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Pipes And Puddles Framework: Risk Management In Manufacturing Processes To Reduce The Total Cost Of Quality

José Costas-Gual[1], Rafael Pastor-Climent[2], Julio César Puche-Regaliza[3*], Javier Puente[1]

[1]*Oviedo University (Spain)*
[2]*Iber-oleff Company (Portugal)*
[3]*Burgos University (Spain)*

jose.costasgual@gmail.com, rafael.pastor@iber-oleff.pt,
[*]*Corresponding author: jcpuche@ubu.es, jpuente@uniovi.es*

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Abstract:

Purpose: An open issue is the decentralization of standards to each process owner. Centralized standards are a common situation which puts a big amount of chore tasks against continual improvement. The Pipes and Puddles framework was born to solve this problem.

Design/methodology/approach: Pipes and Puddles research has been conducted through goal-oriented business requirements engineering, and the model melts the Lean philosophy pillars, the PDCA Deming's cycle for change management, and shapes the three pipes underlying each business process by risk analysis.

Findings: Putting a clear difference among reactive and preventive problem-solving is the first observable change when adopting this framework, which drives to keep cost of poor quality permanently close to zero. Another important consequence of adopting this framework is that each process owner is responsible for continually improving their processes.

Research limitations/implications: This research is still limited to a few empirical cases of use; the diffusion of its benefits and guidelines to its real implementation is an opportunity for a massive adoption.

Practical implications: Pipes and Puddles framework brings to management a roadmap to foster the role of process owner, providing a decentralized approach towards risk management, to react to non-conformities and to implement effective channels for continual improvement.

Social implications: The virtual elimination of cost of poor quality and the empowerment of all employees by having specific roles and regular channels to effectively act as problem-solvers, hence, as agents of continual improvement.

Originality/value: The vision of each process in the firm as the interconnection of three pipes (sub-processes) is a novelty that completely solves common issues for all processes that are transversal to all others (risk management, non-conformant products, customer claims, change management, etc.).

Keywords: risk management, quality management, pipes and puddles framework, continual improvement, process-centric principle

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1. Introduction

Goldratt and Cox (1984) say the goal of an organization is to make more money now and in the future. To make money, throughput of an operating system should be increased while its inventory and operating expenses are being reduced.

To make money today and tomorrow requires a business operating system built with a network of processes, which are adaptable (i.e., changes in it can easily be absorbed). This property (adaptability) is essential because changes in business operating system are the natural way to elevate system performance. Continually (by steps, never ending) introducing changes in the business operating system is what is known as continual improvement. Continual improvement is nowadays preferred instead of continuous improvement because it indicates that improvement occurs through iterated step functions along time rather than a mathematical continuous function. Formulated in the realm of the mathematical categories, we aim for compositionality (ability to understand the business operating system by understanding its components); as we will see later in this work, this is the underlying theory of the Pipes and Puddles framework.

This process centric principle (organizing the system function by a network of processes interacting between them) in Pipes and Puddles is a common one in pull systems like Lean Management and Theory of Constraints, because it matches perfectly with another fundamental principle: customer focus. This principle is the essential characteristic of pull systems: everything is subordinated to customers, and it is one mandatory dimension to evaluate any process, namely efficacy which entails customer satisfaction in quality of products, service, and on-time delivery. The requirements engineering of such a network of processes in an open-ended issue, which involves many problems. According to the auditing procedures of business standards, the repeatedly common problems identified can be classified as shown in Figure 1.

In this work, the most of these issues emerge due to an ill-conditioned way to define processes, which does not convey the conversion of two types of needs into requirements and finally in process characteristics; namely the needs are troubleshooting and continual improvement. Thus, the objective of this work is to build a framework (Pipes and Puddles) that provides an effective solution to the above-mentioned open issues. The rest of the paper is organized in this way: in Section 2, collects the state of the art by examining potentials sources of the enumerated issues. Section 3 builds the conceptual and theoretical framework. Section 4 exemplifies the Pipes and Puddles framework through a case-study. Finally, Section 5 shows a discussion and conclusions.

2. Literature Review

This section explores the different domains of knowledge linked to business process management (Figure 2), and it end up raising some critical questions connected to the list of issues identified in Section 1.

The underlying rationale of Figure 2 collect the blocks described in Section 1: continual improvement, risk management, cost of quality, and requirements engineering, but also adding the change management block to define and maintain processes, because in the end this is the realm where the organization makes business. So, from the literature review the issues raised in Section 1 are reformulated with the aim of identifying the gaps that Pipes and Puddles framework proposed is expected to bridge.

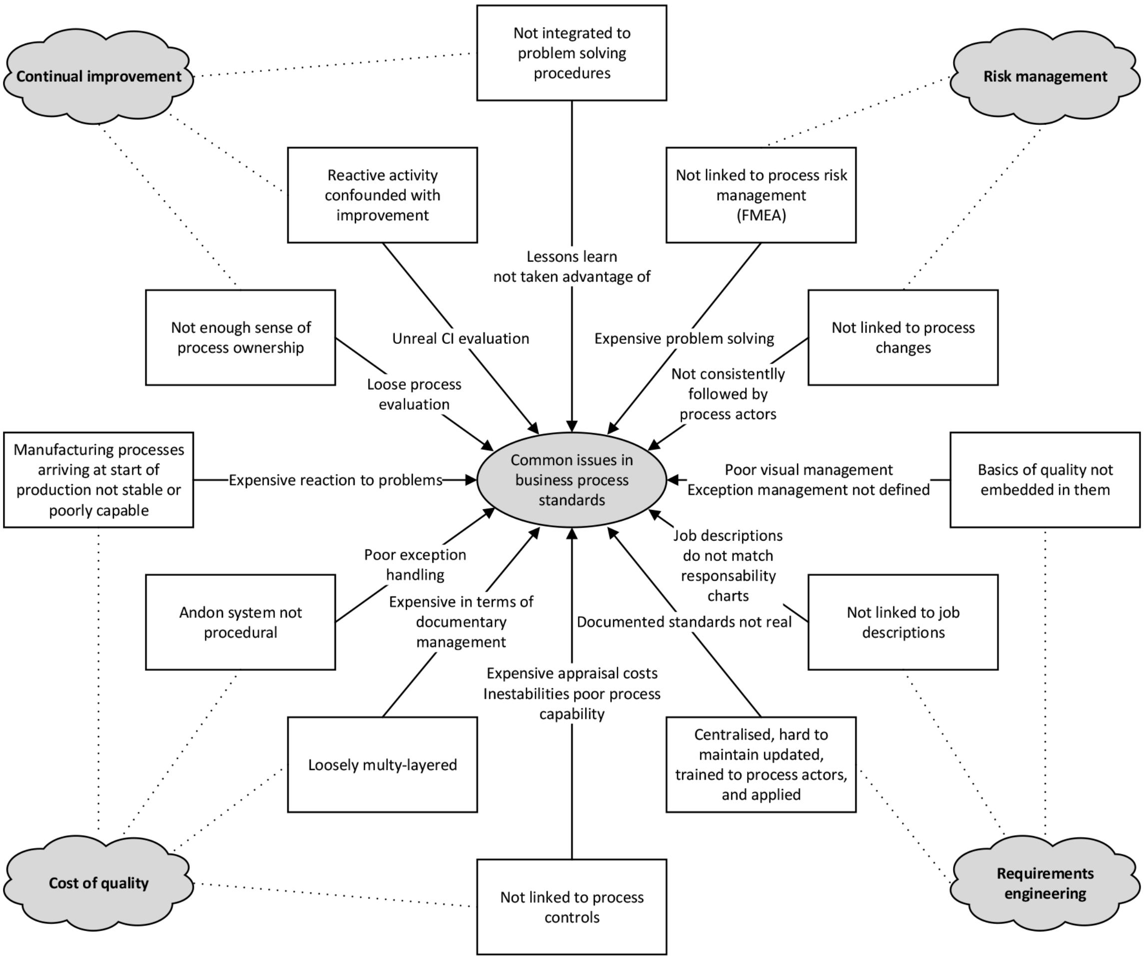

Figure 1. Commonly known problems in industrial process standards

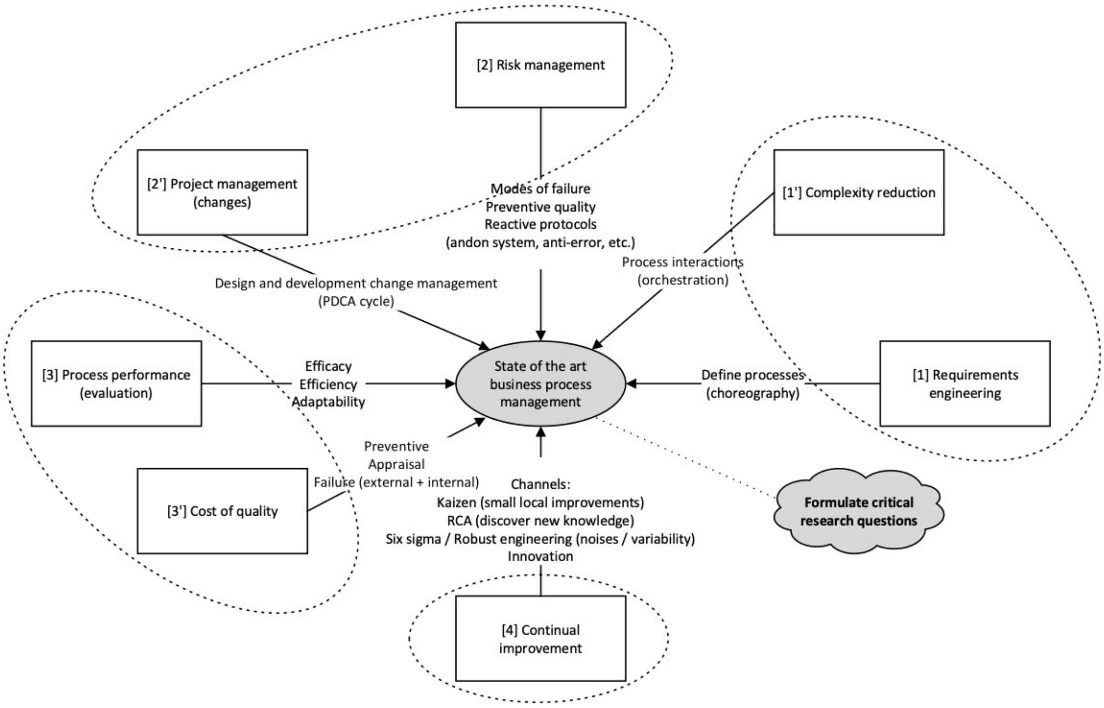

Figure 2. State of the art / business process management

2.1. Requirements Engineering and Complexity Reduction

Lean philosophy has demonstrated to lead organizations towards much higher performance levels, not only on the economic side, but in all safety, quality, delivery, cost, moral and environmental facets (Bhasin & Burcher, 2006). To implement Lean entails many organizational changes and many challenges (Pearce & Pons, 2017). In mass production paradigm the organization is not process centric, does not apply the customer focused principle, problem solving is delayed from its point of cause and assigned to the technicians and engineers rather than carried out through teams with empowered people.

Coetzee, Van Dyk and Van der Merwe (2016) indicate that improving operational performance is a key prerequisite for sustaining and growing an organization. Lean manufacturing is widely considered to be a philosophy that brings about such continual improvement. However, the success rate for lean implementation remains relatively low. Why is this? Prominent among the reasons cited is the intense focus on Lean tools and techniques at the expense of the human side of Lean management.

Concerning software requirements, Van Lamsweerde (2000) enumerate basic questions that have been addressed over the years: what aspects to model in the why-what-how range (ontology of conceptual units), how to model such aspects (structuring relationships), how to define the model precisely (required properties of model components), how to reason about the model (reasoning technique available for the purpose of elicitation, specification, and analysis). Some conclusions in this study are much relevant: much work is needed to support agent-based reasoning during requirements elaboration and, in particular, responsibility assignment, the gap between requirements engineering research and formal specification research is another important one to bridge; roughly speaking, the former offers much richer modeling abstractions while the latter offers much richer analysis, such as model checking, deductive verification, animation, test data generation, formal reuse of components, or refinement from specification to implementation.

In the context of requirements engineering towards process improvement, training and project execution, most of the issues found when distributing processes could be traced back to problems with organizational structure and/or management (Berenbach, 2006). The main issues identified were no cross locations reviews, communications between analysis and design, late feedback, architectural inconsistencies, and avoid spiraling out of control.

To embed quality basics in process protocols and procedures is a real challenge. For an analogy with software embedded systems Mayr, Plösch, Kläs, Lampasona and Saft (2012) Point out that unfortunately, in practice there is a lack of operationalized quality models that cover the specifics of embedded software code quality. Architectural decisions, interdependency and testability were found the major concerns and finally, Worley, Chatha, Weston, Aguirre and Grabot (2005) discuss the difficulties to manage competences, knowledge, job positions, etc. when implementing an ERP, which is a good context to put in value requirements engineering.

Regarding the complexity reduction, De Toni and De Zan (2016) aim to identify ways by which companies could solve Ashby-Luhmann trade-offs (complexity dilemmas), finding solution to increase complexity of behaviors and outputs, through simple solutions. They proposed three tips for dealing with complexity: modularity; simple rules; and organizational capabilities, and four dimensions of complexity are highlighted: interdependence (connectivity, interconnectedness) or degree of interactions and connections among the elements of the system; diversity (multiplicity, variety, heterogeneity) or number, heterogeneity and variety of the elements of the system; uncertainty (ambiguity, not transparency) or degree of unpredictability and ambiguity of the system; and dynamicity (dynamism, fast flux, pace, variability) or speed of flux, rate of change and coevolution of the system. Pipes and Puddles approach to tackle the issues raised by the critical research questions proposed have most to do with the final guidelines to deal with complexity this paper proposes: (1) embrace the paradox of increasing complexity through its local reduction as modularity permits, (2) let complex behaviors emerge by mean of few simple rules, and (3) develop and deploy a coherent level of organizational capabilities in order to manage complexity.

To sum up, Section 2.1 seeks answers to the identified issues relative to requirements engineering and complexity management, i.e., issues concerning standards being real, linked to job descriptions and embedding quality basics as hygienic preventive policies. In overall, the literature review of this block reveals that making real the three pillars (people, process, and problem solving) of Lean manufacturing is a real challenge. Concerning responsibility assignment, and specifically for processes like continual improvement, fast response to react to non-conformities, and change management, Pipes and Puddles bridges these gaps. Another important contribution of Pipes and Puddles concerning requirements engineering and managing complexity will be shown, and it consists of guidelines to build process standards using a multi-layered and decentralized approach.

2.2. Risk Management and Change Management

Provided that risk management work is properly done, the reactive quality procedure should provide a fast diagnosis to set back the production process to its demonstrated stability and capability; and just from time to time, the applications of such pre-defined procedures for fast response may end up with a -no cause found- and hence, an escalation of the problem to another channel. That is: the reactive predefined protocols for problem-solving should end up with a prompt diagnosis and fast response (Coccia, 2018). The efforts on reacting to defects are costs of failure, and there is no process improvement due to this sort of problem-solving. In terms of the appraisal costs, the opportunities for their reduction are linked to the rationale between risks and controls. Risk management, at high maturity level, ends up raising opportunities for process improvement.

Bhuiyan (2011) indicate that new product success still remains the critical challenge for companies. Many companies are aware of the major role new products must play in their future and quest for prosperity: companies are constantly searching for ways to revitalize, restructure and redesign their new product development practices and processes for better results. In Pipes and Puddles framework this concern will be addressed with the meta-process change management.

Although the concerns about risks on processes comes from decades ago (Ványi, 2016), and that failure mode and effects analysis (FMEA) (risk management in processes) was born on the seventies to address these risks, the shortcomings identified in FMEA commonly focus on classifying the risk level with the (old) RPN (deprecated risk priority number to indicate a level of risk in a process in FMEA) (Baynal, Sari & Akpinar, 2018). Beyond the level of risk calculations, the interest of this work goes to the obstacles to generate value for the process owner by the knowledge gathered through risk analysis. Ishikawa (cause-effect) Diagrams have been intensively used in problem solving (Botezatu, Condrea, Oroian, Hriţuc, Eţcu & Slătineanu, 2019) since they were created by Kaoru Ishikawa in the 1960s. Therefore, Ishikawa Diagrams can be generated by FMEA teams to support fast response to known problems. FMEA research work from cause to effects. Once FMEA study is complete is very easy to go backwards to generate Ishikawa diagrams for quick diagnosis of each one of known effects and its known direct causes.

The basics for quality (or the Lean foundations if it is preferred), are commonly used to mitigate risk in processes. For instance, Tortorella, Cómbita-Niño, Monsalvo-Buelvas, Vidal-Pacheco and Herrera-Fontalvo (2020) reports the 5S (deficient organization and cleaning, unsafe or prone to error conditions at the workplace) application to mitigate risks of accidents. Thus, FMEA study provides plenty of insights to decide which specific lean foundations are to be embedded inside the standardized work.

Another very important source of risk is change. Change may be driven by exogenous (government, customers, etc.) or endogenous factors (process improvement, assets renewal, etc.). Wickboldt, Machado, da Costa-Cordeiro, Lunardi, dos Santos, Andreis et al. (2009) show relevant considerations on changes done in information technology work elements and its associated risks. Hence, a transversal meta-process (change management) which applies the Deming's PDCA cycle (plan, do, check, act cycle defined by Deming to manage change) is a requirement for high maturity standards. Lastly, Zhao (2011) highlights the generation of value that comes from FMEA study towards quality preventive controls. Therefore, any time a change is made on a process, there is not a defined systematic way to trigger revising FMEA and control plans. Furthermore, since the PDCA cycle was developed as a tool to drive improvements in a system, it can also be linked to the eight disciplines of problem solving, specifically to the seventh discipline which aims to embedded changes in the standards.

About change management, Lu, Sadiq and Governatori (2009) show that variance in business process execution can be the result of several situations, such as disconnection between documented models and business operations, workarounds in spite of process execution engines, dynamic change and exception handling, flexible and ad-hoc requirements, and collaborative and/or knowledge intensive work, which opens the question: how can the organization manage changes in a way that keeps the effects of changes in process standards updated, actors re-trained, risks and controls in processes affected by the change revised in a robust and unexpensive manner?

In conclusion of this section, it is highlighted that linkage from FMEA to rationale and effective control plans as well as with change management coming from any of the several different channels that bring changes into the business operating system. The main contributions of Pipes and Puddles to these two major issues relatives to this section will be reviewed in the final section.

2.3. Process Performance Evaluation and Cost of Quality

Many authors have dealt with system's evaluation. For example, Hermanns, Herzog and Katoen (2002) indicate that performance evaluation means to describe, to analyze, and to optimize the dynamic, time-dependent behavior of systems. Kaplan and Norton introduced in 1992 the balanced scorecard to study performance measurement (Kaplan, 2009). Şimşit, Günay and Vayvay (2014) point out that nowadays TOC can be used a kind of management philosophy and can be integrated with cost accounting system. It is not of importance which sector your company belongs because Theory of Constraints is actually based on system improvement. In the last 30 years, Theory of Constraints is successfully implemented by almost every sector and with almost every size of companies. Also, the indications of the International Organization for Standardization can be followed, which emphasize that each process should be evaluated in terms of customer satisfaction (efficacy), in terms of efficiency (the opposite is waste or *muda*), and adaptability (flexibility to accept changes). In the Turtle Diagram one of the branches is devoted to this aim. Or the well-known admonition, if you can't measure it, you can't manage it, can be remembered, commonly attributed to the late W. Edwards Deming, a leader in the field of quality improvement.

In relation to cost of quality, Joseph Juran offers a classification, also well known, that splits these costs into preventive and reactive (appraisal and failure) costs (Figure 3).

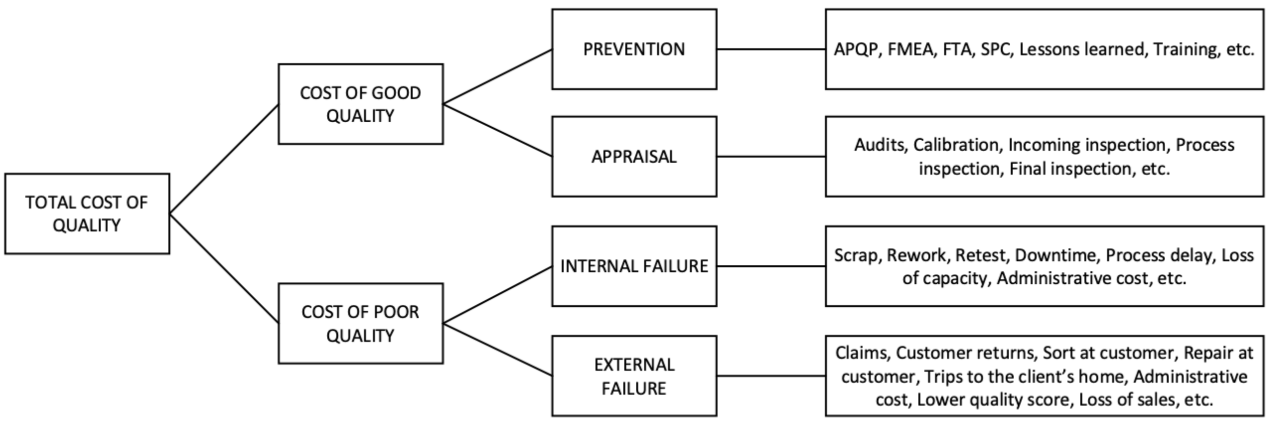

Figure 3. Types of cost of quality (Castillo-Villar, Smith & Simonton, 2012)

In this line, and according to Modrák and Šoltysová (2020), the lower the maturity level of an organization, the more serious are the common shortcomings in their reactive quality systems. Furthermore, sometimes these shortcomings come from a poor use of the organizational knowledge that links modes of failure to defects, which ends up deploying a wrong application of problem solving (Mahmood, 2023). Schiffauerova and Thomson (2006) point out that in the modern vision of total cost of quality, whenever failure cost is not yet zero, there are still opportunities for a trade-off by increasing the appraisal plus preventive costs to keep reducing failure costs until its elimination. This is a shift that fosters continual improvement. As it will be seen later with Pipes and Puddles proposal, the red pipe (that reacts to failures) embraces this model for cost of quality. Under this umbrella of the cost of quality taxonomy, the pinned issues can be cross checked.

Loosely multi-layered standards (Lee & Dale, 1998) raise the issue of entanglement in process improvement: business process management (BPM) is how the host organization's employees aim to improve business processes to achieve their key objectives. The corporate organisation has a set of standard processes in its business architecture which are supported using BPM principles. However, in the business unit, although there are numerous in-process measures, there is little understanding of BPM; the extent to which processes are documented varies enormously and the application of the BPM principles is haphazard. Employees have too little time to spend on process simplification and improvement, what improvement does occur is uncoordinated and dependent on the individual process owner. In short, there is no coordinated approach to BPM and what improvement does occur is not always directed in line with the vital few objectives.

In reference to exception handling (*andon*), Ng, Chen, Lee, Jiao and Yang (2021) extract conclusions about structured reactive procedures: the increase in process complexity, cognitive capabilities and decision support for exception handling, quality control and smartness required a more ground-breaking autonomous agents with contemporary Artificial Intelligence algorithms. In business workflow and process management, unistructural data becomes an important source of decision-making, and we expected that more cutting-edge autonomous agents will be developed to match the business needs in automation in near future.

Also, some confusion can be found between containment and improvement. Bessant, Caffyn and Gallagher (2001) recognize the difficulties to implement the continual improvement principle in business processes: they argue that continual improvement is of considerable strategic importance, but that its management is often poorly understood. The problem occurs in part because of confusion surrounding the term itself since continual improvement refers not only to the outcomes but also to the process through which these can be achieved.

By last, process control must be considered. Khorshidi, Gunawan and Esmaeilzadeh (2013) comment that continual improvement is an important aspect for companies to maintain their position in today's market, and process control can provide this capability for them. Their study aims to facilitate implementing statistical process control in less-developed industries. Due to reaching this goal, FMEA has been employed. FMEA helps the statistical process control implementation either in process selection or output analysis.

2.4. Continual Improvement

Continual improvement comes mainly from problem-solving (Lean philosophy even makes a pillar on that). Ultimately, solving a problem entail introducing a change into a process, besides exploiting (*yokoten*) the lessons learned by solving the problem (Oduoza, 2020; Carrillo & Gaimon, 2000). Moreover, continual improvement must be part of business management, allowing organizations to constantly improve the processes that comprise them (Buendia-Giribaldi, Rojas-Quispe, Tosso-Pineda, Silva-Sánchez, Bravo-Rojas & Espinoza-Santos, 2021; Evans, 2017). Furthermore, continual improvement can be recognized as the most useful aspect to enhance the competitiveness, efficiency, quality, and performance of said processes (Li, Papadopoulos & Zhang, 2016). With these considerations, three key aspects can be highlighted regarding continual improvement:

First, the failure to integrate continual improvement into problem solving procedures can cause the lessons learned to not be taken advantage of. Gray (2001) indicates that it is still not clear how the organizational practices proposed (problem-solving, decision-making theory, etc.) to support the creation, storage and transfer of knowledge can relate to each other in their contribution to organizational performance. Similarly, Manesh, Pellegrini, Marzi and Dabic (2020) request further research on how knowledge management processes must be molded and adapted to the effects produced by the arrival of Industry 4.0, which involves the interconnectedness of machines and their ability to learn and share data autonomously. Finally, Cardenas-Cristancho, Monticolo, Muller and Lhoste (2021) detect problems in the implementation of continual improvement methodologies. Furthermore, they highlight that despite there being studies mainly focused on the identification of failures or success factors in this implementation, the clarification of the organizational process remains unexplored and misunderstood.

Second, reactive activity confused with continual improvement can cause an unreal continual improvement evaluation. In this regard, Nita-Ali, Sun, Petley and Barret (2002) examine the business process of reactive maintenance projects and proposes an improvement through information technology. Among the major problems that have been revealed from the process analysis are getting the right problem for the right contractor, double handling of data entry and transferring information. These are due to lack of knowledge sharing and poor communication between different parties. Rowe, Birnberg and Shields (2008) indicate that there is theory-consistent evidence that the goal-congruent design of redesign of accounting and participation practices in general, and of responsibility accounting in particular, depends on the magnitude, scope, and speed of organizational process change. And Danilova (2019) show a systematic literature review demonstrating the significance of appointing process owners and showcase process owners' role and responsibilities, as well as obstacles to and enablers of effective process ownership. So, Evans and Price (2014) found that is often that responsibility and accountability in the information management decisions are inappropriately imposed.

And third, not having a sufficient sense of ownership of a process can cause losses in evaluation processes. Van Looy (2021) indicates that BPM traditionally focuses on continual improvement, automation, and standardization, while today's organizations increasingly require more agility, flexibility, and innovation, so it is necessary to evaluate processes from these points of view. On the other hand, some studies indicate that total employee involvement has positive influence on organizational performance (Pambreni, Khatibi, Azam & Tham, 2019), suggesting that decentralization is positively associated with organizational performance (Anwar & Abdullah, 2021). Thus, a greater analysis of the effect that the sense of ownership of a process has on the performance of an organization and the way of evaluating its processes is necessary.

To put into practice and implement continual improvement actions in the processes, a multitude of tools, strategies, methodologies, etc. have been proposed. A wide variety of channels are known: *kaizen* (small local improvements), Root Cause Analysis (RCA) (discover new knowledge), Six Sigma / Robust Engineering (noises / variability), innovation, etc. Possibly one of the most used is the well-known PDCA cycle developed by W. Shewart and especially popularized by W. E. Deming as mentioned above. In this regard, Isniah, Purba and Debora (2020) present a useful literature review to describe the relationship between thinking or gaps in theoretical and practical thinking about the application of the PDCA method and the successful implementation in the service and manufacturing sectors, and Costas and Puche (2010) propose a detailed reflection criticism on the deep meaning of the PDCA cycle of continual improvement. Peças, Encarnação, Gambôa, Sampayo and Jorge (2021) study the main Industry 4.0 technological concepts and their possible application towards a typical continual improvement process, establishing the requirements to propose a conceptual approach PDCA 4.0., and Grisold, Mendling, Otto and Vom Brocke (2021) explore how process managers perceive the adoption, use and management of process mining in practice. Along this same line Vinodh, Antony, Agrawal and Douglas (2021) provide a review of the history, trends and needs of continual improvement and Industry 4.0. Specifically, four strategies are reviewed, namely, Lean, Six Sigma, *kaizen* and sustainability.

Define, Measure, Analyze, Improve, and Control (DMAIC) phases are used in the context of Six Sigma paradigm when a project's goal can be accomplished by improving an existing product, process, or service (Flifel, Zakić & Tornjanski, 2017). Trimarjoko, Purba and Nindiani (2020) present a literature review to certify that 72% research in manufacturing industry consistently implemented DMAIC roadmap especially in case study research type for problem-solving, while service industry pointed out fewer number (60%). For his part, *kaizen* can be understood as one of the basic Lean techniques. Continual improvement applied through *kaizen* is a key element of Japanese management and the source of competitiveness (Janjić, Bogićević & Krstić, 2019). Suarez-Barraza, Miguel-Dávila and Morales-Contreras (2022) conduct a review of the *kaizen* literature to determine value and trend conclusions for the academic arena, and Syaputra and Aisyah (2022) aim to find out and provide information about *Kaizen* implementation from various types of industries (manufacturing, logistics, construction, SME, service, healthcare, pharmaceutical and processes for continual improvement). They use the literature review method of research papers that generally apply *kaizen*.

Finally, ISO 9000 also highlights the importance of continual improvement, showing how to implement an improvement system through audits, allowing the identification of challenges and opportunities, these being factors of change and success of organizations (Yánez & Yánez, 2012). Thus, Stertz-Sfreddo, Bergmann-Borges-Vieira, Vidor and Schuch-Santos (2021) carry out a systematic literature review about quality management and organizational performance through ISO 9001 standard, showing that most of the studies found a positive relation between ISO 9001 implementation and one or more dimensions of organizational performance. Moreover, this study indicates the lack of a consolidated model for evaluation of the management system's maturity level and the non-consideration of aspects related to process management in studies about ISO 9001 and organizational performance. By contrast, in a similar study Stertz-Sfreddo, Bergmann-Borges-Vieira, Vidor and Zin (2019) found that the papers analyzed did not address some important aspects in the relationship between ISO 9001 and process management, such as evidence of improved operational efficiency of processes, and cultural changes noticed in organizations after the implementation of ISO 9001. Other works, such as that of Saida and Taibi (2021) explain, in addition to present a literature review about the link between the quality approach and performance, the construction of the conceptual model of the research highlighting the effect of the quality approach on performance. Lastly, some works based on literature review, perform a comparative study on Lean implementation, Six Sigma methodology and ISO 9001. For example, Veena and Prabhushankar (2019) develop a framework which integrates all the three methodologies to fill the gap or meet the challenges or limitations of the above three models.

3. Tools and Methods

The goal of the proposed Pipe and Puddles framework is to provide a methodology in order to raise the level of maturity (Figure 7) of any organization. This has huge implications on the way the company creates, disseminates, train, audit, and specially change its standards. The methodological framework followed for its conception can be reviewed in Figure 4.

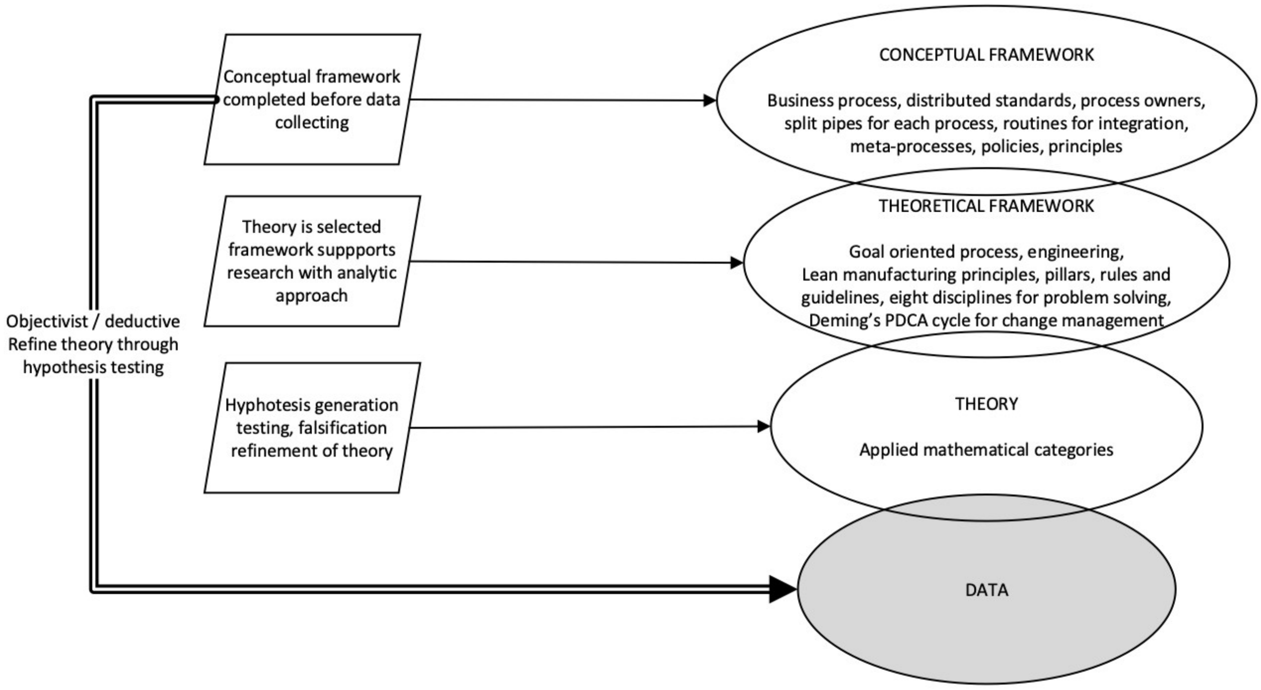

Figure 4. Pipes and Puddles methodological framework

3.1. Pipes and Puddles – Conceptual Framework

According to Varpio, Paradis, Uijtdehaage and Young (2020), a conceptual framework is the justification for why a given study should be conducted. The conceptual framework describes the state of known knowledge, usually through a literature review; identifies gaps in the understanding of a phenomenon or problem; and outlines the methodological underpinnings of the research project. It is constructed to answer two questions: why is this research important? and what contributions might these findings make to what is already known? The conceptual framework is deployed through the process centric and customer focus principles, and the organization goal is to provide a roadmap to step through increasing levels of maturity towards business excellence.

3.1.1. The Process Centric Principle

Business process standardization is the unification of business processes and the underlying actions within a company (Romero, Dijkman, Grefen & Van Weele, 2015). Later, in this section, the role that business process standards play in terms of maturity of the firm, and the importance of having highly adaptable standards to both solve problems very quickly and to keep always the process improving will be revised.

By considering a process as a morphism, Pipes and Puddles aims to structure the business processes in a way that wherever needed processes are composable and composition is associative. Of course, to frame this basic idea in categorical semantics able to develop the conceptual framework, the very important challenges to overcome will be explained later in this section. For instance, processes as morphisms need resources, actors, and entities that get transformed (namely material and data flow); a subset of actors are process owners, and there are process owners for concrete and for meta-processes; to shape the documentary management to update standards will be necessary, and model the gathering and dissemination of new organizational knowledge about the physics of its processes among actors and other interested parts.

A general production process is picked as an example. It begins by defining a process by first considering its boundaries (start measurable point, end measurable point). For instance, a Turtle Diagram (Figure 5) of a production process will in most cases pick boundaries with a work order arriving to the system and ends by closing the work order. Through the input port the process (any effective system cares –orchestration– to have clearly defined seamless interfaces) receives the input entities (mainly materials and data) that the process (composable) function converts into outputs.

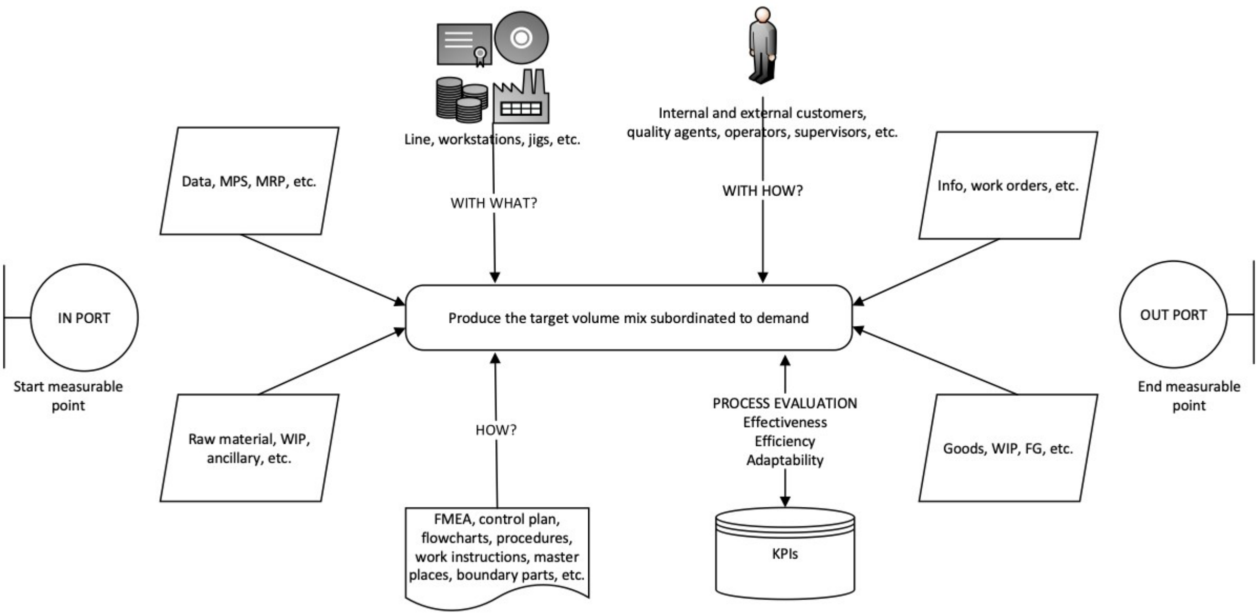

Figure 5. Turtle Diagram / Production process

Processes are classified as customer-oriented processes (COP), they compose the value stream, support processes (SOP) and management-oriented processes (MOP). There are two special processes that the firm needs; one belongs to class SOP, and deals with non-conformities; in many organizations the owner of this process is the quality manager. Another need is continual improvement. This is a MOP process (linked to policy deployment (*hoshin kanri*), and sometimes the quality manager is its owner, and sometimes the owner is the continual improvement manager.

There are meta-processes (as risk management, change management, etc.) that are commonly not identified as meta; this ends up by raising an important barrier to move the organization maturity up to the superior levels (quantitatively managed and optimizing). The reason for that is the fact that meta-processes are needed in each business process. For instance, non-conformities can happen in any process, not just in production, and continual improvement should not be limited to the COP processes but should reach all company processes. To fix ideas, an example of the enterprise overall process map is showed in Figure 6.

Pipes and Puddles framework requires strong vision on processes, requires thinking about standards as a multi-layered structure, which will be elicited later in this section, to simplify the *kaizen* work and all sort of process changes necessary to improve –by using the standards to retain corporate knowledge and train actors of processes. Technology, like a collaborative decentralized environ may be used to help to have agile ways to update the standards, to train actors in processes on changes. So, training process owners goes first. They must be trained to become accountable for the three pipes (explained in Section 3.4), extending the scope of the standards they get accountable for from risk analysis to change management. This training includes to drastically elevate their problem-solving skills. Implementing a documentary management based on collaborative environ is also an important catalyst to distribute work and to reduce the chore tasks of updating standards. Process owners are also trained on documentary management.

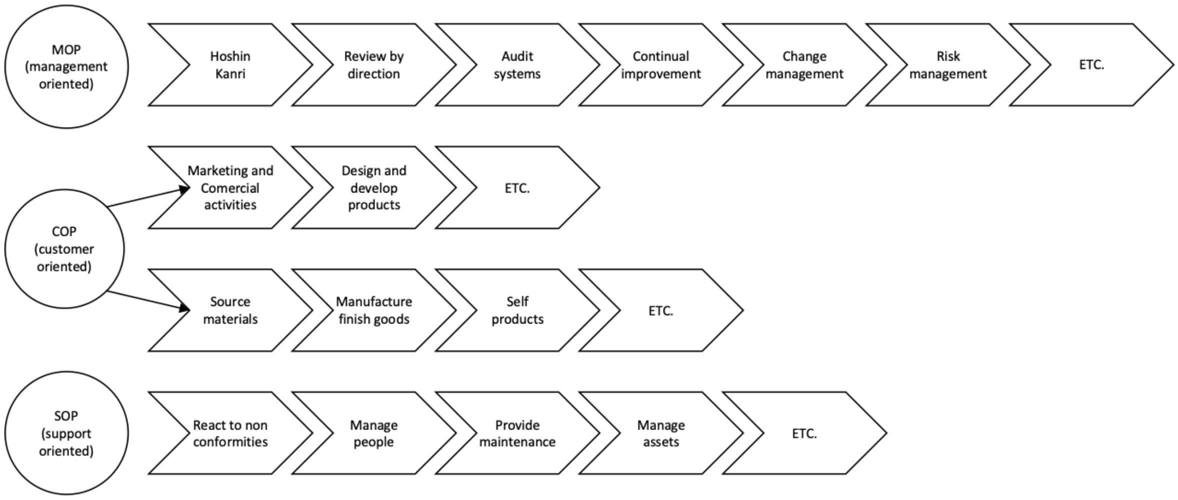

Figure 6. Overall process map

3.1.2. Capability and Maturity Levels

Following the theoretical framework of Goal Oriented Process Engineering (GORE) it all starts by setting the main goal: put the company to move up through the Capability Maturity Model (CMM) levels (Figure 7).

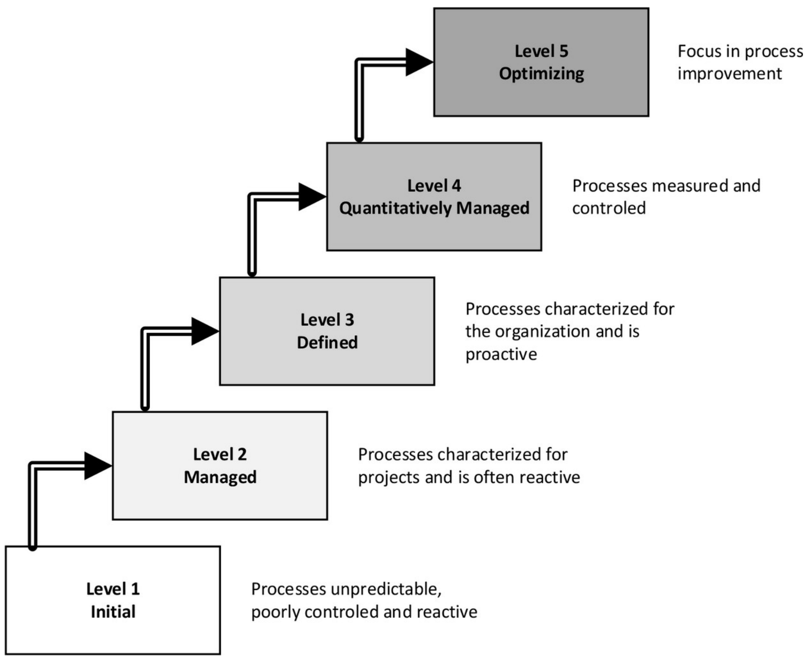

Figure 7. Capability and characteristics of the maturity levels (Software Engineering Institute CMM)

Pipes and Puddles approach starts by classifying the organizational maturity level. So, the way to start Pipes and Puddles implementation depends on the maturity level of the organization. At lower levels of maturity, most of the efforts, energy, and time are wasted in *muri* (pure waste due to assignable (avoidable) causes). Most of the failures (external and internal –see cost of poor quality in Section 2) are due to assignable (avoidable) causes which end up in form of accidents, defects in parts, customer claims, failing on-time delivery, machine breakdowns, etc.

3.2. Pipes and Puddles – Theoretical Framework

In the conceptual layer of Pipes and Puddles framework it all started by introducing the process centric principle, the process ownership condition, and the CMM which is the ladder to climb towards business excellence. Now the main artefacts used to develop the theoretical framework will be introduced (Figure 8).

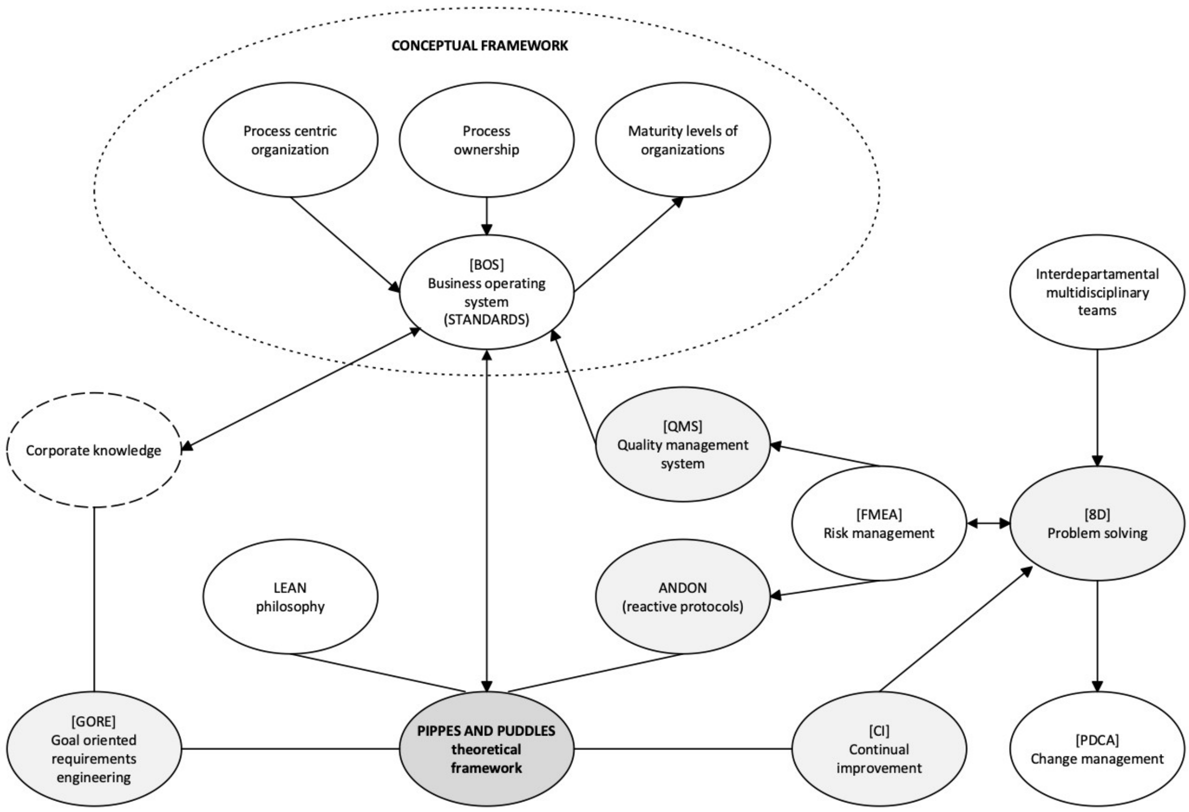

Figure 8. Pipes and Puddles theoretical framework

To start the theoretical framework GORE will be picked, which typically implies several panels:

- The goal panel identify goals, sub-goals, obstacles opposing these goals and key domain properties.
- The responsibility panel assign roles to process actors, which may be implemented through a RACI chart (R = responsible, A = accountable, C = consultant, I = should care to get informed); it answers the question who cares of what?
- The operationalization chart cares on flowcharts (information and material flow, and usage of resources).
- The data model panel cares to solve the need of converting data into actionable information for decision making.

In the end, each system (build with processes) has strategic dependencies (among actors) and strategic rationale (how actors do tasks, react to events, make decisions, and so forth to get the system goals.

Another category inside the theoretical framework is the Lean paradigm, which is devised with system thinking, and built on three pillars: (1) people, (2) working under the process centric principle, and (3) solving problems continually to increase customer satisfaction and, at the same time, reducing the total amount of waste in the system. Lean sets some basic fundamental rules to guide decision making: standardized work (make quick problem solving real), *kaizen* (change standards continually to improve), flow (stocks, inventory, is essential *muda* only justified to support flow), pull (production must always be subordinated to demand), technology is always subordinated to process, and stop-to-fix (defects should never travel downstream, which involves immediate problem diagnosis under any system failure). Lean has a strong presence within the operational standards, where 5S (cleanliness and organized workbench), detailed work-instructions, visual management, anti-error mechanisms, total productive maintenance (TPM) (machine caring by the users of it), and *andon* (exception alerts) are tangible on shopfloor and office. Problem solving is key to improve and the eight disciplines (8D) have strong implications on the methods to apply in any channel for problem-solving (Table 1).

Discipline	What is it about?	Details
1	Teamwork	Autonomous interdisciplinary teams with competences and delegated authority to apply the rest of disciplines in order to solve a problem; a problem is not always bad news (like defects, breakdowns, etc.); problems are mainly opportunities to improve things that work well, which means reduce complexity, increase usability, reduce the seven types of waste (7 types of waste: transport, inventory, motion, waiting, overproduction, overprocess, defects) in the process, mitigate risks, increase flexibility, and so forth.
2	Problem statement	Manageable problem statements, where the object and the deviation are clearly stated; the deviation can be either a non-conformity versus a specification, or versus a desired ideal condition; for non-reactive problems the direct cause (mode of failure) is expected to be clarified here as part of the problem formulation.
3	Temporary containment	A temporary workaround (containment) tolerated during the minimal time window, just to keep customer satisfaction until the problem is solved.
4	Root cause analysis	Should provide methods in each type of problem to identify and verify the cause of the failure; it must work symptom → failure → cause; and it is mandatory to provide evidence of the causal chain; there is a rich variety in discipline 4 depending on the nature of the problem.
5	Seek options for counteractions	Involves creative thinking to identify not only a single potential countermeasure against the verified cause in discipline 4. In general, especially in non-reactive problems, not only to get back the system to the already demonstrated performance is expected, but we expect to elevate the system performance, converting most problems into opportunities to improve. To do so, discipline 5 seeks different potential countermeasures to be evaluated in terms of efficacy, collateral effects, investment (once) cost or capital expenditure (CAPEX), and reduction on regular operating expenses (OPEX).
6	Verify (small scale) counteractions	Verify the selected countermeasure at small scale so that discipline 3 (containment) can be removed.
7	ACT (update standards, train and audit changes are absorbed)	Consists of ACT the improvement implementing the change in the standards of the process, which implies revision of FMEA (risk analysis), flowcharts, work-instructions, training the change to actors involved in the RACI, reviewing preventive plans, TPM, control plan, audit plans, and whatever is necessary so to ensure the change becomes the new state of the system. All of these always with the aim to do better with less.
8	Lessons learned applied by affinity	Has the goal of extend the lessons learned to anywhere are applicable to get more gains with the new knowledge gathered by the teamwork solving the problem. Except for reactive problems, discovery of known things is clearly expected and hence, *yokoten* (extend applications of this new knowledge) is as well expected.

Table 1. The eight disciplines for problem solving

Next, a succinct explanation about the famous PDCA Deming's cycle is introduced. PDCA was created by Walter Shewhart in 1939 but was named and popularized by Deming in the 1950s and has since been known as the

Deming cycle. This artifact aims for a rigorous way of tackling with changes. Success implementing a change (like during the application of the 8D in problem solving) involves plan, do, check, act activities.

Another piece in the theoretical framework is FMEA (AIAG & VDA FMEA-Handbook, First Edition 2019). Risk analysis (FMEA) is conducted by system functions (generally physic laws). A tree of (composable) sub-functions generally explains the main (intended) process function. Functions need work elements (skilled actors, resources in good state) that generate the flow of entities and are exposed to noise conditions (wear-out, environ changes, variability eventually coming from final users, etc.). All of these ends up in form of potential modes of failure; each failure has potential effects. In terms of the failure (cause), the worry is: (1) the promptness of its detection (measured with an ordinal scale 1:10; detecting late or far from the point of cause is a serious issue in terms both on the effects and also the problem analysis will be more difficult and time consuming). Any failure connects to its effect through the p-f window (delay in time, latency, from the event of failure and the event of effect), and (2) the probability of occurrence. In terms of the effects (consequences of a failure) the worry is about its severity.

All these tuples are mapped (effect, severity) ⊗ (failure, detectability) ⊗ (failure, occurrence) into an Action-Priority (AP) color:

- Red flag (H) means that this risk –a pair failure, effect– is too dangerous to try to use controls to defend against it in the long term; so, it will be necessary to temporarily protect (containment), but a ticket (continual improvement project) will be put in the blue pipe (explained in section 3.4) so to reduce its AP.
- Green flag (L) means there is no need to apply preventive quality to protect against it; it is enough to have defined protocol (Ishikawa fast diagnosis fishbone) for reactive plan, which is trained and delegated to the operating actors.
- Yellow flag (M) risks need not only reactive fast response protocols, but also need preventive quality in terms of control plan, preventive / predictive maintenance, checking fixtures or anti-error mechanisms, visual aids, etc. All this preventive quality is embedded in the green pipe (explained in section 3.4) of the standards so to have an affordable bounded level of risk in the worst-case scenario.

3.3. The Theory and Data Layers of the Pipes and Puddles Framework

The block data in this schema is the facts and figures evidence that can be gathered to test this framework in real companies adopting the proposed framework.

The theory block relies on the applied mathematical categories. Baez and Pollard (2017) transform Petri Nets into mathematical categories, indicating that reaction networks, or equivalently Petri Nets, are a general framework for describing processes in which entities of various kinds interact and turn into other entities. In this block, these ideas to open reaction networks are generalized, which allow entities to flow in and out at certain designated inputs and outputs. Open reaction networks are treated as morphisms in a category. Composing two such morphisms connect the outputs of the first to the inputs of the second. A functor sending any open reaction network to its corresponding open dynamical system is constructed. This provides a compositional framework for studying the dynamics of reaction networks. Thus, the theory block is expected to rely on these ideas taken from advanced mathematical categories, where using cartesian products we can create the projections, injections, the necessary functors, natural transformations and adjunctions in order to properly represent the pipes and puddles conceptual framework in formal mathematics.

3.4. Pipes and Puddles Framework Implementation

The Pipes and Puddles framework was devised with the aim to decentralize the process-centric principle (Costas, Pastor & Puche, 2022). With this vision, each process is made of three pipes, as can be seen in the Figure 9.

First it is necessary to explain the green and red pipes of this framework (and forget the blue pipe for now); green and red pipes aim to set the organization performing at least at the third (defined) level of maturity.

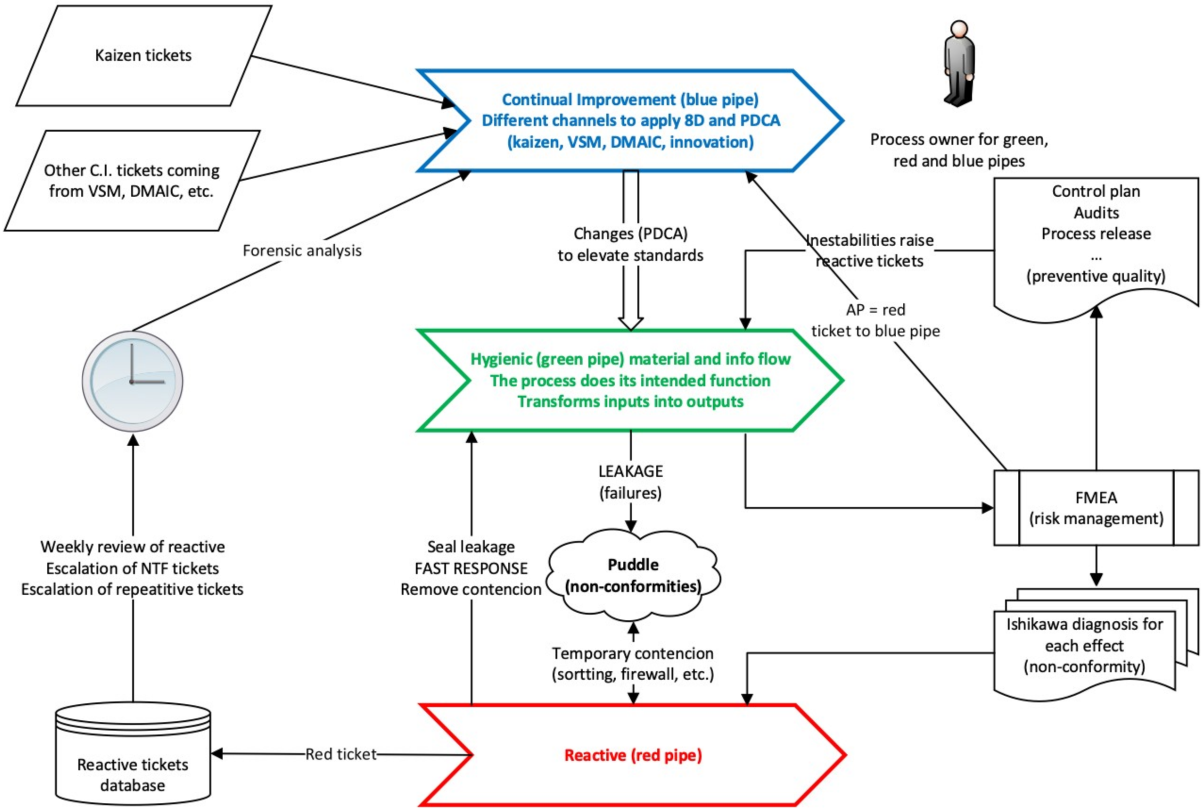

Figure 9. Pipes and Puddles framework

3.4.1. The Green and Red Pipes

At lower levels of maturity there are two critical needs: (1) very relevant changes in the standards are to be implemented through the green pipe, and (2) the red pipe, which many times does not even exist, needs to be implemented.

The hygienic (green) pipe is what at lower levels of maturity tends to be the only organized flowchart (material and information flow for the process orchestration). The scope about having process standards starts and ends with the green pipe. These standards are poorly embedded with the Lean foundations (5S (clean and organized workspace), visual management, *andon* system (exception handling), anti-error, TPM (caring protocols applied by those who use equipment), trained and frequently audit work instructions, etc.), which conform the preventive basics of quality to ensure a correct risk management at the operating level (high detectability of modes of failure in their point of cause – where the problem is generated in space and time). Whenever the point of escape (place and moment of detection of a failure) is not at its point of cause, the problem analysis is much harder (this is very well known for any lean practitioner and the biggest reason for implementing the lean foundations at shopfloor).

The implementation of the red pipe involve: (1) exception handling to react to *andon* conditions, (2) fast response encapsulating available knowledge about common problems, and (3) routines, habits to deal within each shift to effective communications and escalation procedures following the SQDCME panels (safety, quality, delivery, cost, moral, environ panels to prevent surprises at shopfloor).

By embedding Lean foundations in the green pipe and implementing the red pipe, the total amount of *muri* (avoidable waste) can be reduced to virtually zero. Now the organization have savings in cost of poor quality so to be ready to move up to reach level 3; to reach this target condition the organization face the following needs of change. The roadmap to follow by focusing on the production process is detailed: The process owner now is aware that is not only accountable for the green pipe, but also is accountable for the red pipe (which previously was somehow delegated to quality people). Quality people and other support people as well as interdisciplinary teams contribute to manufacturing through the SQDCME panel routines. Pipes and Puddles framework also rules the distribution/decentralization of the documentary management. Each process owner follows centralized guidelines and methods to implement their multi-layered standards to run their processes, as well to interconnect (composability principle taken from the mathematical categories) of processes. As commented before, within the Pipes and Puddles framework, process standards are multi-layered:

1. Turtle Diagrams to tackle about process boundaries and morphisms (connections) to other processes.
2. Flowcharts (procedures) for each thread identified in the Turtle Diagram to deploy the (composable) intended process function.
3. Work-instructions are the low level (derived from procedures).
4. Risk management analysis (in engineering and production: FMEA).
   a. Ishikawa diagrams to apply fast diagnosis and response to failures.
   b. Control plan to ensure the stability of the process.

By properly implementing green and red pipes in each process maturity level 3 is achieved; the following things have changed:

1. Processes can be seen as morphisms; they have composability and associative properties. Whilst this condition was not satisfied most of the issues emerge due to lack or poor composability.
2. The only pipe considered at the lowest maturity level was the green one; hence, all *andon* conditions (exceptions) were managed in a non-structured way, which generated higher cost of poor quality, crisis to react with a fast response (hence, dissatisfied customers), containments (temporary solutions) becoming permanent changes (hence, higher production standard cost). By having a structured, well defined red pipe to manage *andon* conditions (fast response to common, known problems) processes now can be led to stable, predictable behavior, and can be turned back quickly to ordinary conditions by the defined procedures to diagnose and react to exceptions. The problem-solving efforts have been re-directed to quickly drive processes to a real standard, and the work of the red pipe is to continually elevate each process standard, in a decentralized way, towards a stable, predictable, robust green pipe. This achievement soon manifests by a drastic reduction of cost of poor quality and entering to a positive synergic loop where better green pipe gains time to improve red pipe, which at the same time keeps improving the green pipe and so forth. So, in the end, Pipes and Puddles framework generates value in each maturity level of the organization.
3. Process owners understand and assume ownership to the extended red pipe that before was managed under another ownership external to the process which was violating the process centric principle.
4. Certainly, blue pipe only gets priority once level 3 (defined) of maturity is reached.

3.4.2. The Blue Pipe

Once maturity level has reached level 3, Pipes and Puddles framework takes the perspective of the physics of the process in terms of achieving its intended function. Only by a deep understanding of the functional tree, the system work elements and the noise conditions that commonly affect the process can obtain a valuable risk identification and prioritizing which is: (1) the base for improvements on the reactive procedure (red pipe), (2) a much better rational for hygienic controls, and (3) a lever for continual improvement.

GORE consists in converting needs into requirements, in a recursive way, until manageable, implementable artifacts are obtained and embedded inside process standards to store and make real the applications of lessons learned through problem solving (hence, exploit organizational knowledge). So, at lower maturity levels, rather than organizational knowledge, the firm can only count on personal knowledge of its employees facing an issue at any moment. This explains its poor productivity solving (mostly already known) problems, thus, its high cost of poor quality. The target here ended up by re-defining the quality system which drove to a dramatically reduced total cost of quality. At higher maturity levels the firm is ready to tackle some common very hard organizational problems: risk management, change management, inexpensive treatment of non-conformities in each process, and continually elevate standards (improve) in all processes. All these problems have in common that their nature is transversal to all company processes. The goal at this defined stage ends up developing methods for retaining, expanding, and exploiting the organizational knowledge in a multi-layered process standards architecture. Besides, we aim to devise the dynamics to elevate standards once and again by following an organized and highly efficient mechanism (the blue pipe). This way, organizations protect their manufacturing processes. General objectives for Pipes and Puddles in this mature stage can be formulated this way:

- When any process deviates from its objective, the system is provided with methods (red pipe) to give a fast response so that the system is soon back to normality; these troubleshooting methods are based upon knowledge gathered by risk management (FMEA for engineering and production processes).
- Repeatable problems are not any longer dependent on white collars.
- Experts now are not occupied to solve known problems delegated to the red pipe; they are occupied with the hard, challenging problems and opportunities (blue pipe).
- Processes arrive to start of production always stable and with a high capability. Assignable (special) causes (instabilities) are removed during the launching phase.
- Different channels of problem solving are defined by classifying the nature of problems (variability, innovation, value stream, *kaizen*).

As can be seen in Figure 9, the process owner is responsible for green, red, and blue pipes.

First for all, the process owner is accountable, as happened under less mature stages, the green (hygienic) pipe. The green pipe is accountable for the intended process function, so it works using decentralized (process owner is accountable to maintain, train and elevate standards in a collaborative distributed repository) and multi-layer standards (Turtle Diagram, flowcharts, RACI charts, FMEA, control plan, work instructions and so forth). This is called the business operating system, which incorporates the quality management system (specific requirements concerning quality and principles to be applied within the standards like non conformant product segregation, the red bins, etc.) and the Lean foundations (5S, visual management, TPM, *andon* system, etc.). Business operating system and quality management system receive the policy deployment, in terms of *hoshin kanri*, and the audit system plus the performance evaluation.

On the defined level of maturity, processes are predictable, robust against common noise conditions, and the procedures to react to issues are available, documented and trained (of course, before the process goes into production); this is what essentially the red pipe is. The standards are built under the principle of risk management following FMEA, which means that potential (known direct, nor root, causes) modes of failure have a defined way to detect any leakage (failure in its time window p-f) and reaction. The red pipe works with a very agile registration mechanism. The tickets that flow through the red pipe (reactive tickets) are managed at the lowest level of the organization under the principle of quick diagnosis and response to seal the leakage on the green pipe with promptness. This is so because of the work of the interdisciplinary FMEA (risk management) teams. They provide to the workforce the Ishikawa Diagrams (defectology sheets for rapid diagnosis). Forensic analysis is scheduled on regular basis so to check recent history of issues and conclusions are moved upwards to a higher level to check for affinity among issues in different workplaces. The aim is to identify recurrent or severe issues that require action to the blue pipe.

It is also aimed to keep improving the process applying the lean principle of continual reduction of the total essential *muda* within the standards; this requirement is dealt by the blue pipe. The blue pipe manages the portfolio of projects of process owners. The top-level is tracked by the direction board on regular basis and makes essential part of the process performance evaluation through benchmarking and gap analysis versus the best performers in the business area. This pipe is shaped around different channels. *Kaizen* channel is managed at workplace level, whereas signal noise analysis (robust engineering) runs during each project of launching (advanced product quality planning). Problems that raise after start of production due to variability issues are run via the DMAIC channel involving interdisciplinary teams composed by highly prepared people in problem solving techniques with the aim to discover unknown root causes of variability. Problems to reduce essential waste, which is what occurs when the standard is met, go through the value-stream channel applying the lean toolkit beyond the basic *Kaizen* toolkit. Some preventive problem toolkit is part of the standards, as commented earlier, inside the green pipe, like *kamishibai* (lower level of layered audits), process release protocols, *andon* procedures, and so forth.

In the end, Pipes and Puddles framework ends up by building a vision towards processes that focus on high level of standards (green pipe), fast and inexpensive response to leakage (red pipe), and an engine of continual improvement really focused on changing (means of production, choreography and orchestration of the process, competences of process actors, interfaces/connections among processes, procedures, KPIs, gages, etc.), applying the Deming's PDCA cycle.

As summary, the main point here (in Pipes and Puddles framework) is to regard each project as a tuple of three pipes. Being the owner of the process accountable for the 3 pipes.

4. Case Study

This section develops the data block of the framework by recurring to a couple of synthetic case-studies.

4.1. Pipes and Puddles Framework – Injection Molding Process

Consider this first succinct example: the sub-process of production in a first tier of a car maker in automotive sector: the injection molding process.

The green pipe represents the hygienic activity (produce injected parts) of this process. The owner of this process is accountable not only for the green pipe. The owner is also accountable for the red pipe and for the blue pipe. That means the owner is responsible to use the predefined red procedures generated and trained by interdisciplinary teams (FMEA team) for fast diagnosis and reaction to known (by the firm, not just by some staff) problems. That means the owner is also accountable to improve, via the blue pipe, the green pipe performance once and again in terms of customer satisfaction, efficiency, and adaptability to changes. And the owner is as well accountable to improve the red pipe (lower and lower cost of poor quality by better diagnosis and faster reaction to all known problems). Moreover, the owner is also responsible for using the procedures of each one of the channels (unknown root causes identification, signal noise analysis to face variability issues, *kaizen* activity, value stream total waste reduction, innovation, etc.) that are devised by interdisciplinary teams reporting the board of directors to implement the blue pipe.

In manufacturing, common, repetitive problems are consequence of the physics of the process. So, common practice of problem-solving teams is to check the available knowledge on the issues of the process where a problem happens. In the plastic injection molding process, the typical problems are well known in the industrial literature: Flow lines, sink marks, surface delamination, weld lines, short shots, warping, jetting, etc., just to mention the top ones (Rogers, 2015).

Following with this example, problem solving teams would find in the industrial literature: most of the modes of failure of defects are also well-known. For instance, sink marks appear as depressions, dents, or craters in thick sections of a part. Thicker sections take longer to cool, which can have the often-unanticipated side effect of the inner portions of the part shrinking and contracting at a much different rate than the outer sections. Though most often an indicator that the plastic needs more time inside the mold to properly cool and cure, sink marks may sometimes be remedied by reducing the thickness of the thickest wall sections, which helps to ensure more even and thorough cooling. Inadequate pressure in the mold cavity or higher-than-desirable temperatures at the gate can also contribute to the development of the defects. On the design side, the risk of sink marks can be minimized by ensuring proper injection molding rib thickness and wall thickness. These actions can also help to increase the overall strength of the part.

In maturity levels 1 or 2, people tackle each problem as if it were a new one. Once a company's capability and maturity level reach level 3 (defined), the company typically runs under -process centric- principle, which is a basic of Lean production system. What changes the most in this level, compared to level 1 and 2, is how people solve problems. The lean philosophy is built upon three pillars (3P): process, people and problem-solving. Will be seen here how these 3P are used in practice. In level 3, standards created during the advanced product quality planning process (launching policies) are supported with TMP, work instructions, training, visual management, *andon* system, anti-error systems, 5S, and overall quality foundations in order to prevent problems, besides FMEA work to manage process risk by understanding the physics of the process (as seen above in the explanation of known failure modes) and hence, implementing early detection of modes of failure, effective and fast procedures for diagnosis and reactions to problems, and preventive procedures to reduce the level of risk in the physical system. All of this is what makes, of course, a sound difference in the way problem solving takes place.

Pipes and Puddles framework solves the general issue about how the organization is shaped to behave in this much more performant way of solving problems and continually improve processes, by splitting each process in a 3-tuple of pipes, as mentioned. Training process owners to define and maintain with their inter-departmental teams the overall layers of process standards documented with a corporate pattern inside a collaborative environ and applying all meta-processes to have a consistent way to analyse risks, manage changes, conduct the different ticketing systems (channels) of problem solving and so forth.

Any process (in a process centric scenario) has a process owner, and the board of directors do performance evaluation by processes – not by heads of departments. It is each process (like parts procurement, like shipping sales to customers, like producing parts, etc.) which is measured by a calibrated system (as the ERP, a MES, etc.) in terms of effectiveness (customer satisfaction), in terms of efficiency (total waste reduction of all seven types of waste (*muda*)), and in terms of adaptability. These metrics devised to evaluate process performance are not created by the process owner, who is actually accountable to explain process performance.

4.2. Pipes and Puddles Framework – PQ Factory (Goldratt)

Although case study approach has been widely used in management studies and the social sciences more generally (Takahashi & Araujo, 2020), applications can also be found in work related to innovation management (Goffin, Åhlström, Bianchi & Richtnér, 2019). In this same direction, is considered the P-Q factory (Figure 10) (Watson, Blackstone & Gardiner, 2007) so to build with synthetic data a case study in order to show the potential impact using the pipes and puddles framework to organize the company standards, and more specifically, to care about processes whose owner is generally an issue: continual improvement, change management (needed for many types of changes, but also needed for continual improvement), treatment of non-conformant products, etc.

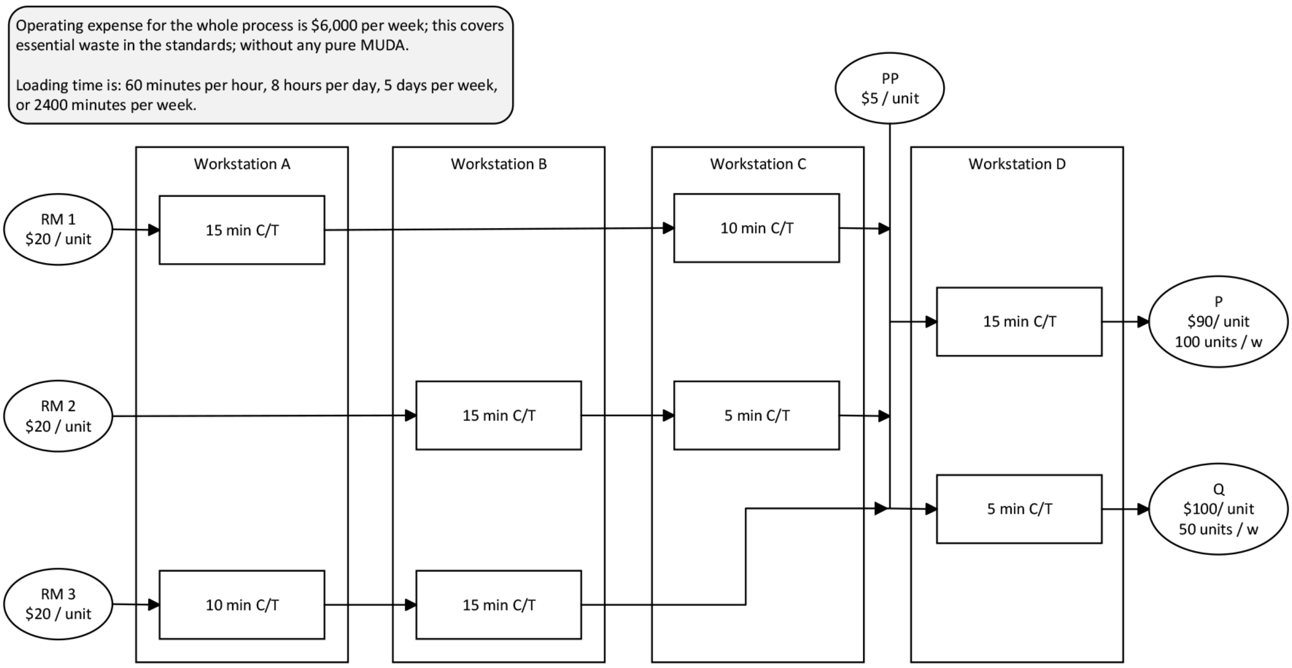

Figure 10. P-Q product process diagram (Goldratt, 1990)

In the P-Q problem it is known that demonstrated stable performance should deliver (each week) a Throughput (T) of $6,300 with a $6,000 Operating Expenses (OE), hence a $300 Net Profit (NP). The visible part of the hidden factory represents 5 to 15% of turnover. But the hidden factory is 3 times this figure, hence the total cost of poor quality varies from 20 to 35% of total sales revenue (turnover). In the P-Q problem the ideal turnover is $12,000.

Considering a baseline in which is assumed a scrap level at 6% in each workstation, a 10% downtime of the loading time, and delays in cycle time that multiply nominal by 1.33. In such immature scenario, the revenue falls to $8,073. The loss of revenue is then $3,927; so, the hidden factory represents 33% of turnover. If the visible cost of poor quality is calculated, $760 for scrap plus $600 would be reporting for the spoiled operating expenses, this $1,360, which is approximately 1/3 part of the total cost of poor quality. Once placed a likely baseline, the implementation of Pipes and Puddles framework can be described.

It is also considered that this P-Q factory is in the low maturity level. Most of its waste is in the *muri* form (poor standards, tampering, failures (hence defects), escaping detection in its point of cause, poor controls, large dependance on inspection, Lean foundations almost absent: 5S, visual management, anti-error systems, long batches, long die changes, TPM, training operators, *kamishibai*, fast problem solving, etc.). Moreover, most of the preventive quality policies – many times compulsory because of applicable norms and regulation – does not have at all its well-intentioned effects and become merely an extra-cost because these policies cannot be effective under a push firefighting culture.

The Pipes and Puddles framework will work as follows. First, a general communication program will make clear and care that most employees buy the program (the survival of the company, the working atmosphere, and other values, like empowerment, participation, transparency, etc. are appealing to everybody). The program implies to adopt lean philosophy, process centric organization rather than departmental, decentralized ownership of processes, customer focus, and broadly speaking, all known drivers of excellence in business.

Once the Pipes and Puddles framework is explained, trained, coached, and applied in all top-level processes, the blue pipes work to get defined and low-level audited standards in order that problems can be fixed using the encapsulated diagnosis and reactive procedures defined by the interdisciplinary FMEA (risk management) teams. At the same time, the red pipes start moving away the sort of problem-solving techniques that used to be applied, and that only are valid for seeking new, unknown root causes of the modes of failure but are not efficient for a prompt return to normality in minutes, with very short containment cost. The focus of hygienic monitoring is in adhering the standards so that the red pipes are effective solving problems in this very fast way, ensuring defects do not travel by enhancing application of lean foundations, and developing an atmosphere of continual learning.

As discussed, all the activity in the red pipe has to do with cost of poor quality, namely, reducing pure waste, which is mainly classified in the correction type of waste (seven waste taxonomy), whereas hygienic pipe concerns are on the culture side, creating liturgies that provide favorable conditions to develop understanding, interdependencies, synergies, good communications and proper space for the different classes of problem solving.

As standardized work grows, interconnection (choreography) of processes becomes seamless, robust, and red pipe removes until virtually zero the cost of poor quality, the blue pipes can spend more and more time, using interdisciplinary teams, in all theirs channels: robust engineering in launchings, root cause analysis for really hard and unknown problems, value stream mapping to reduce the total essential waste using better pull and flow mechanisms, quicker die changes, and at the low-level of the organization the *kaizen* channel provides fast, frequent, simple changes in terms of using better visual aids, better trained work instructions, more appropriate layouts, and in the end, a wise use of the Lean foundations.

With these simple and short exercise, it has been shown that T can be increased by $3,000 per week, being able to remove the large amount ($4,000) of cost of poor quality, and still without considering the increase of profit coming from the blue pipes by rebalancing the line, doing value added value engineering for quicker and simpler manufacturability, grow in sales, and so forth.

5. Final Discussion and Conclusions

In the Figure 11 can be seen that the orientation of the company to its goals implies to develop processes, process ownership, develop a business operating system (the different layers for the standards of each process) embedding a quality management system to protect customers in terms of quality and delivery, and the organization has to find a way to, on one hand protect the application of standards in order to work in a defined (rather than in a firefighting) scenario, but on the other hand standards are expected to be elevated frequently to catch changes coming from problem solving, which is the instrument to improve each one of the processes of the firm.

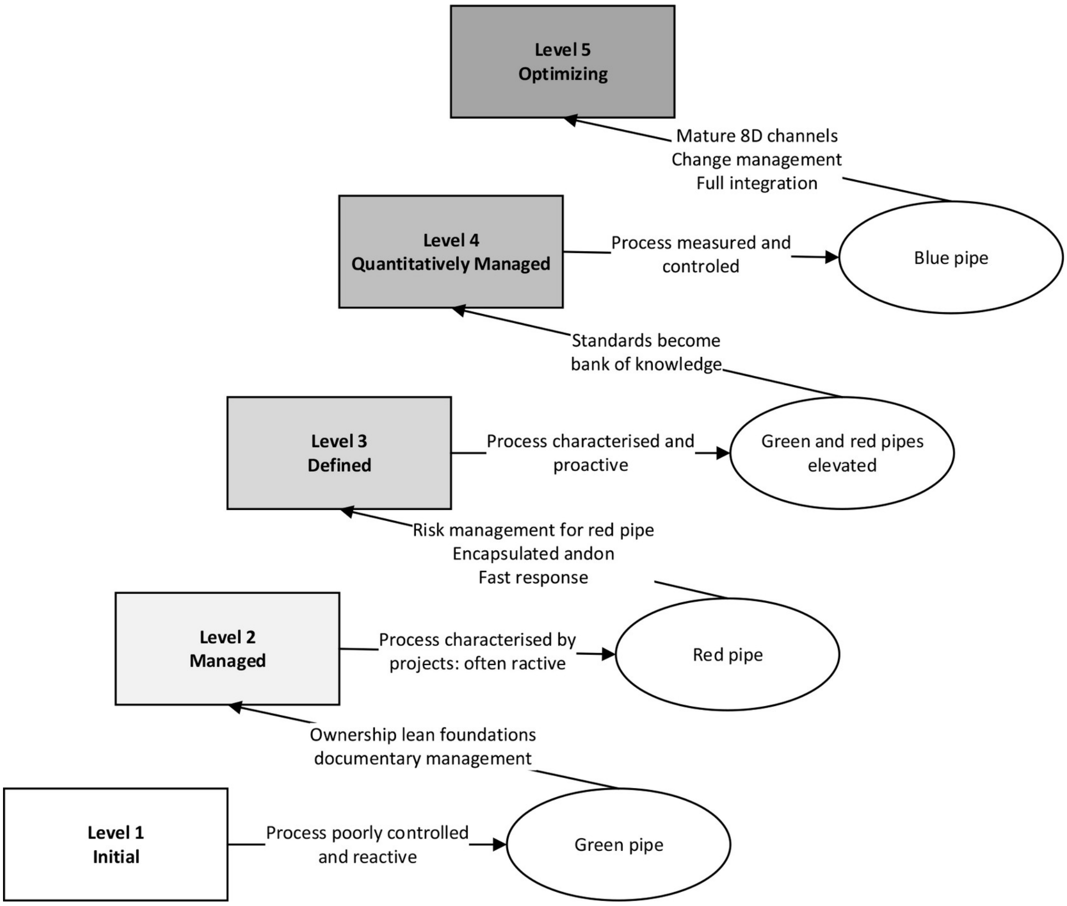

Figure 11. Overall vision of this work contribution

By using the Pipes and Puddles framework at low levels of organization maturity, the following issues identified in the introduction have been bridged (Table 2).

A general advice towards Pipes and Puddles transformation, as it happens in all strategic projects, entails:

- An effective communication program, which entails habits and visual evidence everywhere of the direct support from top management.
- An intensive training for the major actors: the process owners.
- Manage the typical and well-known stages of forming, storming, norming, performing and adjourning.

To highlight some key point concerning changes after implementing Pipes and Puddles:

1. Quality is not any longer delegated to quality assurances agents, but each process owner is accountable for quality and for continual improvement of the process they are in charge of. The quality system gets embedded inside the multi-layered standards, and FMEA is the node from which all reactive and preventive quality is deployed towards instructions, controls, lean foundations at shopfloor and so forth.

2. Adopting Pipes and Puddles framework represents a dramatic change in terms of the total cost of quality. Instead of having a quality system with a questionable cost-effectiveness because it mainly aims to be compliant to regulations, the quality function embedded inside each process through the Pipes and Puddles framework is a machinery of making savings.
3. This framework, Pipes and Puddles has been tested and implemented with success both in a couple of industrial firms, and in a technological firm. The details for the implementation process of Pipes and Puddles goes beyond the scope of this paper; nevertheless, it is important to realize that some key organizational instruments must be put on place, interleaved with the *hoshin kanri*.

Concerning the limitations of this study, the following points are highlighted:

- This work has focused on production systems; to what extent Pipes and Puddles framework is applicable to, for instance, a supply chain is an open issue.
- Moreover, repetitive production systems rather than job shop scenarios (production of single instances – project oriented) have been focused. The application of the Pipes and Puddles framework in a, say, software farm is another open issue.
- For the shake of space in the manuscript, we leave out all the details about training process owners. This entails a huge cultural change about their interactions, attitudes towards change, and actively sharing knowledge.
- The technology (especially collaborative environs for documentary management, the use of the ERP to support information flow for red and green pipes mainly, etc.) can be wisely used to foster Pipes and Puddles implementation.

Finally, future lines of research are directed to the incremental improvement of Pipes and Puddles framework, specifically now on the work to make it doable for management (process owners), providing guidelines, examples, and instructions for implementation.

ID	Issue	Gaps and critical research questions	P&P contribution to bridge the gap
RE-1	Lean foundations, basics of quality, not embedded enough inside process standards	The success rate for Lean implementation remains relatively low. Why is this? Prominent among the reasons cited is the intense focus on Lean tools and techniques at the expense of the human side of Lean management (Coetzee et al., 2016). How can we embed the Lean foundations, the quality basics, so that they are always an intrinsic part of any business process standard?	The way to build standards (green pipe) multilayered, distributed and devised for agile documentary management
RE-2	Process standards not linked to job descriptions	Optimizing the adoption of an ERP system by its users is a difficult challenge, which requires to make evolve both the system (through interface adaptation, etc.) and the people (by clearly defining their role within consistent and optimized processes) (Worley et al., 2005). How can the organization keep aligned changes in process standards (RACI charts) with job descriptions?	RACI charts mandatory to be created by each process owner and integrated in the meta processes to manage the people pillar of Lean
RE-3	Centralized, non-multi-layered standards	Based on the findings of social psychologists, a role-based collaborative system allows users to know and fulfill their obligations while respecting the rights and authority of other users in collaboration (Zhu & Zhou, 2006). How can the organization have distributed work to define and update process standards to their natural owners and, at the same time have uniformity in documentary management and training process actors?	Decentralized requirements engineering to process owners, but with rules to fulfill meta processes that build effective communications among the community of owners through general rules and guidelines

ID	Issue	Gaps and critical research questions	P&P contribution to bridge the gap
RM-1	Changes in processes not analyzed by risk management	Organizational change has been a key component in enhancing performance and organizational design. Previous process-oriented organizational change methods, however, focused on simplifying process flow without examining how it affects other organizational elements. Since an organization consists of several interdependent elements, a change within an organization can affect the other dependent organizational elements. Lack of coordination within an organization can result in unexpected poor performance and high coordination cost (Kim, 2000). To innovate and improve, the company needs change; change involves modify standards with involves the chore documentary management task besides the re-training of actors about the changes done, and other activities derived from change management. So, the question is: how can the company keep been productive under this continuous burden load in changing standards?	The -how?- branch of the Turtle Diagram (procedures to perform the intended process function) gets more robust. Much more cost-effective controls. Statistical process control in a cost-effective way
RM-2	FMEA and process controls mismatch due to updates	A control plan is developed, based on the possible failures of the product functions and the production processes. The production processes are monitored at the locations that may cause the potential product failures. So, the possible linkage between the FMEA report and the control plan can be established according to the potential failure modes developed in the FMEA report (Teng & Ho, 1996). FMEA ends up by raising the AP (risk level) for all identified potential modes of failure and its effects, which is the natural way to stablish rational controls and hygienic defenses inside standards (procedures, work instructions). FMEA work should as well provide fast response protocols to *andon* (alarm) conditions. How the organization ensures that procedures, work instructions, hygienic policies, fast response protocols and FMEA remain always synchronized?	Implement continual improvement based upon FMEA (risk management) and organized in several channels; each one dependent on the nature of problems to solve
COQ-1	Process not arriving to SOP stable and capable	Our analysis extends existing approaches to understanding self-reinforcing relationships in organizations by specifying the physical and behavioral structures underlying the positive loops that create pathological outcomes. The stock and flow structure that relates process problems to defects and process throughput results in two basic options (Repenning & Sterman, 2002). A company with a low maturity level is trapped in the firefighting (internal and external failures) after start of production, then production does not pick enough involvement in projects of launching -> this develops an anti-synergic loop which prevents arriving to SOP with stable and capable processes. How can such a situation be amended?	The training to process owners to take real ownership of the green, blue and red pipes for each process
COQ-2	*Andon* system lack procedures	If the FMEA work is done carefully, no surprises with exceptions when the system is in production. Slopy work during the launching process ends up with costly situations due to shortcoming in the exception handling procedures (*andon* system) (Romero, Gaiardelli, Wuest, Powell & Thürer, 2020). Why organizations fail to stop this avoidable over cost?	P&P makes mandatory to have defined *andon* procedures for each exception handling situation before a real exception is thrown
COQ-3	Expensive documentary management due to poorly layered process standards	Can the organization create a documentary management that promotes autonomy among process owners to commit to keep their standards defined, trained, and audited under common corporate rules, formats, and policies?	P&P rules that documentary management is distributed (decentralized) via a collaborative environ

ID	Issue	Gaps and critical research questions	P&P contribution to bridge the gap
COQ-4	Process controls not rational against risk management	Why can control plans exist without being linked to potential modes of failure identified by interdisciplinary FMEA teams that have regularly scheduled activity?	P&P creates liturgies for FMEA teams and process owners to create effective and rationale control plans derived from risk and change management
CI-1	Losing opportunities to exploit lessons learnt through problem solving	Problem solving captures new knowledge. In which way this new knowledge goes to standards of other processes where applicable? (1) knowledge management must be adapted to the arrival of Industry 4.0, and (2) organizational process remains unexplored and misunderstood, generating problems in continual improvement implementation	P&P approach to knowledge management is by embedding lessons learned through problem solving in the multi-layered standards and training them to process actors, managing their competences though the RACI chart
CI-2	Unclear responsibilities to improve all processes	Who is the owner of improving each one of the business processes? Is a unique job position in the organization chart? An evaluation of processes from agility, flexibility, and innovation points of view is necessary. The effect that the sense of ownership of a process has on the performance should be analyzed (centralization vs. decentralization)	The green, red and blue pipes of P&P provide a framework where responsibilities are crystal clear
CI-3	Continual improvement confounded with reactive activity	Knowledge sharing and communication between right contractor, double handling of data entry and transferring information must be improved. Confirm that responsibility accounting depends on the magnitude, scope, and speed of organizational process change. Delve into the importance of appointing process owners. The process evaluation routines set targets to be on budget, on standard costs. But how can the organization make accountable each process owner to elevate robustness, apply the organization bank of knowledge to her process, increase flexibility?	The red and blue pipes in P&P provide a clear differentiation between reactive and preventive quality. Process evaluation mechanisms are devised to promote customer-focus, efficiency, robustness, simplicity and adaptability.

Table 2. Critical research questions and contributions of Pipes and Puddles framework

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