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Mitigation of Risks Associated With IT & AT Implementation Convergence Using Smarter Operation Transformation (SOT) Methodology

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Abstract — **The intensification of the economic globalization process and the increasing interdependence of markets has been imposing a growing need for improving the competitiveness of all industrial sectors. The convergence of information technology (IT) and automation technology (AT) of productive sectors and administrative corporations is a powerful tool for achieving the high levels of efficiency and effectiveness required in the competitive scenarios of current markets. Despite the progress in connectivity achieved by both technologies, the process of IT & AT integration is complex and presents significant challenges in terms of the management and business environment adherence of the industry that goes beyond the technical aspects of IT & AT convergence. This article presents the development of a methodology for planning the convergence of technology assets, named smarter operation transformation (SOT) methodology, which aims to reduce the risks involved in the integration of IT & AT and outlines the development planning for convergence to critical success factors (CSF) of the company. This article also presents the application of the SOT methodology in a process of convergence and the results for an important company in the sector of consumer good products.**

Keywords — ***IT & AT Convergence; Manufacturing Execution Systems; Risk Probability Number; Methodology.***

I. BACKGROUND

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.

Automation in a manufacturing company may be represented by a model composed of five levels, as shown in Figure 1, which corresponds to 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.

Today, the increasing number of companies and businesses utilizing automation processes demands a comprehensive and growing integration of the various sectors of the corporation. As result, the Information Systems, Production, Maintenance, Quality and Logistics sectors are gradually becoming involved in managing the development and implementation of automation systems.

The integration of IT & AT is complicated by the diversity of knowledge of the participants in the planning of the convergence [2].

Therefore, there is a strong need from the earliest definitions of convergence projects for collaboration between the IT and AT areas of the company.

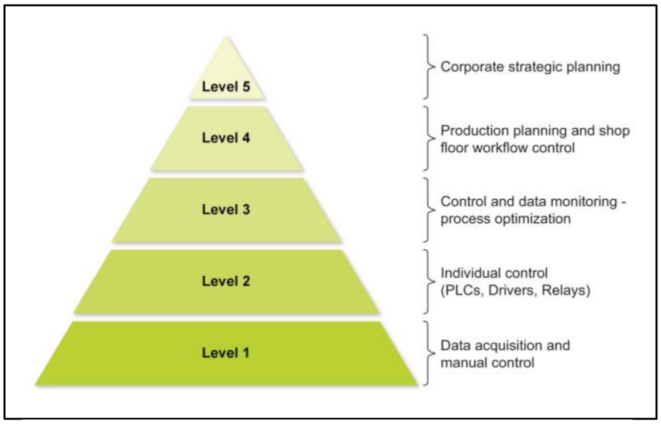

Fig. 1: Automation Pyramid Source: adapted of Züge, 2010 [2]

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.

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 approachs for the convergence architecture of IT & AT [3][4][5][6][7][8][9][10][11][12][13][14][15][16][17].

However, the planning process of IT & AT convergence before the beginning of its customization for a particular plant remains largely unexplored. 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 three macro objectives:

a. Ensuring the construction of an IT & AT convergence aligned with the critical success factors (CSFs) of the company;
b. Optimizing existing investments in technology;
c. Leading the engineering areas with a methodology can be absorbed as a tool to be used in continuous improvement process.

The presentation of the development and ilustration of the SOT methodology is structured into the following topics:

a. The description of the historical evolution of the use of IT, AT and the convergence of IT & AT asset in a productive organization;
b. The description of the risks associated with deploying a new technology;
c. The presentation of the SOT methodology and development methodology process;
d. The illustration of the application and results of the SOT methodology;
e. The conclusions of this study and proposals for future work.

II. 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 from the concept of computer-integrated manufacturing (CIM) initially proposed by Joseph Junior Harrington [18]. The collaborative manufacturing enterprise system (MES-C) model, for example, was presented by the Manufacturing Enterprise Solution Association [19] as an evolution of the manufacturing enterprise system (MES), previously published [20] by the same entity and originating from the 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[21] as manufacturing operation management (MOM). Earlier, this layer had been named in the ISA-95 Part 1 [22] and Manufacturing Operations & Control (MO & C). Another example of a model focused on this layer, collaborative manufacturing management (CMM), was proposed by the ARC Advisory Group [23]. 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 Carnevalli present an extensive review of the different approaches related to the convergence of IT & TA [14].

III. RISKS ASSOCIATED WITH THE CONSTRUCTION OF IT & AT CONVERGENCE

Despite the significant potential benefits inherent in an IT & AT convergence project for an industry, the risks can not be ignored. In the Chaos Report, issued by Dominguez [24] in 2009, of 5000 information technology projects, 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.

According to the institute, lack of proper planning is one of the main causes of deviation in an information technology project, as revealed by the Chaos Report. By extension, it can be deduced that the successful implementation of an IT & AT convergence project is dependent on proper planning.

According to Moore [25], the market development for high-tech products has five stages:

a. The first stage is comprised of enthusiasts, who represent the smallest portion of the total market potential for technology and are primarily motivated by the novelty of the proposal.
b. The second stage is comprised of visionaries, who are the first to realize the potential return of the use of technology.
c. The third stage is comprised of pragmatists, who understand the benefits and risks of technology and only join this new proposal when the benefits outweigh the risks.
d. The fourth stage is comprised of risk-averse conservatives, who only adopt a new proposal after it has already been accepted by the majority of potential users.
e. The fifth stage is comprised of skeptics, who are latecomers to adopting technology.

The third and fourth stages represent the greatest market share.

The transition between the visionary stage and the pragmatic stage is not continuous; there is a gap between these two profiles that, if not successfully overcome, prevents the large-scale adoption of the proposal [25].

Although there is a growing use of IT & AT convergence, it is still within the visionary stage [26] and will remain there until the pragmatists are convinced that the benefits of convergence outweigh the risks. The SOT methodology intends to contribute to the reduction of the risk associated with IT & AT convergence.

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:

a. Methodologies for developing systems [27][28][29][30][31]. 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.
b. Specific methodologies for the convergence of IT & AT [32][33]. 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 adressed by these methodology, 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 current IT & AT assets technological advances, that enables flexible and scalable construction for IT & AT convergence, aligned with holonic manufacturing systems (HMS) and the plant automation based on distributed systems (PABADIS) approaches [5].
c. Methodologies for the functional alignment of assets with business objectives [34][35][36]. 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.
d. Methodologies to improve processes and products [37][38]. 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 analysis and the practices of professionals in the market show that none of the methodologies alone provide support for the planning of IT & AT convergence for a particular existent plant.

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

a. Incorporation of 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 by not only by the new IT & AT assets, but also in priority by the legacy assets.
b. The 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.
c. 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, analyzis, improve and control (DMAIC) core methodology and the failure modes and effects analysis (FMEA) and quality function deployment (QFD) associated tools [38], 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 the groups a, b, c and d were also used to develop the methodology. Figure 2 presents the SOT methodology, which is organized into seven macro steps:

a. *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.
b. *Definition:* This step delimits the scope for the application of the SOT methodology in terms of manufacturing processes (supply of raw materials, weighing, processing, packaging and finished product warehouse), management perspectives (production, quality, inventory and maintenance), indicators related to management perspectives, goals and corresponding current values.
c. *Measurement:* This step involves the determination of the risk that a goal is not achieved because of weaknesses in the workflow due to gaps in the IT & AT architecture.
d. *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 investing in new assets.
e. *Improvement:* This step proposes the workflow for the future and the construction of the IT & AT convergence layer to support the new process.
f. *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.
g. *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.

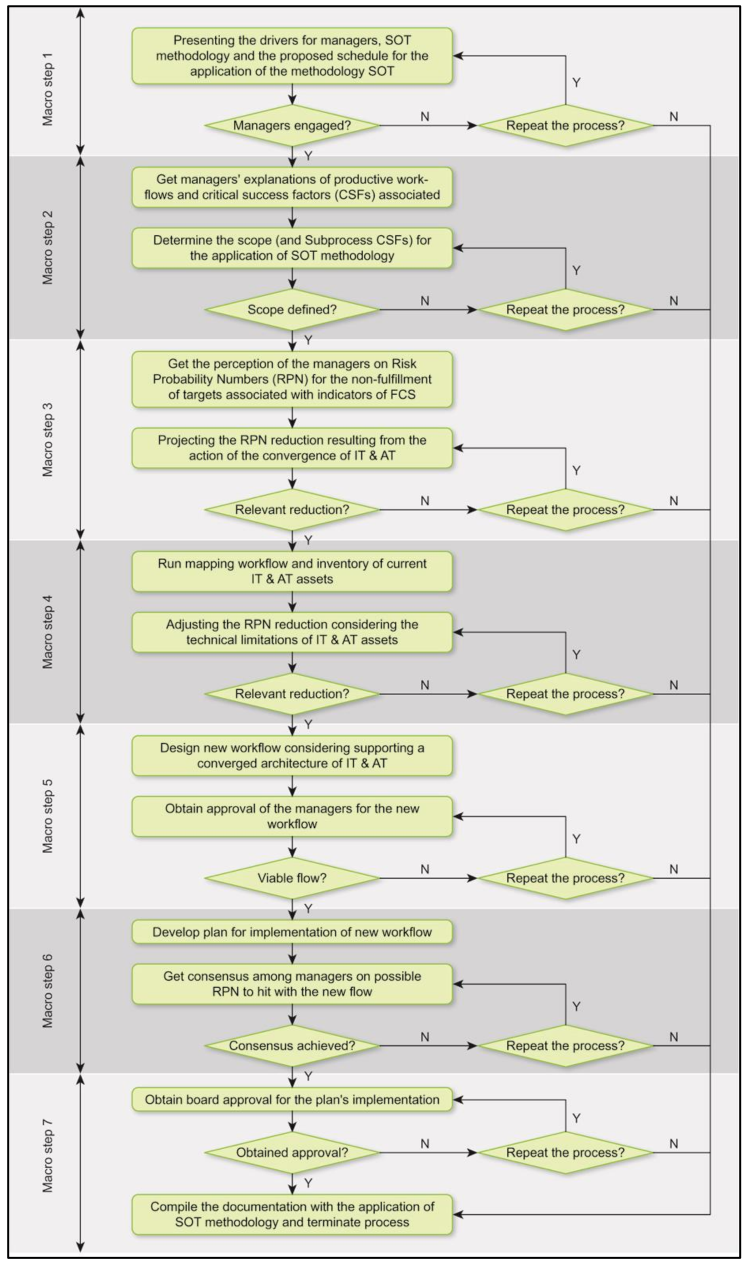

Fig. 2: SOT methodology statement of procedures

V. ILLUSTRATION OF THE APPLICATION OF THE SOT METHODOLOGY

A. Production of Consumer Goods - Case Study

To illustrate the SOT methodology, a case study of a company with batch production process was performed 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 at one of its main plants in Brazil. For this study, five subprocesses were considered:

a. *Storage of raw materials*: material receipt, identification, storage and separation for production;
b. *Weighing and dispensing*: gathering and fractionation of batches of raw materials, identification of sublots, preparation of sets of ingredients for processing;
c. *Processing*: the combination of ingredients and preparation of semi-finished products for packaging;
d. *Packaging*: packing of finished products (FP), FP aggregation into boxes, palletization and preparation of pallets for shipment to FP inventory;
e. *Storage FP*: storage, separation and release of FP for billing and shipping.

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

a. *ERP system*: responsible for managing the activities of accounting, accounts payable and accounts receivable as well as demand management and the planning of production resources;
b. *Asset management system (AMS)*: responsible for the location of the assets used in the shop floor, routine corrective maintenance, preventive and predictive control and spare parts;
c. *Statistical process control (SPC) weight system*: responsible for foresee gaps between the actual and theoretical weight of products in the packaging lines [37];
d. *Post-production system*: responsible for notes on the ERP data for the outcome of the operation of the packaging lines in the industrial floor.

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

a. Wireless barcode-data collectors for reading data from subprocesses involving the inputted raw materials, weighing and dispensing, packaging and storage of the FP;
b. Barcode ID printers for raw, segregated and in-process materials and semi-finished and finished products;
c. Supervisory control and data acquisition (SCADAs) and programmable logic controllers (PLCs) for several generations in the automation of processing and packaging subprocesses;
d. Weighting scales in subprocesses involving the input of raw materials, weighing, dispensing, processing, packaging and storage of the FP.

B. Results of the Application of SOT Methodology

Using the SOT methodology, in the macro step measurement, the 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 can be resolved with the support of the 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 analysis is 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 subprocess 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 workflow future.

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

Figure 3 represents a simplified logic flow for a corrective maintenance activity for packaging equipment wihout the convergence of IT & AT on the left column. The activities in this figure have a duration determined by the

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%															

operator (manual transactions) and by the IT & AT assets (automatic transactions).

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 analized 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 dynamics of the process is defined by the chaining untimed events. The lifecycle of the process begins with equipment fault and ends with the ERP data atualization.

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

Figure 4 illustrates the use of QFD to catalog the AMS identified in the process flow of the corrective maintenance package subprocess. 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 contain the technical requirements necessary to perform the asset functionality within an integrated architecture for IT & AT, for example, to meet the standards of network communication and redundancy or to reserve for future expansion.

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) of 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 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.

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:

a. *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;
b. *System history log*: stores the variation in the current values of the main data processing equipment belonging to the subprocess through the integration of the assets of AT with a server database;
c. *Sequencing production system*: optimizes the sequence in which the products must be packed in the equipment in the packaging subprocess considering the updated information for the industrial floor.

Figure 3 illustrates a proposed flow (right column) based

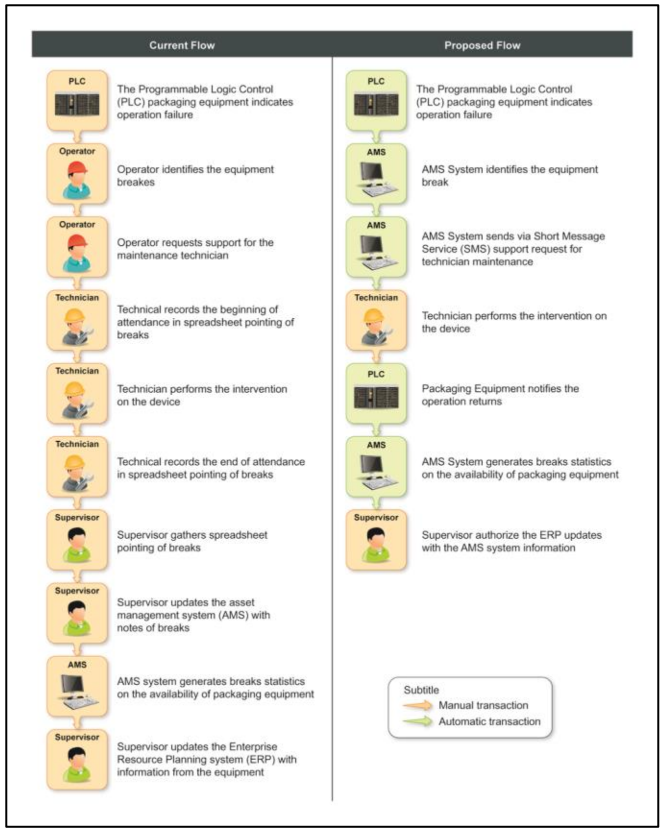

Fig. 3: Flow of current and proposed corrective maintenance in packaging equipment

on IT & AT convergence.The flow summarizes the new process for corrective maintenance in the packaging subprocess, 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 receive notices of equipment malfunction, assets originating from AT, by short-message service (SMS). Additionally, the time spent between the sending and acknowledgment of messages can be monitored, facilitating the implementation corrective actions related to the process to ensure the 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 were necessary, with the third revision of the RPN as defined by the consensus of the managers. Table 1 show, at the control macro stage the reduction of 37.5% in the average of the RPN related to "availability of equipment" indicator in the perception of the managers obtained considering the reused of IT & AT assets.

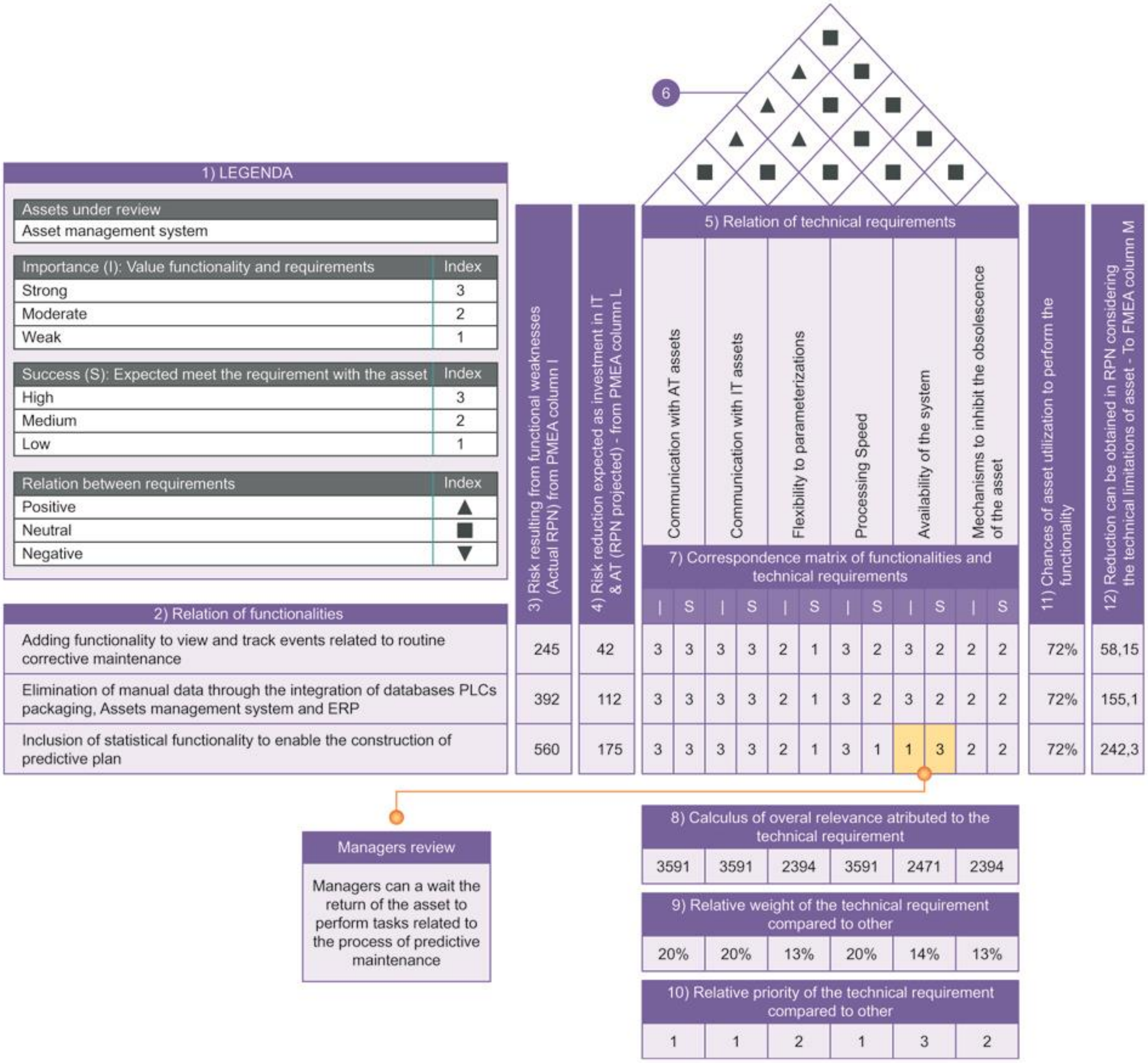

Fig. 4: QFD Management of Assets

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

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. Additionally, a case study was presented to illustrate the application of the SOT methodology.

As evidenced by the analysis of the results, the SOT methodology is a powerful engineering tool to assist in the automation of the organization and reduce the risk of the company's adherence to the CSF solution.

The SOT methodology also contributes to with creation of business skills, thereby providing significant competitive advantages.

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.

Several models, such as ISA-95, specify the need for a convergence layer between IT & AT assets for the automation of the workflow to be completed.

The SOT methodology is an engineering tool optimizer for project design convergence, as it also considers the use of existing investments in IT & AT assets.

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

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

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