A simulation model for the operations management sustainability

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Abstract: A tough challenge for the society is to pursue the occupation of workforce while keeping sustainability. In this sense factories on one side are welcome because of their capacity of employment, but on the other side must face very strict sustainability standards.
There are many efforts to support factories in reaching sustainability. In the Green foundry LIFE project, for instance, the aim is to show the feasibility of a new more sustainable process.
Operations management can be a tool for obtaining an environmentally sustainable production system. The paper aims to verify how acting on the management of the production system with a systematic design, implementation and continuous improvement of all processes the environmental performance increase. The paper proposes a simulation model applied to an industrial case in the foundry sector. The model is applied in production planning in order to reduce storage times. The reduction of these times is necessary for the achievement of the environmental sustainability of an industrial sector that has a significative environmental impact.

Keywords: Operations management; Sustainability; Simulation.

1.Introduction

Operations management are a set of actions and practices to create the highest level of efficiency. The contribution of operations management is not only to strategy, it has a huge potential to deliver sustainable advantage (Slack, 2005).
The integration of operation management and sustainability allows for sustainable production processes economically, environmentally and socially. Improving productivity, the economic benefits increase (Rishi et al., 2018), while focusing on the triple bottom line (people - profit- planet), sustainability get better (Pampanelli et al., 2015, Gimenez et al., 2012, Doolen and Van Aken, 2011).
In literature the issue of sustainable operations management is well known. Kleindorfer et al. (2005), for instance, see new challenges in the integration of sustainability and operation management research. In particular, operations management contribute to sustainability by "reinforce its original links with engineering". He notes that in order to achieve synergy between Lean and Green management must integrate "environmental, health and safety metrics with process metrics". In reality, it must underline that this synergy can be so strong that only lean can allow sustainability, as it is shown in the paper.
Neither, more recently, Martinez et Calvo-Amodio (2017) do not address the possibility that operation management can be a key for sustainability basis. They introduce "lean for sustainability" by using system thinking methods.
Resta et al. (2017) study the integration of lean and sustainability stress the fact that they must be aligned. This alignment can be achieved when operation management allow the introduction of more sustainable processes.
The evaluation of the impact of operational management on environmental sustainability is considered in Antomarioni et al. (2018). They show that operations management improvement obtained by kaizen actions, can improve overall performances, including the environmental ones. Their study can be extended by considering that lean techniques can allow the introduction of new sustainable processes.
The concepts of lean and green can be applied in several stages of products and processes along the supply chain, starting from design, production, suppliers, and customers (Kurdve et al., 2014, Mor et al., 2016).
The contribution of operation management to obtain sustainable production processes and the integration and synergy between the concepts of lean and green management are detailed in the paper. Through the analysis of an industrial sector, the objective is to highlight the great potential that the optimization of operations can have not only for the economic aspect but also towards the environmental one, achieving sustainable processes.
The analysed industrial sector is the foundry industry characterized by an important role and a significative environmental impact. Modifying the industrial layout and balancing the workload (De Oliveira and Barbosa Pinto, 2008) it is possible to implement improvements in foundries production systems. The use of lean manufacturing tools in foundry industry is investigated in 300 Polish foundries through a survey (Jezierski and Janerka, 2013): only the 29% of the foundries have implemented any of the lean tools. However, using lean tools and techniques, the pouring time, the WIP inventories and the production time are reduced, improving the safety and productivities (Jaiswal and Dalu, 2018).
The remaining of the paper is organized as follows: Section 2 is dedicated to the depiction of the methodology used. In Section 3 a case study is presented, while in Section 4 the

results and the discussions are explained. Section 5 contains the conclusions.

2. Methodology

The research question that the work poses is:

• How can operations management be a tool to achieve sustainable processes?

The question arises within a European project, the Green Foundry LIFE project (LIFE17 ENV/FI/000173) that introduces novel technologies for sand-moulding systems to cut emissions, improve indoor air quality and support the circular economy through re-use of foundry sand that is normally landfilled. But before being able to introduce a new technology within a production process it is necessary to analyse its implications on the production line. Operations management therefore help to optimize the production process in order to make it more efficient and subsequently able to introduce new technologies to be more environmentally sustainable.
The research approach is shown in Figure 1. Starting from the analysis of the production line, the research wants to improve the performance of the production system via a simulation.
Afterwards, the aim is to allow environmentally sustainable production by introducing, in the specific case study, new binders to produce foundry cores.

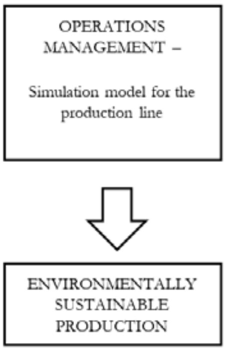

Figure 1: Research approach

The study therefore wants to demonstrate that by acting on operations management it is also possible to improve the company performances from an environmental point of view. This approach is applied to the foundry sector, but the goal is to demonstrate the potential of operations management in improving not only the production system from an industrial point of view, but also to improve its environmental sustainability.

3. Case study

To answer the research question, a foundry is analysed. The foundry industry considered produces automotive parts such as turbines housing (2.5 million items/year), bearing housing (3.2 million items/year) and manifold (1 million/year). These kinds of products are small and quite complex in term of qualitative standard of the foundry operations. It is necessary a high-quality standard with strict constraints in tolerance.

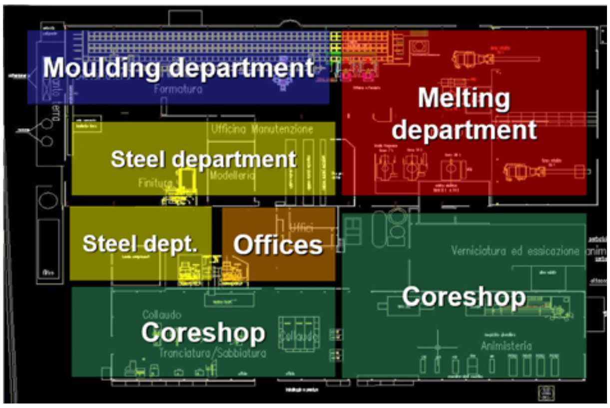

Figure 2: Plant layout

The foundry plant layout considered is shown in Figure 2. Among others, three foundry areas are considered in the study because they are the departments that allow a greater possibility of intervention to improve industrial processes:

(1) the coreshop department: the area for the cores production;
(2) the moulding department: the area for mould preparation and for all operations before casting;
(3) the melting department: the area for the melting and treatment of metal.

These main areas are schematized in Figure 3: the flow through the various departments is shown and also the core warehouse is representing.

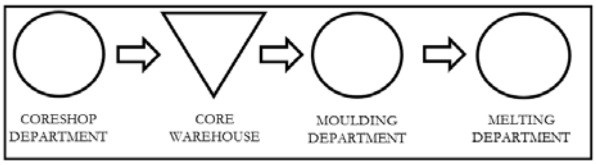

Figure 3: Production flow

The coreshop department produces the cores: elements used to create internal cavities where the melted metal does not have to penetrate, for functional reasons of the piece or to reduce its overall weight. The produced cores must minimize the formation of burrs, satisfy certain requirements, which vary according to the casting technique. After the solidification of the metal, the jet is extracted and the core is removed by dirt (Czerwinski et al., 2015).
The analysed foundry uses the cold box method to form the cores even if there are different processes. The cold-box process, also known as the Ashland process, was tested in 1965 in U.S.A. and was presented in Europe only in 1968. This process allows the production of cores without

using heat. The cores are produced in a few seconds and ready for immediate use.
Figure 4 shows one of the production line of the cores of the analysed foundry. There are three silos (on the right of the figure) each containing a different type of sand (a synthetic sand, a French sand and a national sand) sent in mixture to core blowing machine. The sand is mixed for a time between one and two minutes, with a two-component binder: a phenol formaldehyde resin and a poly-isocyanate. Then the mixture enters the core blowing machine to produce the cores. The line in Figure 4 consists of three core blowing machines: even if they share the same feeding duct for the sand, each machine has an independent mixer to produce different types of core.

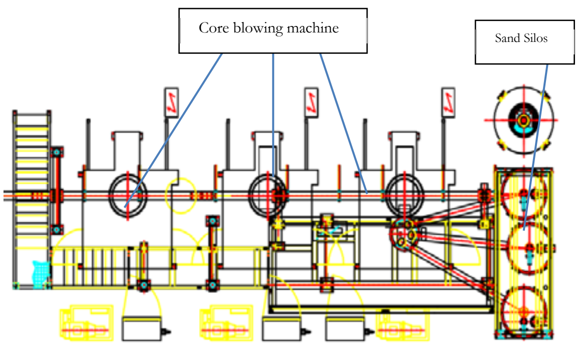

Figure 4: Cores production line

Once produced, the cores are stored in the warehouse waiting to be used in the moulding department, which operation is shown in Figure 5.

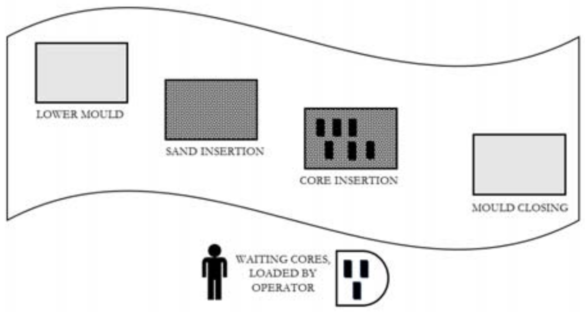

Figure 5: Moulding department

In the moulding department the moulds to produce pieces are assembled and the cores are manually inserted by an operator.
Finally, the mould is sent to the melting department.
Analysing the processes, the coreshop department has a slower production rate than the moulding department, respectively 20 pieces/hour for each core blowing machine and 140 pieces/hour for the moulding line. For this reason, the storage of cores in a large warehouse (about 6.000 m^3) is necessary with an average storage time of a week. This high storage time is induced by some constraints in the production of cores:

(1) setup time for each core blowing machine of 2 hours;

(2) core box cost: the high cost of the core box involves the difficulty of producing the same product in parallel on separate core blowing machines (only for large productions there are multiple moulds).

The first analysis of the production processes highlights the possibility of intervening on the current warehouse management: the long storage time and the large size of the warehouse are critical situations on which it is necessary to operate in order to make production leaner.
A simulation model is developed to simulate the cores production line in order to obtain a leaner warehouse, with fewer pieces and with a storage time reduced to 8 hours. In the as-is case there is no problem in stocking cores: it is possible to produce cores and stock them for weeks. The optimal solution proposed is based on a storage time of 8 hours, set in agreement with the plant manager.
At the present, each week there is a planning of the cores department and a plan for the foundry: you can anticipate cores making by several weeks and the departments are essentially in parallel, because the coreshop department productivity is much bigger than foundry shop.
With the simulation model the coreshop department and the foundry are in serial connection, one before the other, with only 8 hours of delay. It is noteworthy the radical change in the production management.

4. Results and discussions

50 weekly orders which job duration is not known in advance, distributed stochastically with a Beta type probability function are simulated. The Beta Distribution is task duration modelling, for instance in project management.
The chosen distribution, according to data supplied by plant manager, is within the range [0.2 - 3]. This distribution represents the production rate, in hours, of the moulding department. Each order will therefore be kept in moulding for a minimum of 12 minutes (0.2 hours), up to a maximum of 3 hours, with a production rate for the moulding machine of 140 pieces/hour. The average value of the various orders is 0.8 hours. The chosen mode "m" is 0.4 hours since it results as the most probable time to produce a single order. The minimum, the most probable and the maximum estimated values, consider also the efficiency of the production. The distribution curve of the orders is shown in the figure 6.

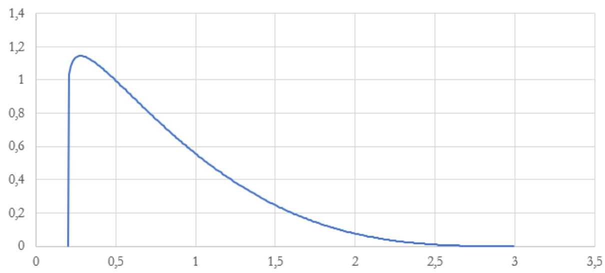

Figure 6: Beta probability distribution of the duration of each 50 weekly orders

Among the 50 weekly orders, 10 daily orders are hypothesized, i.e. 10 different types of cores produced every day.
The production rate in the coreshop department is, as mentioned above, 20 pieces/hour and for each shot, the core blowing machine produced within the same core box up to 24 cores. However, within the same mould more cores are needed, up to 24.
Therefore, the number of cores in a mould and the number of cores produced in a core box change from 2 to 24 (see Figure 7). In the model considered, the ratio between the number of cores per mould and the number of cores per core box is varied.

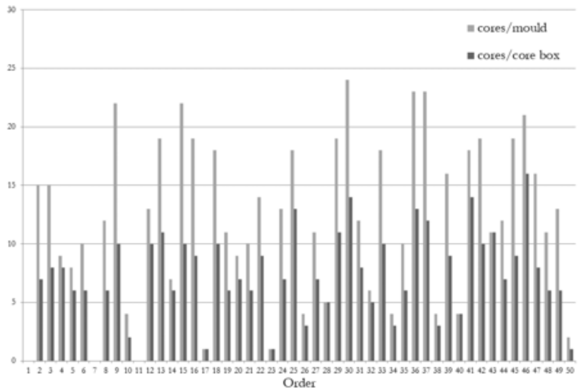

Figure 7: Trend of cores/mould and cores/core box in the 50 orders

The necessary working hours in the coreshop department to produce the quantity of cores required by the moulding department are calculated daily:

$$h_c = Q \cdot T_c + T_{setup} \cdot n_b$$

h_c = daily hours required in the coreshop department;
Q = pieces/day required by the moulding department;
T_c = productive rate of the core blowing machine;
T_{setup} = setup time;
n_b = number of daily batches.

Then, the number of machines necessary to carry out the different daily orders is calculated, avoiding that the storage of cores exceeds 8 hours (Figure 8) and hypothesizing that due to the high production rate imposed by the moulding, the coreshop is organized in two shifts for a total of 16 daily hours, 8 of which are before the work of the moulding department begins.

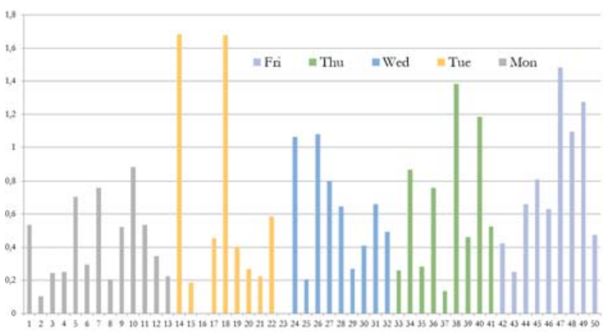

Figure 8: Number of machines

Figure 9 shows the total number of machines needed every day.

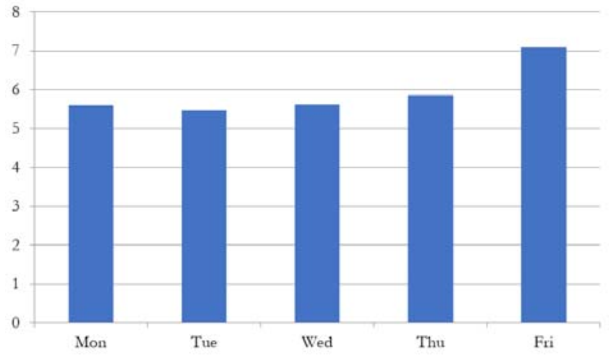

Figure 9: Total number of machines per day

In order to validate the model, the number of simulations is extended for a total of 50,000 replicas. Evaluating the overall result (Figure 10), the sufficient number of core blowing machines is generally 6 and, in order to cover the production peaks, it is necessary to have 8 machines.

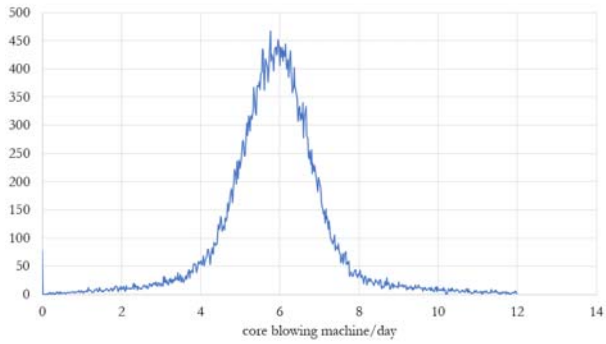

Figure 10: Total number of machines per day after 50.000 replicas

With 8 core blowing machines it is possible to cover peak production, avoid costly downtime on the line and work in parallel on the same product. In addition to the core machines, it is necessary to have more core boxes of the same type. Currently in the company there are multiple core boxes (usually three) of the same type only for large series production. The simulation considers a number of core boxes varying between 1 and 3. The set-up time for each machine can vary from a minimum of 15 minutes to a maximum of 2 hours, depending on the complexity of the core box used on the core blowing machine. The machines number in the core shop department used for the cast iron is 7, so it is necessary to purchase an additional machine according to the results obtained from the simulation. The production of cores will be greater in the time interval and will allow to follow the moulding department production rate.
The simulated industrial process requires some changes respect to the current production line: one more machine is needed. An economic evaluation will be carried out, considering, on one side, the possibility of convert one of

the machines already in the foundry and, on the other side, the purchase of a new machinery. In this second case, also the environmental impacts must be assessed.
The results simulation therefore indicates the possibility of changing the current operation of the coreshop department to make the warehouse management leaner, reducing the warehouse space and costs, and improving the economic performance and sustainability.
The analysed industrial sector is also subject to stringent environmental regulations and it is necessary to introduce actions to improve the processes that lead to a decrease the emissions and environmental impact.
The analysis carried out on the coreshop department, simulating the processes and the changes necessary to achieve a storage time of 8 hours, is completed by an environmental assessment of the department.
Indeed, the cores cause many hazardous emissions in the entire cast iron process. To guarantee the right mechanical resistance of the cores, binders are used: chemical mixtures, with a content from 1% to 3% (the remaining 97-99% is sand), that adhere to the grains provide mechanical resistance to the core. The traditional binders used for the cores emit up to 70% of volatile foundry compounds (VOC) (Izdebska-Szanda and Balinski, 2011). In recent years, the foundry industry has seen environmental standards become increasingly restrictive (UNI EN , 2004 and Directive EU, 2010): the goal is to replace the organic binders with lower-emission binders, which guarantee comparable physical and mechanical properties at high temperatures.
New inorganic binders are introduced first in aluminium foundries: Inotec™by ASK Chemical, Cordis by Hüttenes-Albertus, GEOPOL® by Sandteam CZ and inorganic system developed among the Gietech-Go project are in commercial use or in trial phase.
Inotec binder system consists of a binder (i.e. alkali silicates, a modified blend of waterglass) and a promotor 100% inorganic, consisting of minerals and synthetic raw materials. Curing of Inotec binder system moulds and cores is made by heating, with an optimum temperature about 170-175°C. The recycling of Inotec sand must be made by thermal reclamation. Inotec has mainly been used in aluminium foundries but some trials have been made in ferrous foundries.
Cordis system is essentially like Inotec. Two components are needed: Cordis binder (modified alkali silicate solution) + Anorgit additive (synthetic, inorganic additives). Curing by heating to 130-200°C must be applied. Coating is necessary for ferrous castings: water-based coatings can be used, but drying must be made instantly after painting, otherwise humidity destroys the strength. Cordis system has taken hold in about all foundries, especially in those serving automotive industry but in ferrous foundries. Cordis is still in a trial phase.
The use of inorganic binders is also evaluated through research projects, like the Green Foundry LIFE project. The main objective of this project is the decrease of the environmental impact by introducing new technologies for sand molding systems. In particular, the use of inorganic binders in ferrous foundries applied in sand molding systems improves the environmental and economic impact and also increases competitiveness of the industry. The use of new inorganic binders reduces hazardous air emissions, casting fumes and fine particles like binder aerosols from the casting process. Moreover, the indoor air quality is improved. Saetta et al. (2019) describe some benefits of using inorganic binders in the foundry.
The reduction of the storage time allows the introduction of inorganic binders in the cores production: converting a warehouse with weekly storage time to Just in Time (JIT) management makes possible to store inorganic cores. Due to their hygroscopicity, which leads to loss of mechanical properties, the inorganic cores are characterized by a maximum storage time of 8 hours. The JIT management is a one of the lean techniques that solve the losses and increase the productivity, generating a more sustainable process from an economic point of view (Wee and Wu, 2009; Bergmiller, 2006; Modi and Thakkar, 2014). The case study demonstrates that, in addition to the economic improvement, environmental benefits can be obtained, thus combining the concepts of green and lean production.

The operation management gives the possibility of improving the cores warehouse management and the consequent possibility of using inorganic cores, obtaining both a lean and environmentally sustainable production: a storage time of 8 hours allows for an economic and environmentally sustainable cores production.

5. Conclusions

The paper proposes a simulation model applied to an industrial case in the foundry sector. The model is applied in production planning in order to reduce storage times. The reduction of these times allows the achievement of not only a leaner production system but also an environmentally sustainable production.
The study therefore demonstrates that by acting on operation management it is also possible to improve the company from an environmental point of view.
Future development will concern an economic and environmental evaluation of the new configuration of the coreshop department and the impact of the use of the new binders on the whole production system.

Acknowledgements

The searches mentioned in this paper are co-financed by EU LIFE Programme 2017, Green Foundry LIFE project (LIFE17 ENV/FI/000173). The publication reflects only the Author's view and the Agency/Commission is not responsible for any use of that

may be made of the information it contains. **http://greenfoundry-life.com/**.

References

Antomarioni, S., Bevilacqua, M., Ciarapica, F.E. 2018. More Sustainable Performances Through Lean Practices: A Case Study, *2018 IEEE International Conference on Engineering, Technology and Innovation*, ICE/ITMC 2018; Stuttgart, Germany, 17-20 June 2018, Code 138725.

Bergmiller, G.G. 2006. Lean manufacturers transcendence to green manufacturing: Correlating the diffusion of lean and green manufacturing systems.

Czerwinski, F., Mir, M., Kasprzak, W. 2015. Application of cores and binders in metalcasting, *International Journal of Cast Metals Research*, 28(3), pp. 129-139.

De Oliveira, C. S., Barbosa Pinto, E. 2008. Lean manufacturing paradigm in the foundry industry. *Estudos Tecnologicos* 4 (3), pp. 218-230.

Directive 2010/75 / EU of the European Parliament.

Doolen, T., Van Aken, E. 2011. Achieving Total Sustainability by Cleaning up the Dirty Dozen.

Gimenez, C., Sierra, V., Rodon, J. 2012 Sustainable operations: Their impact on the triple bottom line. *International Journal of Production Economics*. 140(1), pp. 149-159.

Izdebska-Szanda, I., Balinski, A. 2011. New generation of ecological silicate binders. *Procedia Engineering* 10, pp. 887-893.

Jaiswal, T. P., Dalu, R., S. 2018. Analysis and improvements of productivity by using lean manufacturing tools in foundry industry – a case study. *International journal of innovative research in technology,* 4(12), pp. 974-980.

Jezierski, J., Janerka, K. 2013. The lean manufacturing tools in Polish foundries. *Archives of Metallurgy and Materials*, 58 (3), pp. 937-940.

Kleindorfer, P.R., Singhal, K., Van Wassenhove, L.N. 2005. Sustainable operations management, *Production and Operations Management*, Volume 14, Issue 4, December 2005, Pages 482-492.

Kurdve, M., Zackrisson, M., Wiktorsson, M., Harlin, U. 2014. Lean and green integration into production system models–experiences from Swedish industry. *Journal of Cleaner Production*, 85, pp. 180-190.

Martínez León, H.C., Calvo-Amodio, J. 2017. Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective, *Journal of Cleaner Production*, Volume 142, 20 January 2017, Pages 4384-4402.

Modi, D.B., Thakkar, H. 2014. Lean thinking: reduction of waste, lead time, cost through lean manufacturing tools and technique. International Journal of Emerging Technology and Advanced Engineering. 4(3), pp. 339-334.

Mor, R.S., Singh, S., Bhardwaj, A. 2016. Learning on lean production: A review of opinion and research within environmental constraints. *Operations and Supply Chain Management: An International Journal.* 9(1), pp. 61-72.

Pampanelli, A., Trivedi, N., Found, P. 2015. The Green Factory: Creating Lean and Sustainable Manufacturing. CRC Press. ISBN 9781498707855.

Resta, B., Dotti, S., Gaiardelli, P., Boffelli, A. 2017. Lean manufacturing and sustainability: An integrated view, *IFIP Advances in Information and Communication Technology,* Volume 488, 2016, Pages 659-666.

Rishi, J., Srinivas, T., Ramachandra, C., Ashok, B. 2018. Implementing the Lean Framework in a Small & Medium & Enterprise (SME)–A case Study in Printing Press, *IOP Conference Series: Materials Science and Engineering.* 376 (2018) 012126 doi:10.1088/1757-899X/376/1/012126.

Saetta, S., Di Maria, F., Caldarelli, V., Tapola, S. 2019. Improve the use of natural resources: inorganic binders in iron and steel foundries case of the Green Foundry LIFE project. *17th International Waste Management and Landfill Symposium,* 30 Sept - 04 Oct 2019, Italy, poster sessions.

Slack, N. 2005. Operations strategy: will it ever realize its potential?, *Gestào & Produçào*, vol. 12, no. 3, pp. 323-332.

UNI EN 13725: 2004.

Wee, H., Wu, S. 2009. Lean supply chain and its effect on product cost and quality: a case study on Ford Motor Company. Supply Chain Management: An International Journal. 14(5), pp. 335-341.