of the Ishikawa diagrams, a Severity, Urgent and Tendency (SUT) matrix was set up to define the priorities at the time of the elaboration of the action plan according to Figure 8.

Cause	Severity			Urgency			Tendency			Score
	High	Medium	Low	High	Medium	Low	High	Medium	Low	
There is no capacitation to guide shop team		X		X			X			75
There is no capacitation to rolling mil team		X		X			X			75
There is no defition of acceptable wear for static	X				X			X		45
There is no external machining contract for rollers and guides		X		X				X		45
There is no working scope for machining rollers		X		X				X		45
There is using second line components for the guides	X				X			X		45
There is no alignment tool		X		X					X	15
There is no automatic triggering mechanism for the cooling valve	X				X				X	15
There is no roller external maintenance plan		X			X				X	9
There is no cages external maintenance plan			X		X			X		9
There is no guide maintenance of structural parts plan			X		X			X		9
There is no guide external maintenance plan			X		X			X		9
Guide foot with height unstandard		X				X			X	3
Have no standard shims from guide foot			X		X				X	3
Equipment are different from it drawing			X		X				X	3
There is no level tool for to make shure the rest bar is leveled whit both sides in the same height		X				X			X	3
There is no correct tools for to adjust the guide			X		X				X	3
There is no standard alignment specific for each guide			X		X				X	3
There is no standard leveling for guides and cages			X		X				X	3
There is no guide replacement plan			X			X		X		3
Have no standard assemble the static on guide REAO			X			X			X	1

Figure 8. Assembly of the SUT matrix in the definition of priorities for the action plan

With the data prioritized in the SUT matrix, a plan of action was elaborated, focusing on the causes with the highest score. It can be seen that during the execution of the action plan also were being carried out, in parallel, actions of fast gain following the philosophy of 5S. First, a general clean-up was carried out in the cell. The second step was to relocate pieces of sporadic use in the warehouse, discard everything that was taking up space and that was not used. Then the layout was restructured, with the collaborator in the center of the cell so that he can have easy access to all equipment, tools and parts, thus minimizing displacement.

In addition, a second workbench equipped with all the necessary tools for assembly and maintenance of guides has been installed, so that the collaborator responsible for the maintenance can work in parallel with the collaborator responsible for the assembly. All cabinets with doors were discarded and replaced by shelves or trolleys, exposing the organization of materials. The parts shelves have been identified and a fast location scheme has been developed for all parts.

Furthermore, all of the missing profile IDs were purchased, and they were centralized in a single, properly identified panel, as well as some static reservations for the dry guides. The checklists of the cell were restructured in order to simplify as much as possible and eliminate all items deemed unnecessary. And finally, the cell was painted and the lighting was redone.

Despite the difficulties and some delays in the action plan, the results obtained were quite satisfactory, proving that the project has a solid basis and that the proposed changes came to stabilize the process as indicated by the trend line shown in Figure 9.

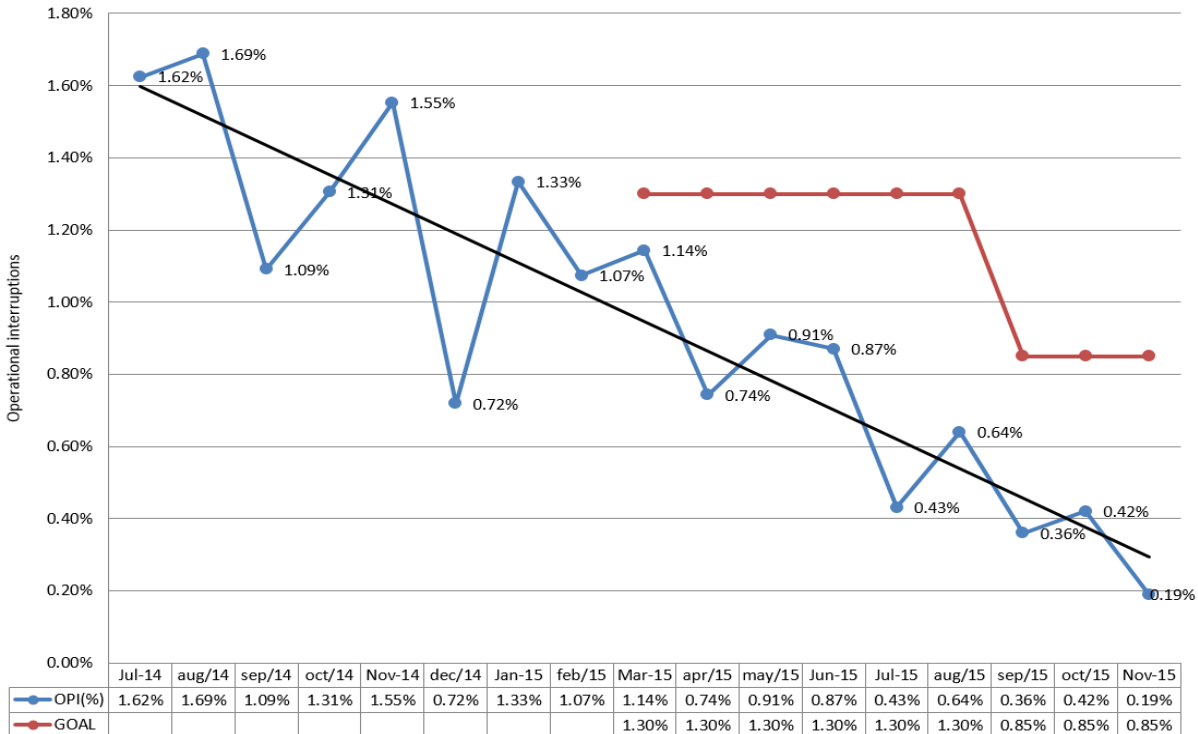


Figure 9. Interruption results collected during project development

Thus, as the work was completed before the end of November, the result described was proportional and shows that decrease 1.5% of interruption's variability in nine months.

6. Conclusions

During the construction of the work, it was noticed that with the correct application of a good working methodology based on lean and six sigma concepts and with detailed planning, discipline and organization, one can achieve the desired kaizen improvements, however it is necessary to exercise negotiation, knowing how to listen, understanding and often disagree, therefore, the human factor is very strong and is always present in projects of team management and process improvement.

In the system records, difficulties of classification of the stop and inconsistencies were found during the records of the events. It is worth noting that the scenario of the analyzed cell presented many opportunities for improvement in the 5S question, especially in the sense of order and use. There was also absence of wear control, parts being accepted outside the desired specification due to lack of planning of purchases, generating rework, missing parts with a frequency above acceptable, lack of control of the rollers to be recovered and, as a result, the lack of them and the lack of qualification of the employees responsible for both maintenance and assembly.

The stratifications pointed out that the alignment failures are the ones with the highest incidence, however, when analyzing the scenario as a whole, it is noticeable that in a way all problems are interconnected and the root cause is in fact lack of capacity and process standardization.

With all of these observation exercises, aided by the selected Six Sigma tools, a number of considerations were arrived at, some of them already explained in the analyzes. The most latent finding is the lack of training of the professionals who are part of the operational team. The differences in performance of employees after training were noticeable. What most attracted attention was the lack of motivation and the difficulty of some employees to visualize the change and to leave the zone of comfort. After the initial resistance, the work was taking shape and as the results appeared, the team was increasingly adhering to the proposed changes and even suggesting others.

From the results obtained, it would be interesting to continue the work of renewing and updating the equipment, in addition to continuing to train the team in Lean Six Sigma concepts and tools and standardizing procedures so that the knowledge is perpetuated and improved. Although the studied cell presents very adverse conditions such as physical space limitation and high production range, with the continuation of the work still can become reference in the group. For this to be effective, it is important to maintain follow-up and collection management, constant training and compliance checks.

References

- Aziz, R.F., and Hafez, S.M., Applying lean thinking in construction and performance improvement. *Alexandria Engineering Journal*, Vol. 52, no.4, pp. 679-695, 2013.
- Comm, C.L., and Mathaisel, D.F.X., A case study in applying lean sustainability concepts to universities. *International Journal of Sustainability in Higher Education*, Vol. 6, no.2, pp. 134-146, 2005.
- Childe, J.S. Case studies in operations management, *Production Planning & Control*, Vol.22, no.2, 107-107, 2011.
- Dombrowski, U., and Mielke, T., Lean Leadership – 15 Rules for a sustainable Lean Implementation. *Variety Management in Manufacturing*, In *Proceedings of the 47th CIRP Conference on Manufacturing Systems*, Vol.17, pp. 565-570. 2014.
- Eisenhardt, K. M. Building theories from case study research. *Academy of Management Review*, Vol. 14, no.4, pp. 532-550. 1989.
- Franchetti, M.J. *Lean Six Sigma for Engineers and Managers*. 2015.
- George, M.L. *Lean Six Sigma: Combining Six Sigma Quality with Lean Production speed*, McGraw Hill, 2002.
- George, M.L. *Lean Six Sigma for service: how to use Lean speed and Six Sigma quality to improve services and transactions*. New York, McGraw-Hill, 2003
- James, J., Ikuma, L.H., Nahmens, I., and Aghazadeh F., The impact of Kaizen on safety in modular home manufacturing. *International Journal of Advanced Manufacturing Technology*, Vol. 70, no.1, pp.725–734, 2014.
- Kumar, S., Luthra, S., Govindan, K., Kumar, N., Haleem, A., Barriers in green lean six sigma product development process: An ISM approach. *Production Planning & Control*, Vol. 27, pp. 604–620, 2016.
- Machikita, T., Tsuji, M., and Ueki, Y., Does Kaizen create backward knowledge transfer to Southeast Asian firms? *Journal of Business Research*, Vol. 69, pp. 1556–1561, 2016.
- Martínez León, H.C., Calvo-Amodio, J., Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective. *Journal of Cleaner Production*, Vol. 142, pp. 4384–4402, 2017.
- Miguel, P. A. C. *Recomendações na Adoção de Estudo de Caso como Abordagem Metodológica*. XII SIMPEP – Bauru, SP, Brasil, 7 a 9 de Novembro de 2005.
- Ohno, T. *O Sistema Toyota de Produção: além da produção em larga escala*. Porto Alegre: Bokmann, 1997.
- Parast, M.M. The effect of Six Sigma projects on innovation and firm performance. *International Journal Project Management*. Vol. 29, pp. 45–55. 2011.
- Popa, A., Ramos, R., Cover, A., and Popa, C., Integration of Artificial Intelligence and Lean Sigma for Large-Field Production Optimization: Application to Kern River Field. *Proc. SPE Annual Technical Conference and Exhibition*, 2005.doi:10.2523/97247-MS
- Productivity Press Development Team. *Kaizen for the shop floor*. Productivity Press, NewYork. 2002.
- Taghizadegan S. *Design for Lean/Kaizen Six Sigma. Essentials of Lean Six Sigma*. USA: Elsevier Inc. 2006.
- Voehl, F., Harrington, H.J., Mignosa, C., and Charron, R. *The Lean Six Sigma Black Belt Handbook - Tools and Methods for Process Acceleration*. Taylor and Francis Group. 2010.
- Voss, C., Tsikrikis, N., and Frohlich, M., Case research in operations management. *International Journal of Operations & Production Management*, Vol 22, no. 2, pp. 195–219, 2002.

Biography

Vinicius Souza de Moura, is graduate at Mechanical Engineering from PUCRS (2016), acting on the following subjects: Lean Manufacturing, Mechanical Fabrication, Operations Management, Steel Fabrication, Six Sigma and Kaizen.

Carlos Alexandre dos Santos, is graduate at Mechanical Engineering from School of Piracicaba Engineering (EEP, 1994), master's at Mechanical Engineering from State University of Campinas (UNICAMP, 1997) and Ph.D. at Mechanical Engineering from State University of Campinas (UNICAMP, 2001). He has experience in Material Science and Metallurgical Engineering, focusing on Material and Manufacturing Processes, acting on the following subjects: Continuous Casting of Steels, Solidification of Metals, Mathematical Modelling, Mechanical Properties, Biodiesel and Renewable Energy. Dean of School of Engineering at PUCRS since 2012.

Daniel Luiz de Mattos Nascimento, is Engineering Consultant at Tecgraf Institute/PUC-Rio, is Master in Mechanical Engineering with emphasis in Industrial Construction at Federal Fluminense University. Professor of MBA in Maintenance and Production Management at Federal Fluminense University and is currently a Ph.D. candidate in Civil and Environmental Engineering at PUC-Rio. Daniel acts as a researcher and has scientific productions in the areas of Building Information Modeling, Multicriteria Methods, Industrial Plants Construction, Manufacturing, Operations Management, Sustainable Development, Sustainable Construction, Smart Cities, Industry 4.0 and Lean Thinking.

Rodrigo Goyannes G. Caiado, is currently a PhD candidate in Sustainable Management Systems in Production Engineering Program, with emphasis in the area of decision support in organizations at the Federal Fluminense University (UFF); Master in Civil Engineering with emphasis in Construction Management and Graduated in Production Engineering from UFF. Mr. Caiado acts as a researcher and has scientific productions in the areas of Project Management, Multicriteria Methods, Sustainability and Lean Six Sigma. In addition, Mr. Caiado holds an MBA in Business Management and professional experience in projects in the Oil and Gas and Naval Construction sectors. He has taught courses in entrepreneurship, management and corporate sustainability and innovation for engineers and administrators.