Incorporating IT & AT Convergence into Lean Thinking/Six Sigma via the Smarter Operation Transformation (SOT) Methodology

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***Summary* —** The growing demands for industrial products are imposing an increasingly intense level of competitiveness on the industrial operations. In the meantime, the convergence of information technology (IT) and automation technology (AT) is showing itself to be a tool of great potential for the modernization and improvement of industrial plants. However, for this technology fully to achieve its potential, several obstacles need to be overcome, including the demonstration of the reasoning behind estimations of benefits, investments and risks used to plan the implementation of corporative technology solutions. This article focuses on the evolutionary development of planning and adopting processes of IT & AT convergence. It proposes the incorporation of IT & AT convergence practices into Lean Thinking/Six Sigma, via the method used for planning the convergence of technological activities, known as the Smarter Operation Transformation (SOT) methodology. This article illustrates the SOT methodology through its application in a Brazilian company in the sector of consumer goods. In this application, it is shown that with IT & AT convergence is possible with low investment, in order to reduce the risk of not achieving the goals of key indicators.

***Keywords*—**IT & AT Convergence; Manufacturing Execution Systems;Risk Probability Number;Methodology; Lean Thinking/Six Sigma.

I. Introduction

The constant need to improve the quality and performance of products and services produced by corporations while reducing manufacturing costs is promoting a new revolution among industrial sectors and service providers. Thus, nearly all productive sectors are investing in the integration of information technology (IT) and automation technology (AT) assets to permit the implementation of a comprehensive automation of administrative and production flow that implies significant gains in efficiency and effectiveness [1].

In this study, IT and AT assets are the hardware and software platforms under the management of the functional areas of information systems and automation engineering, respectively.

The Automation in a manufacturing company may be represented by a model composed of five levels, as shown in Figure 1, which corresponds to the automation pyramid. In each level, modeling refers to a layer formed by logical processes and, hardware and software assets. In the automation pyramid, IT and AT assets are found at level four [2], which is precisely where production and operational management decision-making occurs.

The integration of IT & AT is complicated by the diversity of knowledge of the participants in the implementation of the convergence. Therefore, a strong need from the earliest definitions of convergence projects for collaboration between the IT and AT areas of the company has been analyzed in technical and scientific works [3].

It is assumed that, for this collaboration to be completely adherent to the needs of the company, the future users of the automation must also participate in the planning of the IT & AT convergence; otherwise, the success of the business would be jeopardized. In particular,to accelerate the adoption of IT & AT convergence from the corporate culture point of view is mandatory to add this technology to the toolbox of production engineers.

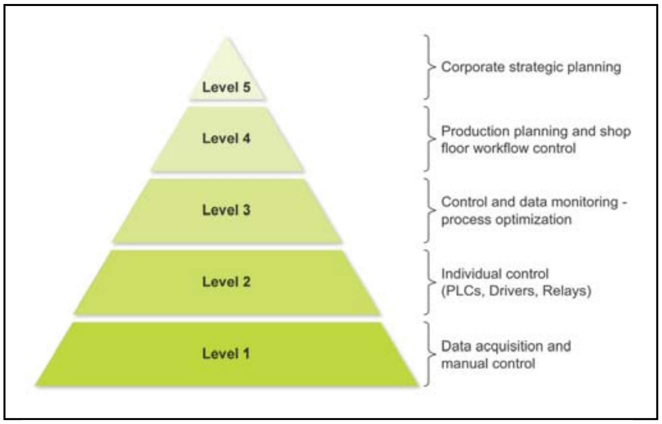

Fig. 1: Automation Pyramid
Source: adapted of Webb and Greshock, 1990 [2]

The importance that the planning of the information systems be led by their own users was first emphasized by Rockart [4] in 1979. In the IT & AT convergence domain, the production engineers are the ones who are responsible for leading the Lean Thinking/Six Sigma [5] initiatives in the corporations and the first users of IT & AT convergence. The Lean Thinking/Six Sigma projects are,nowadays,the main drives to company transformation [6]. Despite the fact that IT & AT convergence is presented as an allied technology [7] for facilitating the work of process review and improvingit in several ways, the integration of IT & AT convergence will not be treated by the production engineers as a tool to enable new production processes until they are able to plan IT & AT convergence with the specific purpose of supporting their projects with the same ease as they do when they specify a machine for the plant floor.

IT & AT convergence has been discussed extensively in many scientific technical articles featuring case studies of operational productivity benefits of IT & AT convergence and comparisons between different approaches for the convergence architecture of IT & AT [8][9][10][11][12][13][14][15][16][17][18][19][20][21][22].However, the planning process of IT & AT convergence before the beginning of its customization for a particular plant remains largely unexplored.

In the Chaos Report, issued by Dominguez [23] in 2009, of 5000 information technology projects, group in which the convergence of IT & TA can be inserted, 32% were completed on time, within planned costs and meeting expectations; 24% failed completely and were abandoned; and the rest exceeded the original cost and/or time budgets. A proper planning, with benefits, investment and risk well defined, is one of the main actions to mitigate the deviation in an information technology project. However, the planning itself is a risk process, failing in several aspects. A key factor to avoid the risk in the planning processis the understanding of the reasoning behind estimations, which should be provided by a methodology support [24]. Therefore, this article investigates the construction and application of a methodology for planning the convergence of IT & AT assets, named smarter operation transformation (SOT), which has four macro objectives:

1) Ensuring the construction of an IT & AT convergence aligned with the critical success factors (CSFs) of the company;
2) Optimizing existing investments in technology;
3) Mitigating the risk associated with IT & AT convergence;
4) Leading the production engineers with a methodology that provides clear reasoning behind estimations.

Through this proposed incorporation of SOT methodology in the Lean Thinking/Six Sigma toolbox, it is expected a logical chain establishment, in which the increase of SOT methodology utilization will accelerate the IT & AT convergence adoption. Such convergence adoption will enable the Lean Thinking/Six Sigma evolution at the company.

The presentation of the development and illustration of the SOT methodology is structured in five topics:

1) Description of the historical evolution of the use of IT, AT and the IT & AT convergence;
2) Integration between the IT & AT convergenceand production operations;
3) Presentation of the SOT methodology and development methodology process;
4) Illustration of the application and results of the SOT methodology;
5) Conclusions of this study and proposals for future work.

II. HISTORIC EVOLUTION OFTHEUSEOF IT, AT AND IT & AT CONVERGENCE

A. Historical evolution of the use of information technology (IT) in industrial automation

A company adds value to the product or services it offers to the market through its supply chain, which consists of five main activities: inbound logistics, operations, outbound logistics, marketing and sales, and services [25].

Within industrial plants, IT assets are represented primarily by software called enterprise resource planning (ERP), which emerged with the initial goal of supporting the activity of operating a business through validation and registration of the events of each process in the system's central database [26].

For some time, ERP was introduced as a solution that could establish a direct connection to the automation technology in the industrial plant and be the only company system. This view began to be discarded as soon as companies realized that the bias adopted by ERP prioritizes support to the financial transactions of the company instead of its operational processes.

Starting in the late 20th century, IT began to evolve from a purely administrative sphere to a tool intended to exercise operational control, and therefore it became necessary to review priorities and seek integration with automation technology (AT).

B. Evolution of the use of automation technology (AT) in industrial automation

The assets of automation technology (AT) have been developed as a result of the historical evolution of the theory of automation and control. The starting point of this trajectory can be established in the second decade of the 20th century with the beginning of the theory of systems analysis and performance through differential equations. The stages of this evolutionary phenomenon began with the use of electromechanical equipment in the fourth decade of the 20th century and experienced tremendous advancement as of the seventh decade of the same century, given the adoption of:

1) Digital signal transmission;
2) Robots;
3) Machines with programmable numerical command centers (CNC);
4) Programmable logic controllers (PLC);
5) Distributed control systems (DCS);
6) Supervisory control and data acquisition systems (SCADA).

In this evolution of the use of AT, integration with IT assets has been an ongoing process, which was first used on the industrial floor in the late 20th century, and the mentioned assets still represent an AT challenge within organizations [27].

C. Historical evolution of the use of IT & AT convergence.

The convergence of IT & AT assets has been represented by a new class of systems, commonly called manufacturing execution systems (MES), which aim to transport the layer information field of IT to AT and vice versa. These systems are constructed based on different models stemming from the concept of computer-integrated manufacturing (CIM), initially proposed by Joseph Junior Harrington [28]. The collaborative manufacturing enterprise system (MES-C) model, for example, was presented by the Manufacturing Enterprise Solution Association [29] as an evolution of the manufacturing enterprise system (MES), previously published [30] by the same entity and originated from CIM.

Some entities, linked to industrial automation, have targeted the maturation process of integrating IT& AT assets. This line includes the International Society of Automation (ISA), which developed a model named in the publication of the document ISA-95 Part 3 [31] as manufacturing operation management (MOM). Earlier, this layer had been named in the ISA-95 Part 1 [32] as Manufacturing Operations & Control (MO & C). Another example of a model focused on this layer is named as collaborative manufacturing management (CMM) and was proposed by the ARC Advisory Group [31]. These proposals add, subtract, or group disparate features to offer a more holistic and cohesive model in terms of the complexity of production systems. Chacon and Carnevallipresent an extensive review of the different approaches related to the convergence of IT & TA[19].

Fig. 2, adapted from the document ISA-95 Part 3, illustrates what is called a domain between IT & AT layers [31]. Based on Fig. 2, it is possible to define different areas of the domain for each technology; however, the boundaries of each area are not rigid, allowing the company to configure existing IT or AT assets in order to facilitate the construction of the layer of IT & AT convergence.

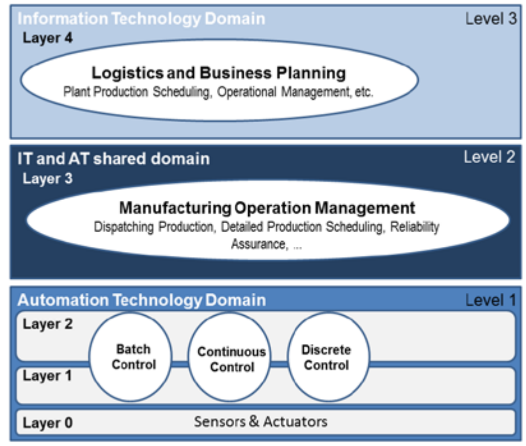

Figure 2: Illustration of the areas of the technology field
Source: Adapted from ISA-95 Part 1, 2000

A significant contribution to promoting the adoption of IT & AT convergence is a paradigm shift in how the integration is addressed with the development of holonic manufacturing systems (HMS) and plant automation based on distributed systems (PABADIS). These new approaches are opposed to the hierarchical view of the automation pyramid [2], which guided most integration models focused on IT & AT convergence. This paradigm emphasized the need for the architecture of the industrial enterprises' technology to be flexible and adaptable to the point of being formatted according to market requirements. Another contribution to accelerate the adoption of IT & AT convergence is the overcoming of the rigidity and centralization which are characteristic of computerized architecture through intense effort made in the creation of standards. However, despite all these efforts to implement IT & AT convergence, the adoption will not be as fast as possible without the support of a methodology in line with the evolutionary approach followed,nowadays,by most of the companies. Without overcoming this barrier IT & AT convergence will still be presented as a technological trend for the near future [34].

III. Integration between IT & AT convergence and prodcution operations

Popularized due to the success achieved by the Japanese industry in the case of Lean Thinking, and by General Electric in the case of Six Sigma, the proposal of Lean Thinking/Six Sigma focuses on the elimination of waste in production and on an increase in the quality of products and processes [35] [36] [37].

The start of the global spread of Lean Thinking/Six Sigma in the last two decades of the 20th century coincided with the deepening of discussions about reference architecture proposals for IT & AT convergence [17]. However, this was not a harmonious coexistence. In the view of many experts in the application of Lean Thinking/Six Sigma, the use of computer systems on the shop floor was counterproductive because of the centralizing character of the systems, which were little adaptive to the reality of the shop floor, and because it was necessary to prioritize the review and simplification of production processes before automating [38] [39].

At the beginning of the 21st century, there was a confluence between Lean Thinking and Six Sigma, because the IT & AT convergence came to be seen as an important platform, the use of which could be shared in order to support continuous improvement workshops in factories, providing information and automated control appropriate for a Lean Thinking/Six Sigma project [7]. In these technical and scientific discussions, the focus has been on establishing a correspondence between tools belonging to Lean Thinking/Six Sigma and features intrinsic to the layer of IT & AT convergence that could facilitate the implementation of such tools, with the assumption that there is a convergent IT & AT platform. In these discussions what should be done in order to build an IT& AT convergence, if it is not available, is not approached.

IV. Construction of the Smarter Operation Transformation (SOT) Methodology

The development of the SOT methodology was based on an analysis of the main existing methodologies that seek to meet, even partially, the objectives of IT & AT convergence or deploy the development of software systems and automation projects.

The methodologies that were the basis for the SOT methodology presented in this study are classified in four groups:

1) Methodologies for developing systems [40][41][42][43][44]. This group is composed of methodologies that focus on the development of a piece of software or system, starting from a stage in which the desired features are defined, as well as their correspondence with the CSFs of the organization. In these methods, the existence of legacy technology is not considered.
2) Specific methodologies for the convergence of IT & AT [45][46]. This group is composed of methodologies for linking the different dimensions of IT & AT convergence, such as workflow and data flow between the layers of IT & AT. The methods in this group seek to define a reference architecture which should be used in the planning of the IT & AT convergence. Legacy of technology is an issue addressed by these methodologies, but these works do not provide the instruments that determine how planning should be conducted. The methodologies in this group were developed considering centralized reference architectures for IT & AT convergence. The planning of IT & AT convergence to existing plants in these methods starts with an extensive modeling of the "as-is" process, time consuming and expensive, not taking advantage of the current IT & AT convergence paradigm that enables flexible and scalable construction for IT & AT convergence.
3) Methodologies for the functional alignment of assets with business objectives [4][47][48]. This group is composed of methodologies that support the diagnosis of technology in the organization, prescribe procedures to ensure that the governance of technology resources is aligned with the diagnosis, and guide managers so that they can actively participate in the governance of technology. The methods of this group define the diagnostic process of functional requirements in terms of CSF. However, the methodologies in this group do not prescribe how to specify the technical requirements of IT & AT that must be met to enable the integration of technologies.
4) Methodologies to improve processes and products [49][50]. This group is composed of methodologies focused on structuring the transformation from the current stage (“As Is”) to the future scenario (“To Be”). These methodologies do not attempt to establish a link between processes and information technology and automation.

Scientific analyses and practices of professionals in the market show that none of the methodologies alone provides support for the planning of IT & AT convergence for a particular existing plant.

To this end, a methodology that considers the following three features is needed:

1) Incorporating the technology needs of businesses and linking them to the key process indicators (KPIs), workflows, features provided in ISA-95 that support the workflows and technical requirements that must be met not only by the new IT & AT assets, but also in priority by the legacy assets.
2) Measurement of qualitative benefits and establishment of mechanisms to translate the qualitative benefits of IT & AT convergence to quantitative business performance in terms of KPIs.
3) Practicality and friendliness as well as prescription of tools that enable the practical application of the methodology as part of the continuous improvement routine.

The SOT methodology was developed and structured using the define, measure, analyze, improve and control (DMAIC) core methodology and the failure modes and effects analysis (FMEA) and quality function deployment (QFD) associated tools [51], which were adapted for the SOT method. In addition to DMAIC and tools that are a part of the culture of most industrial organizations, the concepts belonging to main existing methodologies were also used to develop this newproposal. Figure 3 presents the SOT methodology, which is organized into seven macro steps:

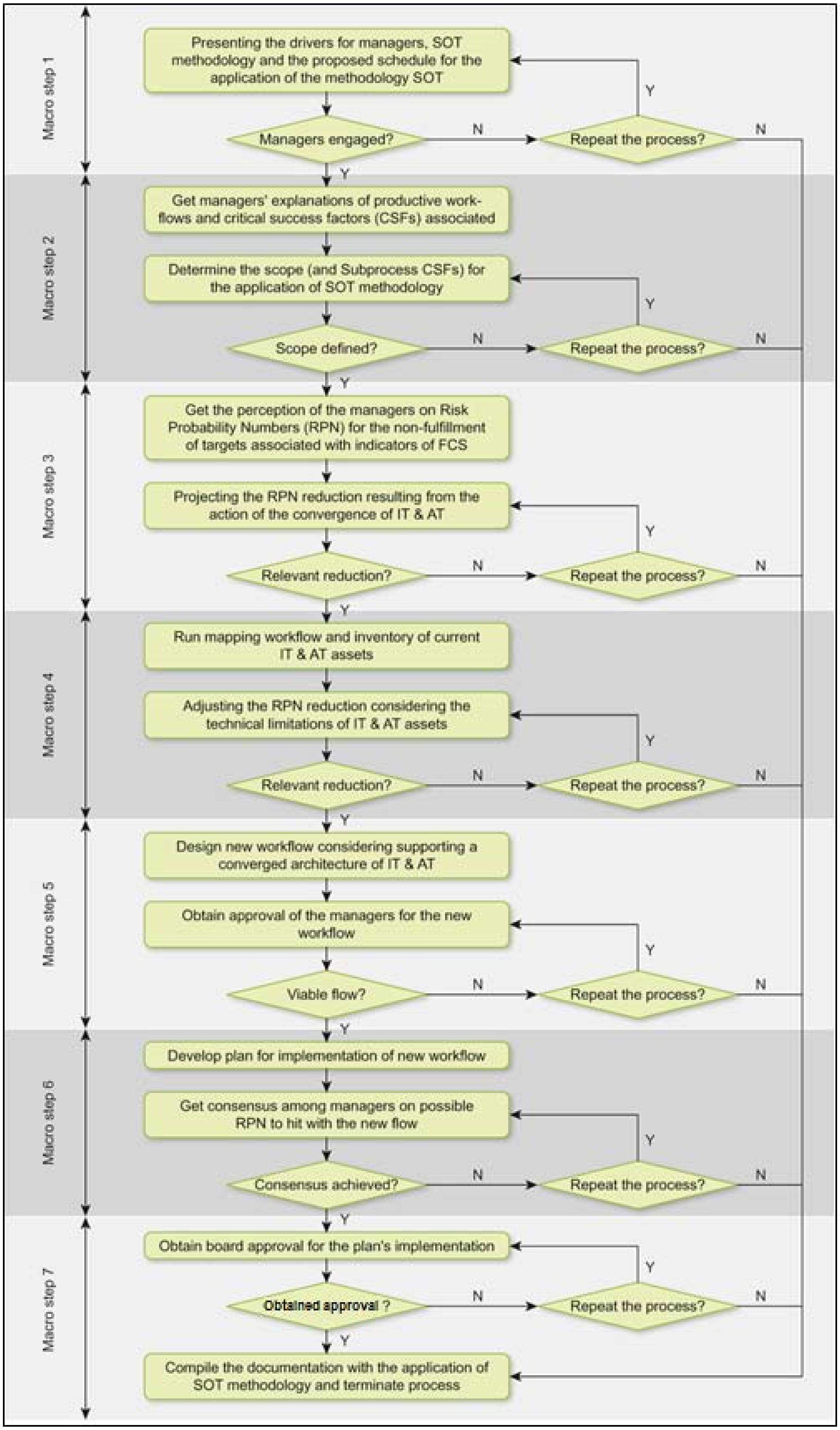

Fig. 3: SOT methodology statement of procedures

1) *Presentation*: In this stage, we present the motivators for applying the SOT methodology and the SOT workflow methodology, select the team responsible for the implementation of activities and establish a schedule for the steps.
2) *Definition*: This step delimits the scope for the application of the SOT methodology in terms of manufacturing processes (supplying of raw materials, weighing, processing, packaging, and finished product storaging), management perspectives (production, quality, inventory and maintenance), and indicators related to management perspectives, goals and corresponding current values.
3) *Measurement*: This step involves the determination of the risk of not achieving a goal because of weaknesses in the workflow, due to gaps in the IT & AT architecture.
4) *Analysis*: This step analyzes the possibility of reducing the risk of achieving a goal associated with the indicators by adding new features to the existing IT & AT technology assets or by investing in new assets.
5) *Improvement*: This step proposes the workflow for the future and the construction of the IT & AT convergence layer to support the new process.
6) *Control*: This step is utilized by managers to reduce the risk of not meeting the targets fixed for the indicators, due to the implementation of the proposed workflow, and also proposes a timeline for implementing changes in processes, architecture and IT & AT assets.
7) *Closing*: In this stage, the results of applying the SOT methodology are reviewed, and a plan for the deployment of convergence is released, if applicable.

The use of Lean Thinking/Six Sigma tools as ground for SOT methodology was based on four pilars:

1) The SOT methodology was developed and structured based on everyday tools for continuous improvement projects at its center, thus facilitating their absorption by industrial engineers, as well as making them understand the reasoning behind estimations.
2) The SOT methodology treats the planning of IT & AT convergence as a recursive activity which can occur several times during the lifetime of a plant, and not only at the time of its implementation.
3) In its application the methodology values the search for the use of IT & AT legacy in line with Lean Thinking/Six Sigma, that is, the avoidance of waste.
4) The architecture of IT & AT convergence generated by applying the SOT methodology has, as its main function, the enablement of the implementation of more robust processes in accordance with Lean Thinking/Six Sigma, serving the industrial and automation engineer in the same way as any other technology applied in continuous improvement projects.

V. Illustration of the Application of the SOT Methodology

A. *Production of Consumer Goods–Application Illustration*

To illustrate the SOT methodology, the proposal was applied in a company with batch production process under a non-disclosure agreement. The chosen company is a leader in all segments in which it operates worldwide and has an operation with a line of hundreds of products. The study was conducted in one of its main plants in Brazil. For this study, five sub processes were considered:

1) *Storage of raw materials*: material receipt, identification, storage and separation for production.
2) *Weighing and dispensing*: gathering and fractioning of batches of raw materials, identification of sub lots, preparation of sets of ingredients for processing.
3) *Processing*: the combination of ingredients and preparation of semi-finished products for packaging;
4) *Packaging*: packing of finished products (FP), FP aggregation into boxes, palletizing and preparation of pallets for shipment to FP inventory.
5) *Storage FP*: storage, separation and release of FP for billing and shipping.

In terms of systems, the company has four key applications:

1) *ERP system*: responsible for managing the activities of accounting, accounts payable and accounts receivable as well as demand management and planning of production resources.
2) *Asset management system (AMS):* responsible for the location of the assets used on the shop floor, routine corrective maintenance, preventive and predictive control and spare parts.
3) *Statistical process control (SPC) weight system*: responsible for foreseeing gaps between the actual and theoretical weight of products in the packaging lines [50].
4) *Post-production system*: responsible for notes on the ERP data for the outcome of the operation of the packaging lines on the industrial floor.

The company uses different technology assets in the automation of industrial operations on the shop floor among sub processes, with a total of eighty six separate assets in four groups:

1) Wireless barcode-data collectors for reading data from sub processes involving the inputted raw materials, weighing and dispensing, packaging and storing of FP.
2) Barcode ID printers for raw, segregated and in-process materials and semi-finished and finished products.
3) Supervisory control and data acquisition (SCADAs) and programmable logic controllers (PLCs) for several generations in the automation of processing and packaging sub processes.

4) Weighting scales in sub processes involving the input of raw materials, weighing, dispensing, processing, packaging and storing of FP.

A. Results of the Application of SOT Methodology

Using the SOT methodology in the macro step measurement, managers identified key indicators in the operational process related to production management, quality, inventory and maintenance projects, whose goals prior to the IT & AT convergence were unaffected, due to workflow vulnerabilities that could be resolved with the support of IT & AT convergence.

From the managers' perspective, these layers tend to contribute to reducing the risk of not meeting the company's business goals. This analysisis supported by forms adapted to the FMEA methodology. Table 1 shows an example of these findings for the "availability of equipment" indicator, one of the key indicators of the sub process package.

In the example, Column I shows that the risk probability number (RPN) of the target is not achieved due to the occurrence of the event identified in Column E. Column J describes actions that can mitigate this risk. These actions, which are usually loosely defined when using FMEA for other purposes, should be determined based on the features assigned to the ISA-95 [21] layer convergence of IT & AT, when applying the FMEA methodology within SOT. Column L provides the projected RPN, considering the adoption of the recommended action before the analysis of the technological limitations of IT & AT assets and based on a superficial view of the future workflow.

Starting from FMEAs generated for the production sub processes and following the SOT methodology, the macro analysis stage comprised created selective mappings of workflows with current weaknesses that can be addressed by IT & AT convergence.

Figure 4 represents a simplified logic flow for a corrective maintenance activity for packaging equipment without the convergence of IT & AT on the left column. The activities in this figure have a duration determined by the operator (manual transactions) and by the IT & AT assets (automatic transactions).

TABLE 1.Illustrative the application of FMEA for a key indicator of subprocess of Packaging

A	B	C	D	E	F	G	H	I	J	K	L				M
Subprocess	Potential failure mode indicator	Potential effects of failure	Severity	Potential Causes	Occurrence	Current Controls	No Detection	Actual RPN	Recommended Actions	Responsible and target date	Projected RPN				Consensual RPN
											Severity	Occurrence	No Detection	RPN	
Packaging	Availability of equipment less than 95%	Reduction of return on assets	7	Failure workflow corrective maintenance - slowness to return the equipment in operation	7	Asset managem-ent system	5	245	Adding functionality to view and track events related to routine corrective maintenance	Managers - date to be defined	7	3	2	42	58
Packaging	Availability of equipment less than 95%	Reduction of return on assets	7	Failure workflow preventive maintenance - preventive development plan, based on manuals data low reliability, not effective for the equipment	8	Asset managem-ent system	7	392	Elimination of manual data through the integration of databases PLCs packaging, assets management system and ERP	Managers - date to be defined	7	4	4	112	155
Packaging	Availability of equipment less than 95%	Reduction of return on assets	7	Failure workflow predictive maintenance - no plan for predictive maintenance	10	Asset managem-ent system	8	560	Inclusion of statistical functionality to enable the construction of predictive plan	Managers - date to be defined	7	5	5	175	242
RPN current average: 399 - Average risk of non-compliance with current goal: 40%: RPN average consensus: 152 - Average risk defined by consensus of non - compliance Goal: 15%															

The performance indicator “availability of equipment” is defined in part as a function of flow with the following human agents in the process: the operator responsible for the equipment, the maintenance technician responsible for supporting the continued manufacturing operation and the supervisor responsible for the packaging sector. In terms of IT & AT assets, in the analyzed process the PLC is used for the automation of the packaging equipment. Additionally, the asset management system (AMS) is designed to support the activities of predictive, preventive and corrective equipment maintenance, and the company’s ERP system uses data from the AMS in its production planning for the sector.

In addition to technology resources, spreadsheets are also used to record manual data. The lifecycle of the process begins with equipment fault and ends with ERP data correction.

The process modeling tool is used in the SOT methodology as a basis to represent weaknesses in the current workflow and it identifies IT & AT assets relevant to the development and convergence of future workflows. The assets identified in the modeling are cataloged using QFD adapted to the SOT methodology.

The use of QFD to specify IT assets has been reported previously [39]. The SOT methodology utilizes QFD to focus on the IT & AT convergence and expands its use by also applying it in the analysis of AT assets.

Fig. 4: Flow of current and proposed corrective maintenance in packaging equipment

Figure 5 illustrates the use of QFD to catalog the AMS identified in the process flow of the corrective maintenance package sub process. The example is composed of eleven blocks.

Block 1 identifies the activities and displays the caption used. Block 2 lists the features that are expected from the asset.

Blocks 3 and 4 inform managers about the current and future RPN defined in FMEA associated with a particular functionality.

Block 5 presents the technical requirements that must be met to enable the functionality. This block in the SOT methodology should fillout with:

1) The technical requirements necessary to perform the asset functionality.
2) The technical requirements required to enable the asset future integrations.

It is fundamental for reducing the risk of the IT & AT convergence implementation in the QFD that the fill-out process be specifiedwith technical requirements which assure an IT & AT architecture design ready for incremental improvements.

Since one of the objectives of the SOT methodology is to turn the convergence of IT & AT into a tool incorporated by the Lean Thinking/Six Sigma,the concepts of such incremental improvements must be preserved there by the architecture resulting from the SOT methodology.This architecture must be designed to supportredesigning production process evolutions.

Block 6 shows the correlation between the technical requirements. Block 7 shows the importance (I) of the technical requirement for a given functionality as well as the chance of success (S) in meeting the requirement for using the asset. Blocks 8, 9 and 10 compare the sums between the technical requirements. Block 11 contains the chances of successfully using the asset to perform a defined functionality, considering the technical constraints arising from the unique characteristics of the asset. Based on this factor, managers must determine whether the asset will be part of the architecture of the future technology. Block 12 contains a second RPN review based on the hypothesis that the asset will be used to compose the IT & AT architecture in the future. The RPN reviewed at this stage was recorded on FMEA forms in column M.

Based on the set of documents collected and generated in the previous steps of the SOT methodology, the improvement macro step was executed, in which the architecture layer convergence of IT & AT was developed and new process flows were designed.

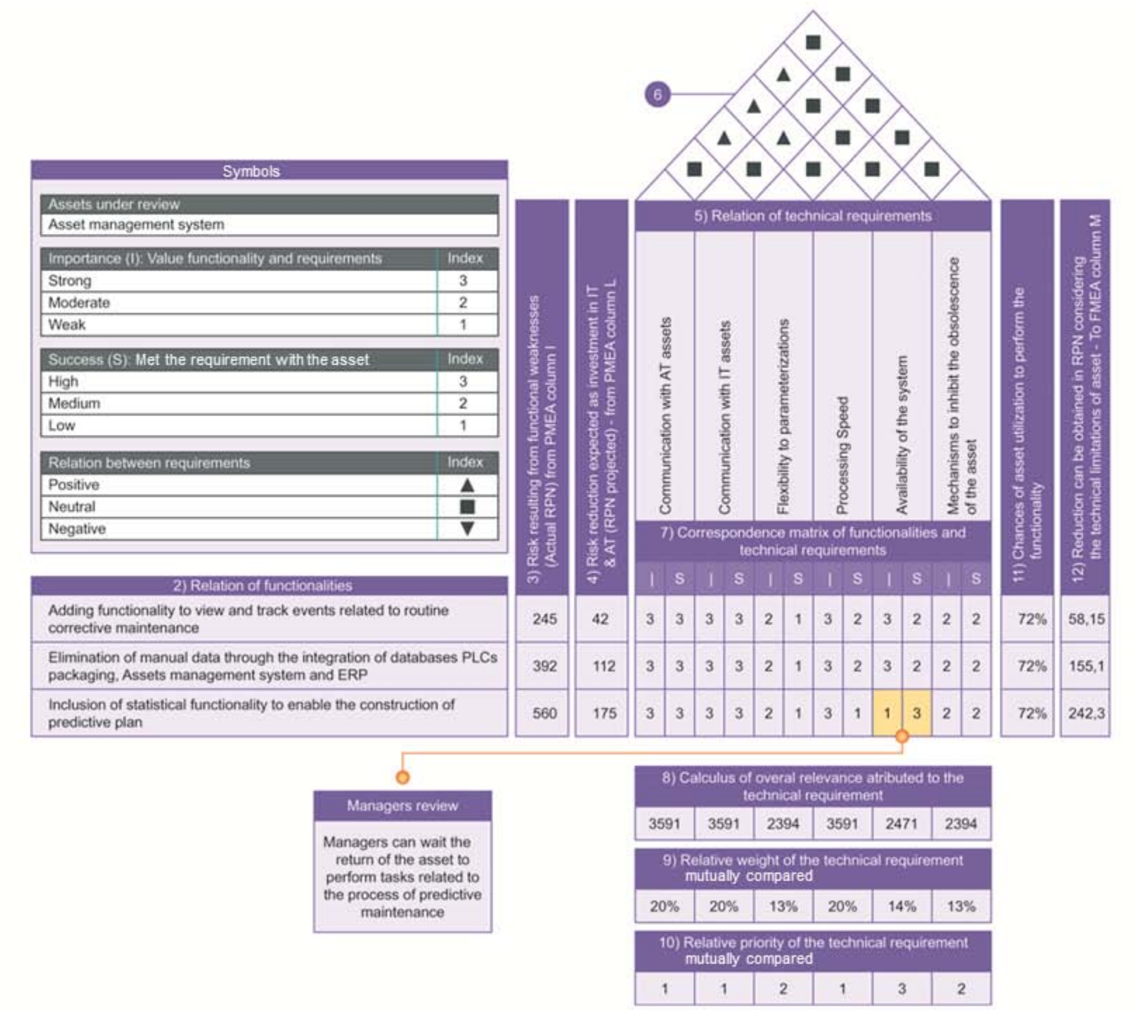

Fig. 5: QFD Management of Assets

The design layer convergence of IT & AT of the company, as well as adjustments in existing applications, provides a complement to the portfolio of applications with the adoption of three new applications:

1) *Weighing system*: responsible for controlling the weighing and dispensing process in real time to replace manual procedures through the integration of ERP, data collectors, a barcode printer and scales in a single environment.
2) *System history log*: stores the variation in the current values of the main data processing equipment belonging to the sub process through the integration of the assets of AT with a server database.
3) *Sequencing production system*: optimizes the sequence in which the products must be packed in the equipment in the packaging sub process considering the updated information for the industrial floor.

Figure 4 illustrates a proposed flow (right column) based on IT & AT convergence. The flow summarizes the new process for corrective maintenance in the packaging sub process, aiming to increase equipment availability.

These new components are utilized in a technology architecture that supports the flow beyond the existing assets and were added to the architecture to establish a network infrastructure for data communications and telephony. The proposed infrastructure allows service technicians to receive notices of equipment malfunction, assets originating from AT, by short-message service (SMS). Additionally, the time spent between sending and acknowledging the messages can be monitored, facilitating the implementation of corrective actions related to the process to ensure process strength.

In the control macro step, the actions required to implement the schedule for the deployment of convergence were defined. Based on the proposed workflows, the FMEA forms were checked and the M column cells were revised where necessary, with the third revision of the RPN as defined by the consensus of the managers.Table 1 shows, at the control macro stage a reduction of 37.5% in the average of the RPN related to the "availability of equipment” indicator in the perception of the managers obtained considering the reuse of IT & AT assets.

The definition by consensus of the RPN is an important step to create the base for an organization commitment with the IT & AT convergence. This commitment among all the participants might be, in the future, a relevant asset for the project leader responsible for the IT & AT convergence implementation during the change management process.

The set of documents generated by applying the SOT methodology was presented by the managers to the company management and made available for approval, finalizing the last step of the macro SOT methodology.

VI. Conclusions

For an organization to achieve operational excellence, it is mandatory that it have an efficient integration between what is planned and what is actually executed on the shop floor. This can be achieved through the convergence of the assets of information technology (IT) and automation technology (AT), usually represented by the hardware and software layer known as the Manufacturing Execution System (MES).

Much has been done to promote convergence between IT and AT, but there are many barriers in planning this convergence. This study discussed different methodologies linked to the development of systems and presented a new methodology, the SOT methodology, to reduce the risks involved in IT & AT convergence.

This paper presented and proposed the use of the Smarter Operation Transformation (SOT) methodology as a tool for industrial and automation engineers to be able to facilitate this convergence in an evolutionary manner. The proposal was illustrated by applying the methodology to a Brazilian manufacturer of consumer goods.

The proposed SOT methodology is constitutedof seven steps that prescribe the chain of tools that are part of the technical and academic training of production and automation engineers. These have been adapted for ensuring that the planning of IT & AT convergence will be conducted by the engineers themselves, with a focus on increasing the efficiency and effectiveness of the industrial processes.

In the company in which the SOT methodology was applied, it was identified that with IT & AT convergence, it was possible to get a 37.5% reduction of the risk of failure to achieve the targetfor key indicators. This reduction was credited to the automation of several transactions enabled by an IT & AT architecture, which preserved the majority of IT & AT assets. In this case study, the following was shown with regard to the SOT methodology capacity of mitigating the risk associated with IT & AT convergence:

1) The SOT methodology drives the design of IT & AT convergence to reduce the risk of the company’s adherence to the CSF solution.
2) The SOT methodology makes possible that the IT & AT convergence be led by industrialengineers, avoiding the risk of the gap between the production process, designed based on Lean Thinking/Six Sigma practices, and the IT & AT hardware and software architecture.
3) The SOT methodology enables preserving the assets and enforcing flexibility as a key feature in the architecture design.
4) The SOT methodology increases the commitment of the board as well as the commitment of all those directly or indirectly involved in the process.

It should be noted that the investment required for the development and implementation of IT & AT convergence is usually significant. Therefore, it´s vital that convergence is performed to ensure that the expected competitive advantages are obtained based on the performance of the operational management of production, inventory, quality, and industrial floor maintenance.

Through this work, a viable way has been presented to extend IT & AT convergence. Thus, it is believed that the proposed model can be used in companies by contributing to the proper use of a technology that has not yet been fully adopted by industries.

The path outlined in this article is only one of the possibilities, so it is recommended that other studies be developed which use other approaches, with the aim of identifying which is the more efficient and effective in the planning of IT & AT convergence, or even with the aim of proving this proposition through empirical research.

With regard to the conducted case study, it is important to note that the answers should not be generalized and should be treated only as an indication of the relevance of the topic and of how to support future work.

This study also suggests that investments in research related to IT & AT convergence need to be constant, for the more effective and efficient the use of technology in managing the operation is, the better the productivity and competitiveness of industries are.

Thus, the authors recognize the need for continued research in the area and further improvement of the SOT methodology.

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