1st World Congress on Industrial Engineering and Operations Management
October 09-11, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/WC01.20240166
Published: October 09, 2024

Conception of Competitive Processes Using Coarse System Dynamics-Based Models

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Abstract

Several methodologies use group discussion to identify the root causes of the weak performance of a process. These methodologies conceive process improvements by suggesting modifications to the root causes based on the feelings of the employees. However, these methodologies do not include the positive and negative cause-effect relationships between the process performance and its root causes, nor the multiple antagonistic process performances desired by the stakeholders. In order to fill this vacuum we suggest the use of models based on system dynamics with coarse functions to avoid the complex modeling of the activities details. These models specify the intensities of the conceived improvements and their systemic impact on the process performance. We apply these models to conceive the organizational improvements of the process of developing microprocessors.

Keywords
System dynamics, business process management, operations management, continuous improvement, and product development.

1. Introduction

A system is a set of elements interacting toward a common objective (Kossiakoff et al. 2011) whereas a process is a set of activities making a specific product or delivering a specific service (Brocke et al. 2015). A process is a subset of a system. Processes are kept by companies as long as they satisfy the performances desired by its stakeholders (customers, owners, employees, suppliers, and others). In practice, most of the time the process's performances differ from the ones desired by the stakeholders so it is necessary to conceive and implement improvements.

This paper is focused on services (banks, insurance, government institutions, health centers, education centers, and others). Intelligent models to support the conception of process improvements are available for manufacturing (Macedo, Ruiz Usano 1994) but not for services. The improvements of services are still conceived by brainstorming and benchmarking in group, as suggested by continuous improvement methodologies (total quality control, kaizen, business process reengineering, business process management, DMAIC and others). However, these methodologies do not include an effective tool to optimize the intensities of the conceived improvements and to estimate their impact on the process performance. In order to fill this vacuum we suggest a new tool that uses system dynamics models (Forrester 1961) with coarse functions (Perale et al. 2020) instead of complicated equations that model in detail the process activities. This tool prescribes the candidate improvement intensities so that the gap between the current and the desired process performance satisfies all stakeholders. We apply this tool to conceive the improvements of a microprocessor development process.This paper includes four sections. In section 2, the problem of conceiving the improvements of a problematic process is clarified. In section 3, a procedure to conceive these improvements is presented. In section 4, this procedure is applied to support the conception of the improvements of a microprocessors development process.

2.The problem of conceiving process improvements

In services industry the resources (employees, materials and equipment) interact to execute activities and deliver some services. These activities constitute processes that are observed and represented by process diagrams (Brocke et al. 2015). On the other hand, the stakeholders desired performances are caught with requirements diagrams and use cases (Friedenthal 2012). At this point note that the conception of the process improvements is a complicated task: the process performances desired by the stakeholders are several and antagonistic, the resources have many interactions and the root causes of the process performance have different natures and are anywhere in the company. In addition, most of the time the observed performance of the process differs from the desired one so that the process

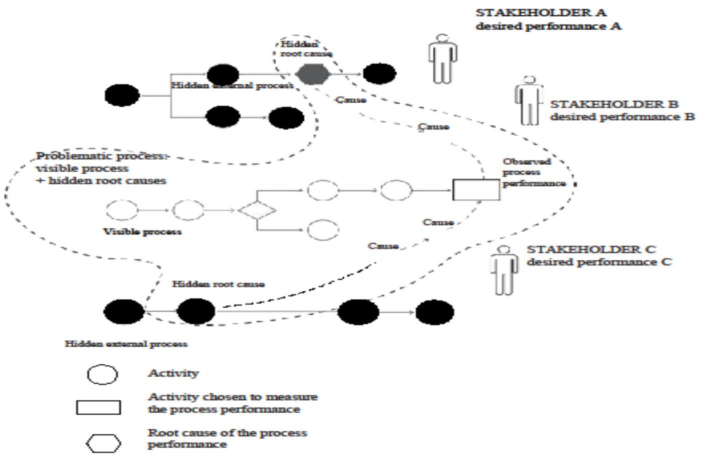

Figure 1. Most of the time the root causes of the observed process are hidden because they belong to processes which are external to the observed process. In addition there are many stakeholders and they desire antagonistic performances for the process.

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is called problematic and requires improvements (Figure 1). In order to conceive the improvements of a problematic process continuous improvement methodologies exist (total quality control, kaizen, business process reengineering, business process management, DMAIC and others). All of them require drawing a diagram of the problematic process and then forming discussion groups that build cause-effect diagrams. The latter are built by asking the question “What is the cause?” of the process performance variables behaviors and this question is re-asked many times until the root causes are identified. At this point note that the cause-effect diagrams currently used ignore the positivity and negativity of the cause-effect links (Islam 2016, Kumar 2008) although researchers suggest including them (Kaplan et al. 2004). Otherwise, the process improvements are the modifications of the root causes reducing the gap between the observed and the desired performance of the process. It is worth noting that the discussion groups estimate these gaps reductions by feelings, experiences or some arbitrary procedures (Albliwi et al. 2015, Furterer 2009, Islam 2016, Kumar 2008, Oliya et al. 2012, Riley et al. 2013, Laureani et al. 2013, Yadav 2016).

In order to make more objective estimations of the impacts of the candidate improvements on the process performance four quantitative tools can be used: Discrete simulation (El-Haik et al. 2006), business process management software (Reijers 2021), system dynamics simulation (Cardiel-Ortega et al. 2017) and response surface technique (Myers et al. 2009, Ascough et al. 2013). The structures of the equations of the discrete simulation and business process management software allow modeling sequential activities only. Because the root causes of the process performance are most of the time anywhere in the company the models built with these tools risk of not including all of them or including them with difficulty (Figure 1). Hence, these methods cannot evaluate completely the impact of the candidate improvements on the process performance. On the other hand, using differential equations, system dynamics models can catch any type of variable across the company. Hence, these models can include any root cause of the process performance but their construction requires a lot of time. In addition, the response surface technique requires a lot of data (most of the time unavailable) and the construction of its models is tedious. At this point note that people of the discussion groups conceiving the process improvements are reluctant to use complicated tools (Yadav 2016).

In sum the four quantitative tools above are not completely suitable to estimate the impact of candidate improvements on the process performance. In order to fill this vacuum we suggest a new tool that prescribes the candidate improvements intensities so that the gap between the current and the desired process performance satisfies all stakeholders. This tool uses system dynamics models (Forrester 1961) but replacing the detailed equations by monotonically increasing and decreasing functions (Kuipers 1994) to ease the model construction. In addition, these models include the positive and negative cause-effect links generated by the multiple interactions of the process resources, as suggested elsewhere (Kaplan et al. 2004). Furthermore, these models can catch any root cause of the process performance independently of its nature and location in the company. It is worth noting that the variables of the cause-effect diagram of our tool (named systemic causal map) allow the identification of key performance indicators to control the implementation of the improvements, as suggested elsewhere (Heavy et al. 2012).

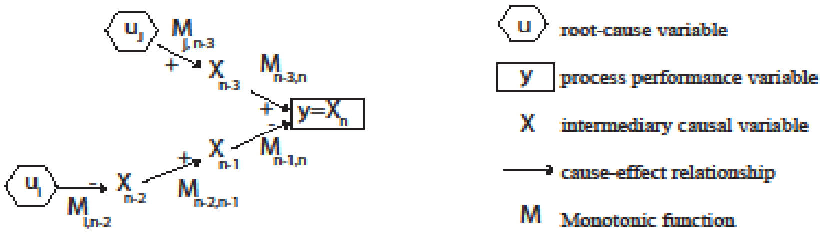
3.A procedure to conceive the process improvements

The conception of the improvements of a problematic process includes two steps. The first step is the identification of the natures of the improvements. This is done by the questioning exercise above until the root causes of the performance process are identified. The second step is the estimation of the improvements intensities so that the gap between the current and the desired performance of the process satisfies all stakeholders. We suggest making this estimation by iteratively solving a coarse optimization model. The latter includes an objective function, constraints and a systemic causal map. At this point note that the root causes rates of variation obtained by solving the coarse optimization model indicate the required improvements of the problematic process. These rates of variation can be integrated to obtain their corresponding level values.

A systemic causal map is a cause-effect diagram represented by differential equations as in system dynamics models (Sterman 2000) but with simplifications. A systemic causal map includes three types of variables: Performance variables (in rectangles in Figure 2), root causes (in hexagons in Figure 2) and intermediary causal variables (without shapes in Figure 2). The performance variables and the root causes are connected by intermediary variables (identified by asking the question “What is the cause?” as explained above). The cause-effect links are modeled by differential equations that connect the rate of variation of the cause variable with the rate of variation of the effect variable. In addition, these equations include increasing or decreasing monotonic functions (Kuipers 1994) that create positive or negative cause-effect links and also convert the units of the cause variable into the units of the effect variable. Otherwise, the objective function of the coarse optimization model is the integral of the quadratic deviations of the process performance variables with respect to their desired values (Figure 3).

As shown in Figure 3, the procedure to estimate the intensities of the process improvements is done by iteratively solving the coarse optimization model until the gaps between the observed and the desired process performance satisfy all stakeholders. The objective function of the coarse optimization model includes penalties that can be modified at each iteration to strengthen or weaken the different gaps according to the stakeholders preferences.

Process diagram



Matrix notation

$$\dot{X}_n = M_{n-3,n}\,\dot{X}_{n-3} - M_{n-1,n}\,\dot{X}_{n-1}$$

$$\dot{X}_{n-3} = M_{j,n-3}\,\dot{u}_j$$

$$\dot{X}_{n-1} = M_{n-2,n-1}\,\dot{X}_{n-2}$$

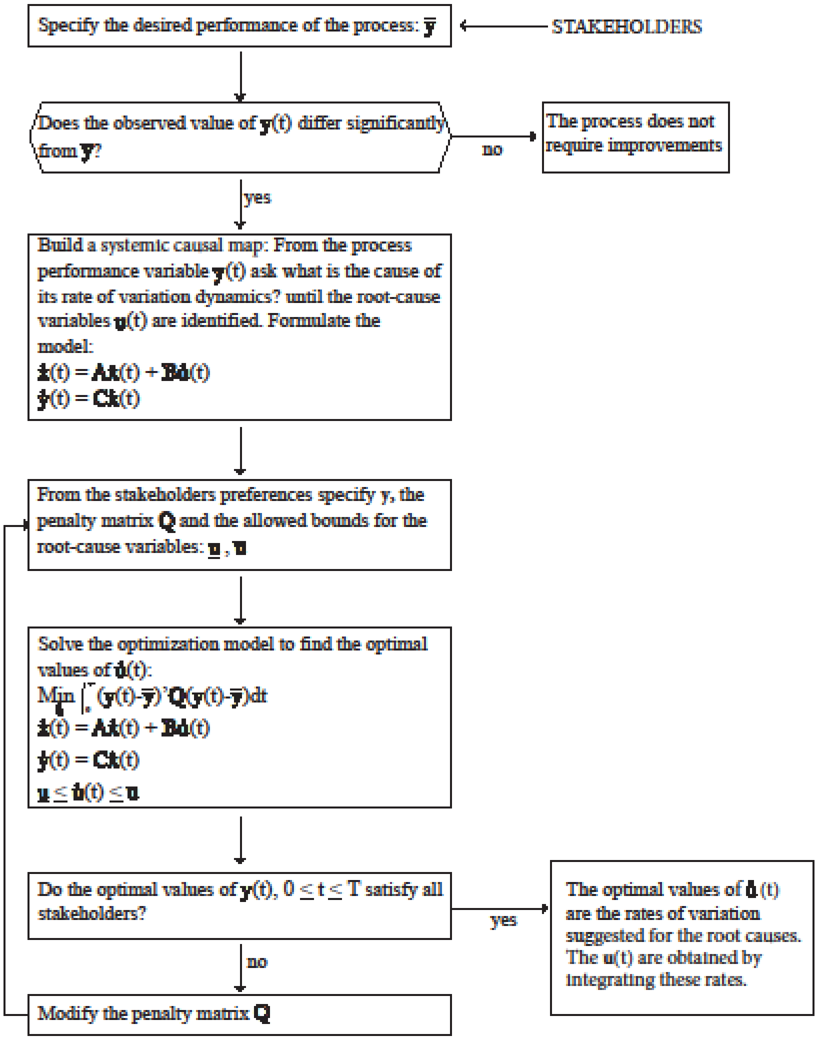
$$\dot{X}_{n-2} = -M_{l,n-2}\,\dot{u}_l$$

$$\dot{y} = \dot{X}_n$$

$$\underbrace{\begin{bmatrix} \dot{X}_{n-1} \\ \dot{X}_{n-2} \\ \dot{X}_{n-3} \\ \dot{X}_n \end{bmatrix}}_{\dot{\mathbf{x}}(t)} = \underbrace{\begin{bmatrix} 0 & M_{n-2,n-1} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -M_{n-1,n} & 0 & M_{n-3,n} & 0 \end{bmatrix}}_{\mathbf{A}} \underbrace{\begin{bmatrix} \dot{X}_{n-1} \\ \dot{X}_{n-2} \\ \dot{X}_{n-3} \\ \dot{X}_n \end{bmatrix}}_{\dot{\mathbf{x}}(t)} + \underbrace{\begin{bmatrix} 0 & 0 \\ -M_{l,n-2} & 0 \\ 0 & M_{j,n-3} \\ 0 & 0 \end{bmatrix}}_{\mathbf{B}} \underbrace{\begin{bmatrix} \dot{u}_l \\ \dot{u}_j \end{bmatrix}}_{\dot{\mathbf{u}}(t)}$$

$$\underbrace{\begin{bmatrix} \dot{y} \end{bmatrix}}_{\dot{\mathbf{y}}(t)} = \underbrace{\begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}}_{\mathbf{C}} \underbrace{\begin{bmatrix} \dot{X}_{n-1} \\ \dot{X}_{n-2} \\ \dot{X}_{n-3} \\ \dot{X}_n \end{bmatrix}}_{\dot{\mathbf{x}}(t)}$$

Figure 2. Systemic causal map structure.



$\mathbf{A}$: Matrix of monotonic functions
$\mathbf{B}$: Matrix of monotonic functions
$\mathbf{C}$: Matrix that extracts $\mathbf{y}$ from $\mathbf{x}$
$\mathbf{x}(t)$: State variables
$\mathbf{u}(t)$: Root-cause variables
$\mathbf{y}(t)$: Process performance variables
$\bar{\mathbf{y}}$: Desired value of $\mathbf{y}(t)$
$\underline{\mathbf{u}}$: Lower bound of $\mathbf{u}(t)$
$\bar{\mathbf{u}}$: Upper bound if $\mathbf{u}(t)$
t: Time
T: End time value
$\mathbf{Q}$: Matrix of penalties

Figure 3. Procedure that estimates the root cause values and their impact on the process performance so that the stakeholders are satisfied.

4.Application

To survive in the arena of international competition, companies of electronic products desire to improve their processes performances (Sauer et al. 2006). In this context, a company that designs microprocessors wants to improve its microprocessors development process so that its performance reaches the one desired by its stakeholders. The latter have antagonistic goals: the company owners want to spend a maximum of 8000$ for developing a new product (COST), the customer service requires the development of a large number of new products i.e. 30 new products per year (NP), the suppliers tolerate at most two failed developments (TDEF) and the sales representatives want a short development time of 100 days (TOT). The current performance of this process (see the values of COST, NP, TDEF and TOT in rectangles in Figure 5) does not satisfy these goals so that it requires improvements.

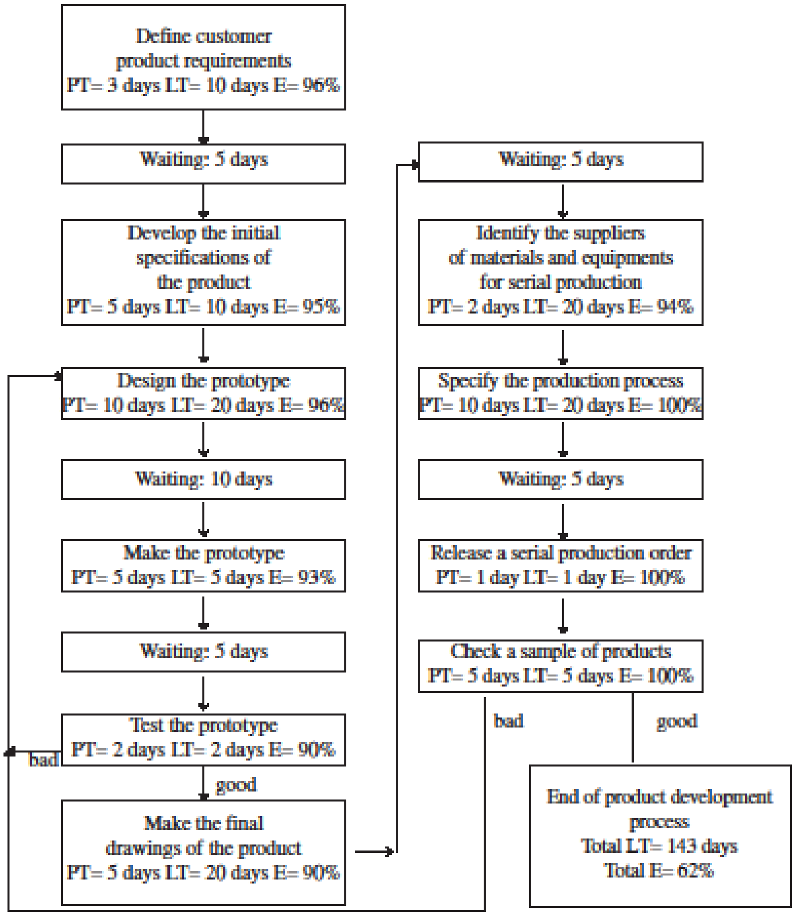
In order to define the problematic process, the product development activities (Burd et al. 2002) were observed and the diagram of Figure 4 was built. Then five employees built systemic causal maps to identify the root causes of the process performance. The last systemic causal map they built is in Figure 5, as shown the root causes of the process performance are: The distance between the product requirements office and the product specification office (DE), the collaboration intensity with suppliers (CF), the frequency use of a library of templates to design the products (LIB) and the free time access to common equipment to make the prototype and then to test it (AC).

During the continuous improvement meetings, the group of participating employees suggested two strategies to reach the desired performances above: "minimum cost strategy" consisting of strengthening the cost reduction and "maximum product variety strategy" consisting of strengthening the number of developed products. Hence two coarse optimization models were formulated. The first one includes the optimization function in the top of the second column of Table 1 and the systemic causal model in Figure 5. The second one includes the optimization function in the top of the third column of Table 1 and the systemic causal model of Figure 5. The solutions of both models are the root causes rates of variation in Table 1. By integrating these rates of variation the level values of the root causes can be obtained. For example, the collaboration intensity with suppliers (CF) has a current value of 2 (at time 0) and should be increased to 3.73 (at time 5) in the "minimum cost strategy" and to 6.02 (at time 5) in the "maximum product variety strategy" (Table 1). At this point note that these solutions are not black boxes but can be justified by following the cause-effect links of the systemic causal model. For example, as shown in Figure 5, when CF (collaboration intensity with suppliers) is increased, FAC (time to identify the materials suppliers) decreases and TOT (total time to develop a product) decreases. At this point note that understanding the impact of any proposed improvement on the process performance is important for the group that conceives the improvements.

Otherwise, key performance indicators can be attached to the systemic causal map variables to control the effectiveness of the improvements during their implementations. For example, a key performance indicator like "number of days spent to identify a new supplier" can be attached to variable "time to identify the materials suppliers" (FAC in Figure 5) in order to track the effect of improving the cause root "collaboration intensity with suppliers" (CF in Figure 5).

5.Conclusions

The current continuous improvement methodologies allow identifying the natures of the improvements of a problematic process. However, the estimation of the intensities of these improvements cannot be completely supported by the available quantitative tools. These estimations are important to confirm the suggested improvements will allow reaching the process performance required by all stakeholders. We have suggested building and solving coarse models that include the positive and negative cause-effect relationships linking the process performance to its root causes. These models include also the antagonistic process performances desired by the stakeholders and can catch root causes of the process performance independently of their nature and location in the company. We have applied these models to estimate the intensities of the improvements in a company of engineering services but they can be applied to processes in other services as for example in banks, insurances, health, education, government agencies.



PT: Average production time.

LT: Average lead time (PT plus inefficient activities times).

E: Efficiency (percentage of times an activity is done successfully).

Figure 4. Diagram of the process to develop a new microprocessor. The activities were identified by direct observation.

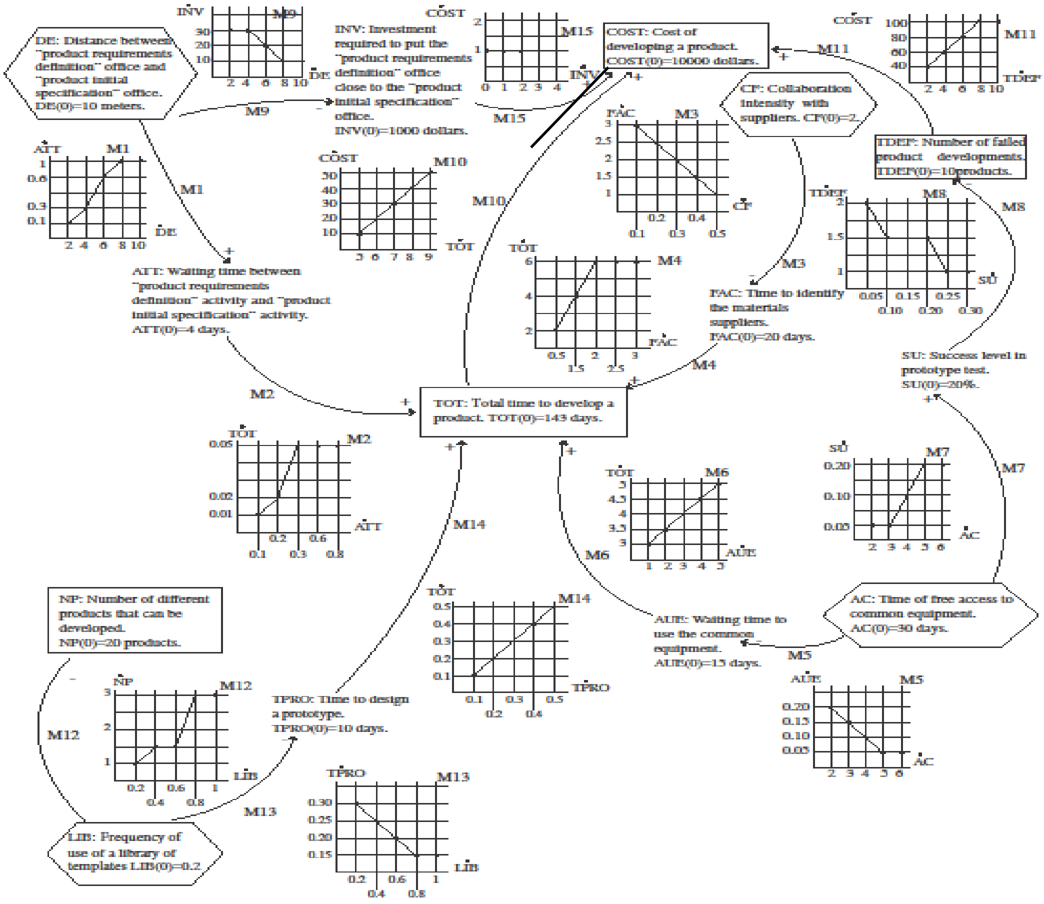


Figure 5. Diagram of the systemic causal map of the process to develop microprocessors. The root-causes of the process performance are in hexagons and the process performance is in rectangles.

Figure 5. Diagram of the systemic causal map of the process to develop microprocessors. The root-causes of the process performance are in hexagons and the process performance is in rectangles

Table 1. Optimal values of the root-causes rates of variation and the resulting process performance.

Process variables	Minimum cost strategy: $\text{Min}\int_0^{40} 10(\text{COST}-8000)^2+(\text{TDEF}-2)^2 + (\text{TOT}-100)^2+(\text{NP}-30)^2 dt$ $2 \le \mathring{\text{DE}} \le 10\ ;\ 0.1 \le \mathring{\text{CF}} \le 0.5$ $2 \le \mathring{\text{AC}} \le 6\ ;\ 0.2 \le \mathring{\text{LIB}} \le 1$	Maximum product variety strategy: $\text{Min}\int_0^{40} (\text{COST}-8000)^2+(\text{TDEF}-2)^2 + (\text{TOT}-100)^2+200(\text{NP}-30)^2 dt$ $2 \le \mathring{\text{DE}} \le 10\ ;\ 0.1 \le \mathring{\text{CF}} \le 0.5$ $2 \le \mathring{\text{AC}} \le 6\ ;\ 0.2 \le \mathring{\text{LIB}} \le 1$
Root causes:		
DE rate of variation	0.79	2.0
CF rate of variation	0.35	0.80
AC rate of variation	6.00	6.00
LIB rate of variation	0.60	0
DE at t=0	10	10
CF at t=0	2	2
AC at t=0	30	30
LIB at t=0	0.20	0.2
DE at t=5	13.93	20.17
CF at t=5	3.73	6.02
AC at t=5	60	60
LIB at t=5	3.21	0.2
Process performance:		
TOT at t=0	143	143
TDEF at t=0	10	10
COST at t=0	10000	10000
NP at t=0	20	20
TOT at t=5	132.31	130.98
TDEF at t=5	4	4
COST at t=5	9653	9634
NP at t=5	13.97	20

References

Albliwi, S., Antony, J., Halim Lim, S., A systematic review of lean six-sigma for the manufacturing industry, *Business Process Management Journal,* vol. 21, no. 3, pp. 665-691, 2015.

Ascough, J., Fathelrahman, E., Hoag, D., Using response surface methodology for economic and environmental trade-offs at the farm level, *Air, Soil and Water Research*, vol. 6, pp. 73-89, 2013.

Brocke J., Rosemann M., *Handbook of Business Process Management*, Springer-Verlag, Berlin, Germany, 2015.

Burd, Th., Brodersen, R., *Energy Efficient Microprocessor Design*, Springer, New York, NY, 2002.

Cardiel-Ortega, J., Baeza-Serrato, R., Lizarraga-Morales, R., Development of a system dynamics model based on six-sigma methodology, *Ingenieria e Investigacion*, vol. 37, no. 1, pp. 80-90, 2017.

El-Haik, B., Al-Aomar, R., *Simulation Based Lean Six-Sigma and Design for Six-Sigma*, Wiley, New York, NY, 2006.

Forrester, J., *Industrial Dynamics*, MIT Press, Cambridge, MA, 1961.

Furterer, S., *Lean Six Sigma in Service: Applications and Case Studies*, CRC Press, Boca Raton, FL, 2009.

Friedenthal S., Moore A., Steiner R., *A Practical Guide to SYSML: The System Modeling Language,* Morgan Kaufmann, Waltham, MA, 2012.

Heavey, C., Murphy, E., Integrating the balanced scorecard with six sigma, *The TQM Journal*, vol. 24, no. 2, pp. 108-122, 2012.

Islam, S., Credit card account opening excellence using six-sigma methodology, *International Journal of Lean Six Sigma,* vol. 7, no. 3, pp. 294-323, 2016.

Kaplan, R., Norton, D., *Strategy Maps: Converting Intangible Assets into Tangible Outcomes*, Harvard Business School Press, Boston, MA, 2004.

Kossiakoff, A., Sweet, W., Seymour, S., Biemer, S., *Systems Engineering Principles and Practice*, Wiley, Hoboken, NJ, 2011.

Kuipers, B., *Qualitative Reasoning: Modeling and Simulation with Incomplete Knowledge*, MIT Press, Cambridge, MA, 1994.

Kumar, S., Wolfe, A., Wolfe, K., Using six-sigma DMAIC to improve credit initiation process in a financial services operation, *International Journal of Productivity and Performance Management,* vol. 57, no. 8, pp. 659- 676, 2008.

Laureani, A., Brady, M., Antony, J., Applications of lean six-sigma in an Irish hospital, *Leadership in Health Services,* vol. 26, no. 4, pp. 322-337, 2013.

Macedo, J., Ruiz Usano, R., 1994, An intelligent system to recognize the appropriate organization for a factory, in Karagiannis D., Database and Expert Systems Applications, *Lecture Notes in Computer Science*, vol. 856, pp. 193-203, Springer, Berlin, Germany, 1994

Myers, R., Montgomery, D., Anderson-Cook, Ch., *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, Wiley, New York, NY, 2009.

Oliya, E., Owlia, M., Shahrokh, Z., Olfat, L., Improving marketing process using six sigma techniques (case of Saman Bank), *International Journal of Six Sigma*, vol. 3, no. 1, pp. 59-73, 2012.

Perale, G., Rossi, F., *Spinal Cord Injury (SCI) Repair Strategies*, Woodhead Publishing, Duxford, UK, 2020.

Riley, B., Kovach, J., Carden, L., Developing policies and procedures manual for a consumer lending department: A design for six sigma case study, *Engineering Management Journal*, vol. 25, no. 3, pp. 3-15, 2013.

Reijers, H., Business process management: The evolution of a discipline, *Computers in Industry*, vol. 126, no. 103404, 2021.

Sterman, J., *Business Dynamics: Systems Thinking and Modeling for a Complex World,* Mc Graw Hill, New York, NY, 2000.

Sauer, W., Oppermann, M., Weigert, G., Werner, S., Wohlrabe, H., Wolter, K., Zerna, Th. (2006), *Electronics Process Technology*, Springer, London, UK, 2006.

Yadav, G., Desai, T., Lean six sigma: A categorized review of the literature, *International Journal of Lean Six Sigma*, vol. 7 no. 1, pp. 2-24, 2016.

Biography

Julio Macedo is currently a senior consultant at Institut Strategies Industrielles in Montreal, Canada (www.isiconsultant.com). He is specialized in processes organization (manufacturing and services) so that they become competitive. He is a pioneer in the application of intelligent neuro-fuzzy models to increase the competitiveness of industries. He was a full-time professor at the University of Quebec (Outaouais) and then at the

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