POLITECNICO DI TORINO

Department of Mechanical and Aerospace Engineering

Master's Degree Course in Automotive Engineering

Master's Degree Thesis

RELEVANCE OF KEY PERFORMANCE INDICATORS TO THE MONITORING PHASE OF INDUSTRIAL WORKFLOWS, AND CONTROL CHARTS IMPLEMENTATION AS AN IMPROVEMENT PROPOSAL

Academic Supervisor

Prof. Paolo De Blasi

Candidate

Giuseppe Scifo

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Abstract

The thesis project, developed in partnership with Capgemini Italia S.p.A., had the goal to highlight the relevance of Key Performance Indicators (KPIs) to the monitoring and control phase of industrial processes and to search for potential areas of improvement, by considering a simulated Capgemini client (an engineering and manufacturing company) standard process monitoring method for the purpose of this paper.

The paper focuses on one hypothetical work perimeter, defined as Services (S), which is linked to the management of engineering technical information.

Key Performance Indicators data and some of their structures, described in this paper, have been modified to respect potential confidential constraints, but in such a way that in some cases the original trend has been maintained while in others, new trends have been simulated to test

the sensitivity of the statistics implementation described in the improvement proposal, which is part of this thesis.

The paper initially provides, through the first chapter, a description of the four macro-phases of Project Management workflow, highlighting the relevance of the "Monitoring and Control" phase, where Key Performance Indicators are involved.

The second chapter instead, provides an overview about two main regulations related to Quality, such as the ISO 9001 (applicable to all companies) and the IATF 16949 (specific for the automotive sector), underlying the importance of their implementation. The aim of these regulations, respectively, is to provide specific requirements for the management of the company organization, targeting customer satisfaction and to provide improved quality products to automotive customers worldwide.

The third chapter then describes the work perimeter in question and its field of application, to deliver an example on how the IATF 16949 is practically expressed, also considering the simulated client requirements.

The fourth one instead, focuses on the detailed description of how Key Performance Indicators are designed, applied, monitored, and reviewed, in the work perimeter previously described.

Finally, the fifth chapter focuses on the improvement proposal regarding the standard monitoring method, describing the implementation of Control Charts and highlighting the related advantages.

Chapter 1

1. Project Management workflow

Manufacturing companies need to apply an organized and well-structured set of activities for the achievement of their targets by considering fundamental constraints such as time, cost, and quality. To do that, they need to apply the Project Management discipline, which will be described in this first chapter by providing an overview on its four macro-phases and on the “monitoring and control” one, in which KPIs are involved.

1.1 Project management definition

A project can be defined as a temporary endeavor undertaken by the company to achieve a specific target, that could be the production of a product or a service. It is essential to underline the fact that it’s temporary, so it means that has a beginning and a definite end, which will define the “time to market” and other related time-indicators. Project management instead is the managerial approach focused on the delivery of that project target, by defining deliverables (and milestones) and planning the activities to obtain them under constraints and by monitoring and controlling. This approach involves the balancing of three fundamental constraints such as time, cost, and quality. Each project is divided into phases, each of them made of several activities that are identified by their deliverables. These latter are defined as tangible results that must be achieved by a specific time to respect the “time to market” target established at the beginning. Project management discipline undercovers several knowledge areas such as:

- Integration management: processes required to ensure that coordination is ensured.
- Scope management: processes required to ensure that the project is completed successfully by using the right number of resources.
- Time, cost, and quality management.
- Human resource management: processes required to ensure that the all the people in the project are effectively involved.
- Communication management: processes required to ensure that all the important information regarding the project is correctly generated, collected, communicated, and stored.

- Risk management: processes required to ensure that risks are identified, analyzed and a set of corrective actions properly planned, implemented, and controlled.
- Procurement management: processes in which the acquisition of goods and services is properly planned and implemented.
- Issue and change management: processes that define the activities regarding the re-balancing of the project if an issue occurs and its consequences affect the project target.

1.2 Project management macro-phases

There are four macro-phases:

1. Identification and feasibility analysis
2. Planning
3. Programming and scheduling
4. Monitoring and control

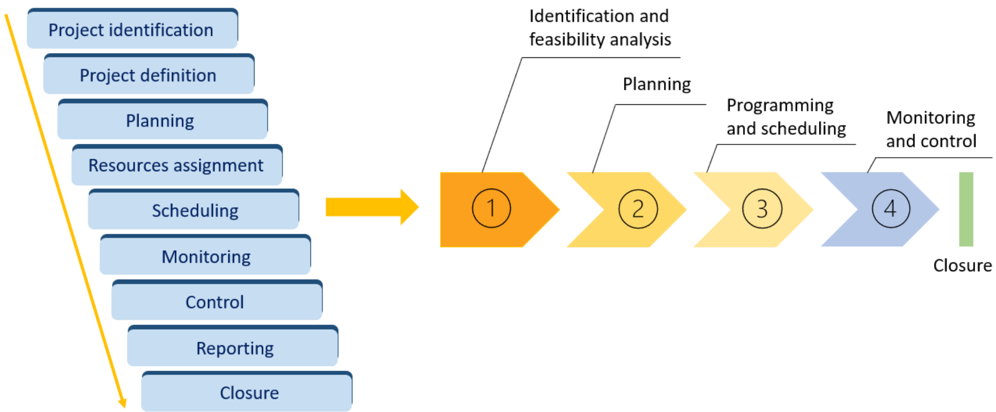

Figure 1: Project Management macro-phases

1) Identification and feasibility analysis

In this preliminary phase, the company needs to identify and clarify which are the best project objectives, underlying which are their technical contents but also analyzing their economic feasibility indicators such as for example the ROI (Return Of Investment), the Net Present Value (NPV) and many more. There are different aspects to be considered such as:

- Market analysis: which involves trends, market segmentation, potential production volumes.
- Product characteristics: main requirements and features, key differences respect to competitors, technical and technological requirements, risks, and availability.
- Preliminary planning of time, resources, and investments.
- Financial analysis of the overall initiative.

In this phase, the usage of the SWOT analysis (Strength Weaknesses Opportunities and Threats) and of economic and financial indicators is fundamental in order to decide to approve or not the project.

Figure 2: SWOT analysis.

2) Planning

At the end of the previous phase, there is the decision to start or not the project, and this will lead to the Planning macro-phase, in which project objectives are identified, activities are defined and required resources estimation is provided.

It is essential to have an appropriate planning phase in order to correctly schedule the project activities in a way that reflects the resources availability, but also to identify the specific responsibility and consequently define the work packages (WP).

Planning can be schematized in three main steps:

1. Identification of deliverables.
2. Identification of processes (activities) needed for each deliverable and evaluation of required quantities and resources.
3. Assignment of the responsibilities.

This type of schematization can be defined as deliverable-oriented approach, in which the Work Breakdown Structure (WBS) and Organization Breakdown Structure (OBS) logics are applied.

WBS is a method to subdivide the project into work elements that permits to highlight a clear structure of the project, to be shared and effectively communicated among the project team and shareholders. WBS can be defined as the Bill Of Material (BOM) of the project because it permits to have an analytical representation of the project divided by activities with an increasing level of detail. The definition of deliverables (1) and processes (2) is part of the WBS.

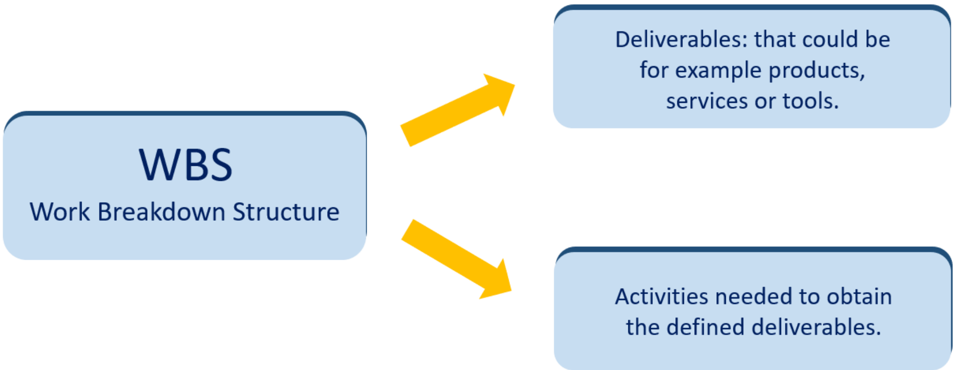

Figure 3: Work Breakdown Structure logic.

The maximum level of detail of this analytical decomposition of the project is the Work Package (WP), which describes cost, timing, constraints, and progress level and can be assigned to a specific function of the organization.

The OBS consequently, permits to identify roles and assign responsibilities (3) for each Work Package, also considering the organization hierarchies of the project in question.

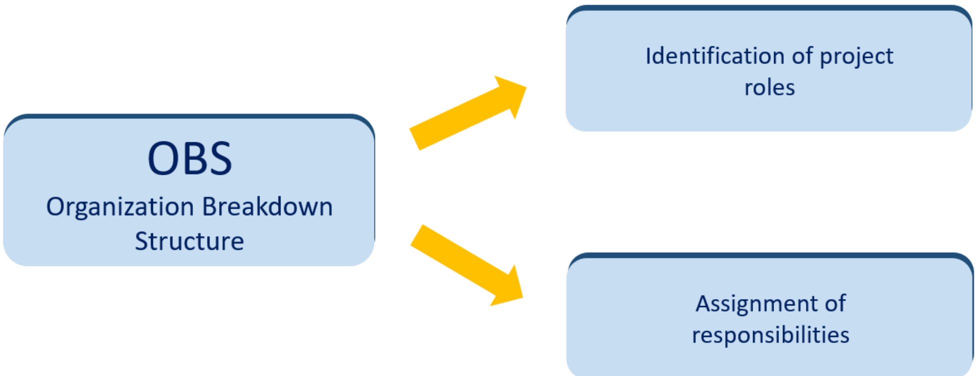

Figure 4: Organization Breakdown Structure logic.

Finally, the combination of the WBS and OBS logics permits to achieve a Tasks-Responsibilities matrix.

3) Programming and scheduling

In the third phase of the Project Management workflow, assignment of dates and constraints of all the activities defined in the WBS is performed. It enables the creation of the Project Plan, which is a master document that describes the temporal deployment of the project activities, based on constraints and resources availability.

To obtain that result, there are four main steps to follow at first:

1. Definition of the logical dependencies among the activities.

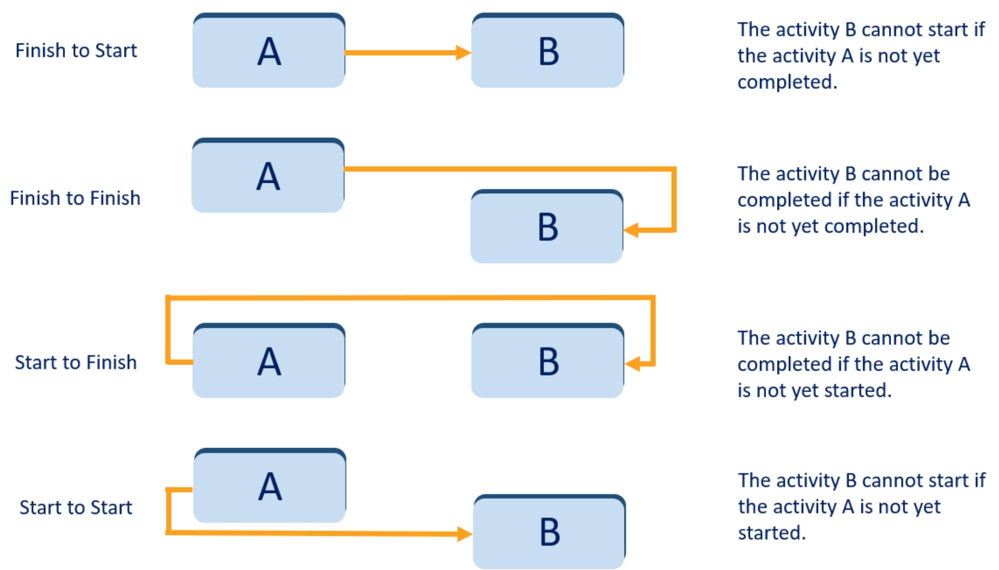

Figure 5: Activities logical dependencies.

2. Scheduling: assignment of start and finish expected dates considering the estimated duration, the sequencing and project milestones. The Project Calendar is then produced. In these preliminary phases, the hypothesis of infinite available resources is considered. Only later, specific levelling techniques for resources will be applied.

At this point, a Gantt chart is one of the tools used to have a visual representation of the overall activities, by representing each one as a bar with a length proportional to the duration of the activity itself. Milestones are also considered in this chart, and by definition they have null duration. The milestone coincides with a specific decision to be taken regarding the project itself.

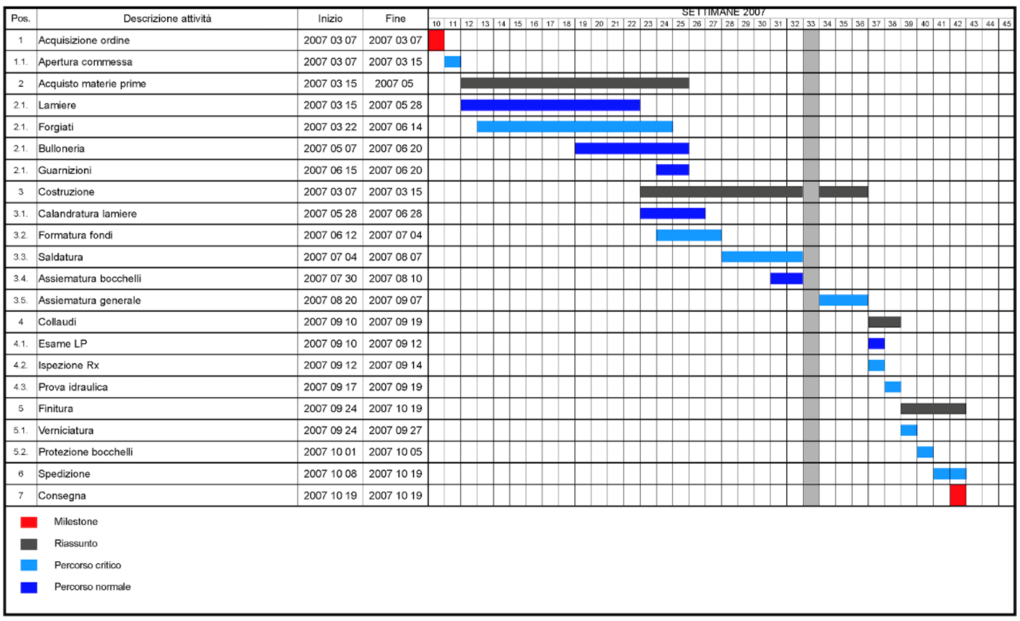

Figure 6: Example of GANTT chart.

3. Project network diagram: which is a graphical representation of all the activities displayed according to a specific method, that could be AON (Activity On Node) or AOA (Activity On Arrows).

   The major goal of the project network diagram phase is to identify the activities that really are constraining the total duration of the project, called critical path. The latter is defined as the activity whose completion cannot be postponed without affecting the total duration of the project.

   There are two different techniques to evaluate the activities duration: PERT (Project Evaluation and Review Technique - probabilistic method) and Critical Path Method (CPM – deterministic method).

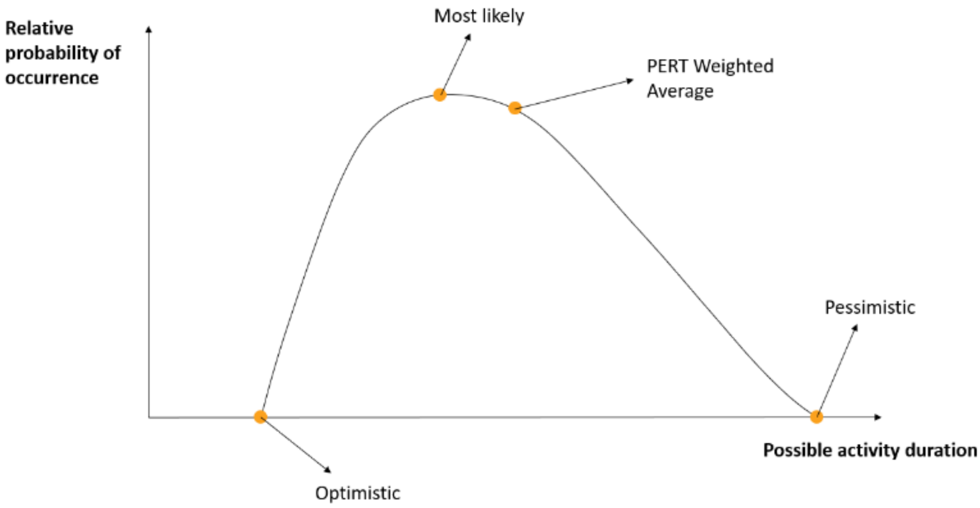

Figure 7: Example of PERT approach.

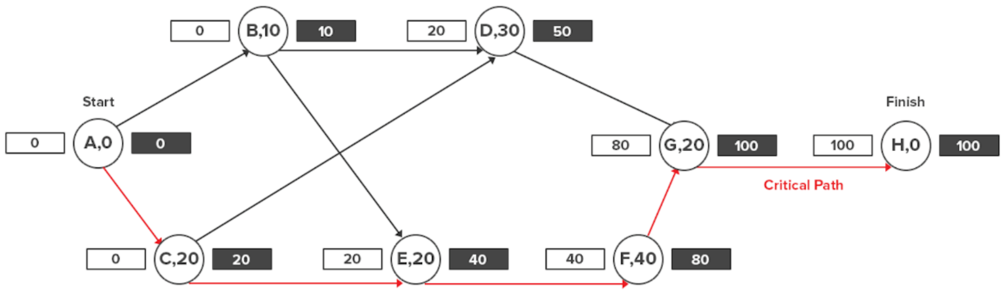

Figure 8: Example of CPM approach.

All the previous steps are under the hypothesis of infinite resources, as previously mentioned, and for this reason the next step requires to apply Resources Levelling techniques.

4. We need to consider the available resources and the required ones in order to understand which type of criticality could occur.

   There are two main types of criticalities:

   - Overload: which means that the required resources exceed the available ones.
   - Underload: which means that the available resources exceed the required ones.

   To counteract these two conditions, there are two levelling techniques:

1. Fixed duration scheduling: the total duration of the project cannot be changed and for this reason we need to increase the number of available resources.
2. Fixed resources scheduling: the total amount of resources cannot be increased and for this reason we need to postpone the project milestones and increase the TTM (Time To Market).

Project budgeting is a process that starts during the first macro-phase of the Project Management workflow, but in the programming and scheduling phase, it is analyzed and updated according to the result of the previously described steps, that lead to planned activities and estimated effort.

Project budgeting enables to create a document, following a bottom-up approach in which by computing the costs associated to each Work Package, it is possible to draw the cumulated curve of such costs that it is called the "S-curve".

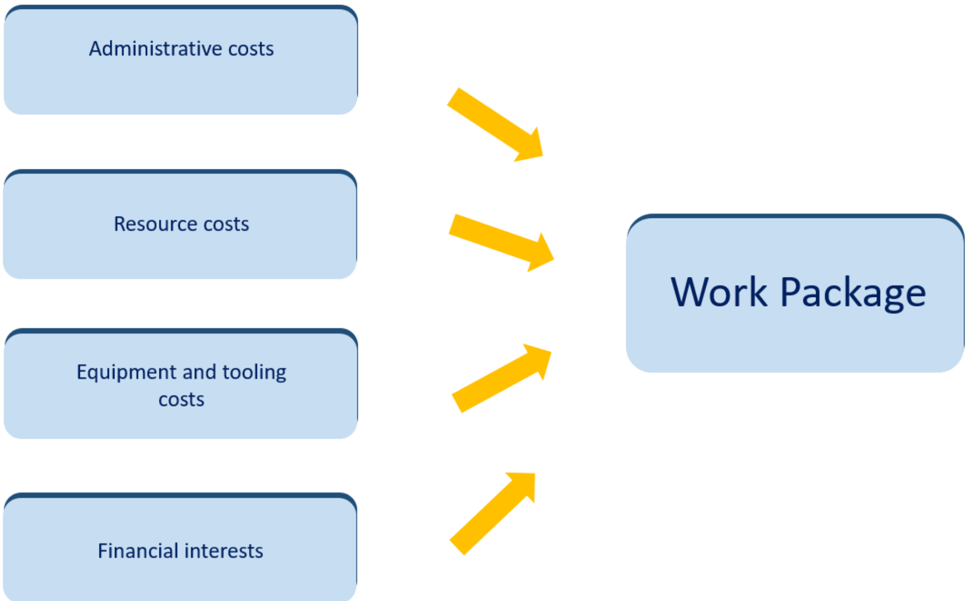

Figure 9: Costs associated to the Work Package.

The result is the total estimated cost of the project, called Budget At Completion (BAC).

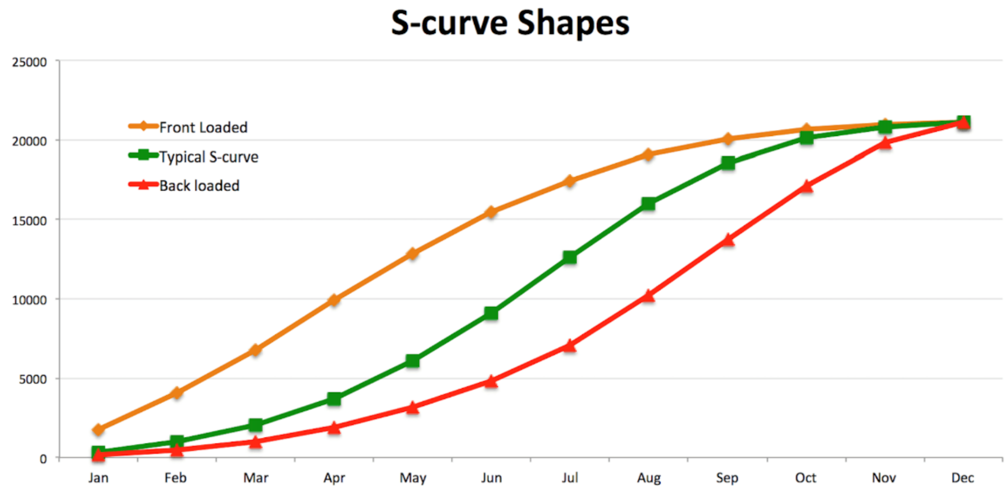

Figure 10: Example of S-curve.

4) Monitoring and control

The fourth phase is characterized by two main activities:

1. Monitoring: it enables the verification of the project activities progress and the identification and analysis of possible variations with respect to targets.

   It means collecting information and data to be compared with expected performance and identify issues to be solved. It is fundamental to establish the proper set of control criteria and goals, specifically which Key Performance Indicators (KPIs) should be used.

   The level of detail achieved by applying the Work Breakdown Structure must be coherent with the frequency of the monitoring and control activity, to avoid excess of details that are not useful.

   Identification of potential issues or gaps compared to the expected performance is essential, but the related consequences on the project must be properly defined in order to effectively plan recovery actions that will be implemented in the next phase.

2. Control: it requires the identification of the causes of the previously defined gaps or issues and the definition and implementation of recovery actions, with a proper update of the project plan targets.

Reporting, instead, happens beside the two previously described activities. It consists of storing all the data and information collected and effectively communicate them to all the involved parts of the company.

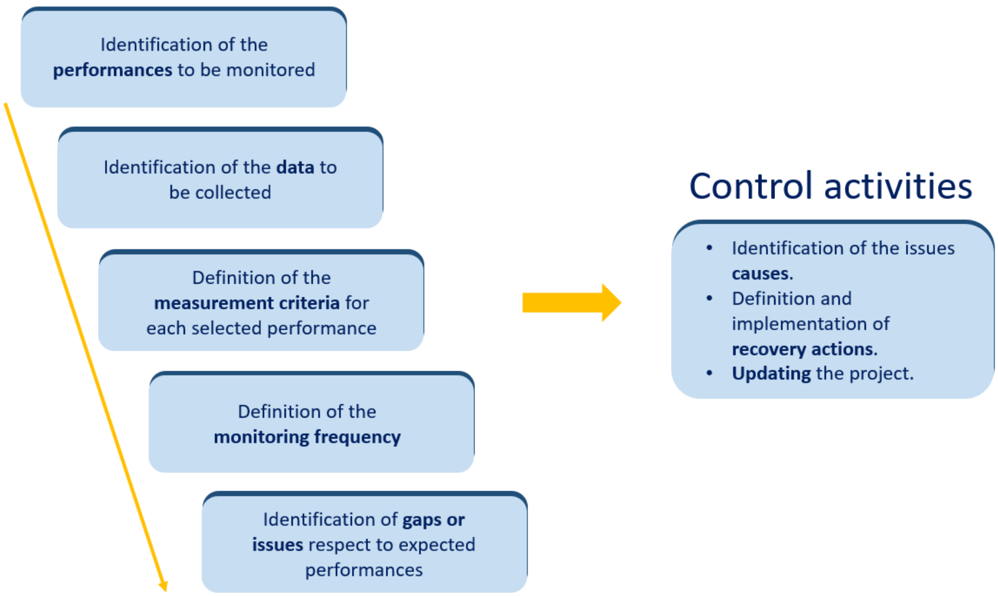

Figure 11: Monitoring and Control activities.

1.3 Key Performance Indicators (KPIs)

KPIs are fundamental because they permit to monitor the performance of the project (or the product development process) and in case of issues or gaps respect to the target, define proper corrective actions. These indicators are used throughout the entire process, and they can be suited to measure a specific phase or to monitor the overall performance.

The type of KPI chosen could be different whether it is needed to monitor a project or a product. For example, in case of a project, indicators such as sustained costs, time resource usage or completed milestones percentage could be appropriate. Instead for a product, we could refer to all the technical and economic indicators useful for the product development process.

Frequency is another key aspect, and it consequently influence the effort of the monitoring activity itself.

KPIs - Criteria examples

For performance and progress measurements, possible indicators are:

- Percentage of completed output units: the progress status is monitored by considering the ratio between the actual completed output units and the total number of units planned.
- Intermediate milestones: the progress status is monitored by the cumulated value achieved considering the intermediate milestones and their respective weights (influence on the project).
- Resource usage: this indicator is defined by the ratio between the actual spent resources and the planned ones. Resources could be referred to economic ones, hours of work and others.

For each KPI, there must be a detailed activity of reporting and communication. There is several essential information about the KPI itself that must be clear before its implementation, such as:

- Analytical description and objectives.
- PDP (Product Development Process) phase of application.
- Measurement frequency.
- Owner and data source.
- Historical data.
- Benchmarking if available.

KPI should be structured to be easily managed and comprehended, to permit not only an effective communication to all the parts involved, but also because they are a first tool of root-cause screening. In fact, in case of negative performance result, provided by the KPI itself, it is then necessary to use specific tools such as the Ishikawa diagram or the 5 WHYs approach in order to understand the root causes, based on the preliminary information about the issue, provided by the KPI.

However, the complexity of the KPI itself is discussed at the beginning, to understand the effort required, in terms of data acquisition, to keep it updated and the typology of information required by the company.

Traffic lights colors can be used to highlight the result in an effective way for communication activities. At each specific review, the results will be analyzed and in case of gaps respect to the planned targets, corrective actions are defined.

Chapter 2

2. Quality international standards in the automotive sector

Quality requires standards procedures and methods that companies can use to properly structure their industrial processes. ISO 9001:2015 and IATF 16949:2016 represent two typologies of international standards that allow companies to elevate their business, by improving different areas of their industrial processes, guided by specific requirements. The chapter gives a brief overview on these two important standards and the benefits of their implementation:

2.1 ISO 9001 overview

Obtaining the ISO 9001 certification means implementing measures that benefits the company on multiple levels, consequently creating or increasing its competitive advantage respect to competitors because it shows that a business takes care and focus on improving its product and services. It can be used by any organization, independently by its size and field of activity.

Measures that benefit the company business includes:

- Processes that help to be better prepared in situations with product defects in the production process, by following specific procedures.
- Methods to effectively track customer satisfaction and responding to any issues raised.
- Procedures that enhance employee satisfaction and job security, by implementing well-defined and clearly managed processes.
- Reductions of cost overall, and lower insurance premiums since insurers recognize that appropriate processes and controls have been implemented in order to reduce and control risks.
- Methods that enhance appropriate continuous improvement activities, providing a solid foundation to the quality backbone structure of the company.

2.2 IATF overview

IATF (International Automotive Task Force) is a group of automotive manufactures, also considering their respective National Automotive Industry Associations, the aim of which is to provide improved quality products to automotive customers worldwide.

Specifically, IATF was established to develop a consensus regarding international fundamental quality system requirements, but also considering the participating companies' direct suppliers and other correlated parties in the automotive industry.

IATF provides policies and procedures for the common IATF third party registration scheme to ensure consistency worldwide, but also proper training to support IATF 16949 requirements and the IATF registration scheme. To establish formal liaisons with proper bodies to support IATF objectives, is another aim of the IATF.

2.2.1 IATF 16949:2016

IATF 16949:2016 is a standard, specific for the automotive industry as previously described, that provides requirements on the Quality Management System (QMS) in order to enhance continuous improvement activities, prevention of defects and industrial processes waste reduction.

ISO/TS 16949 (first edition) was originally created in 1999 by the IATF, with the aim of harmonizing different assessments and certification systems worldwide in the supply chain for the automotive sector. Then, two revisions were made in 2002 and 2009, and in 2016 the ISO/TS

16949:2009 has been replaced by IATF 16949:2016, maintaining a strong cooperation with ISO, assuring a consistent alignment with the ISO 9001:2015.

IATF 16949:2016 is in fact a supplement to the ISO 9001:2015 (international standard previously described, that specifies requirements for a company QMS) and it is meant to be used in conjunction with the ISO 9001:2015 itself.

The IATF 16949 is applicable to whatever company that produces components, assemblies, sub-assemblies, and parts for the automotive industry, and it includes 16 areas of automotive-focused QMS requirements to provide value-adding concepts and methods to improve the industrial processes at multiple levels:

1. **Product Safety:** it is essential to provide a coherent and strong set of regulatory and industry-driven safety requirements.
2. **Risk Analysis:** availability of specific tools for several purposes such as analyzing, planning, minimization, and risks prevention.
3. **Customer Specific Requirements (CSR):** inclusion of customer specific requirements in order to enhance customer satisfaction.
4. **Competence:** skills needed to produce products that meet customer requirements.
5. **Plant, Facility and Equipment Planning:** methods for facilities and equipment planning.
6. **Measurement Traceability:** it includes specific automotive requirements for optimizing measurement equipment, its usage and calibration.

7. **Organization Manufacturing Feasibility:** due to the complexity and high volumes of the automotive sector, specific approaches are needed to ensure manufacturing capabilities beyond those of generic process validation.
8. **Design and Development:** requirements to define common elements that automotive manufacturing companies must complete.
9. **Control of Documented Information:** specific documentation required for instructions and others, that generic standards cannot include.
10. **Supplier Management:** specific processes required in order to ensure quality and delivery throughout the supply chain.
11. **Product Approval:** approval processes for all automotive products.
12. **Production Control:** mandated methods and enhanced controls on the manufacturing processes.
13. **Corrective Action:** methods to implement permanent corrective actions with a structured approach on problem solving and preventive recurrence.
14. **Monitoring, Measurement, Analysis and Evaluation:** methods to ensure that the product meets the planned specifications.
15. **Internal Audit and Management Review:** approaches needed to ensure that the complex automotive requirements are met.
16. **Continual Improvement:** enhance and provide strong focus on continuous improvement activities at every level, throughout the QMS of the company.

IATF 16949:2016 plays a key role in the automotive manufacturing companies environment, allowing the implementation of specific work perimeters that permits to ensure that these requirements are respected, effectively tracking quality implementation performance results, and by providing improvement proposals based on a proper data-driven logic.

Chapter 3

3. Main work perimeter

Automotive companies, as a result of the IATF implementation, properly define and structure their industrial processes, coherently with the international standards guaranteed by the IATF 16949.

The chapter describes the main professional perimeter in question, defined as Services (S), which is linked to the management of the engineering technical information. This perimeter is part of the organizational structure of the simulated Capgemini client in question.

For the purpose of this paper, the simulated client, is an engineering and manufacturing company that operates also in the automotive sector.

3.1 Services (S) work perimeter

The Service department requires three main activities:

1. **Process formalization:** to define and properly structure procedures for the industrial processes.
2. **Process diffusion:** to provide effective training activities to spread and consolidate work methods.
3. **Process monitoring:** to provide Monitoring and Control activities by using proper Key Performance Indicators.

These three previously described macro-activities are structured accordingly to the principles and requirements of the IATF 16949.

It is fundamental to underline the fact that it’s a Co-Design process between Capgemini and the simulated client, since the latter must participate actively in all the activities in order to properly achieve the desired results:

- Process formalization requires clear roles definition and a direct involvement in the drafting of the procedures.
- Process diffusion requires active participation to the training activities.
- Process monitoring requires precise knowledge from the client in order to properly define the KPIs and avoid situations in which those indicators do not reflect concretely the industrial processes in question.

Procedure creation and activities sharing with all the involved client functions, permit the reduction of future claims and increase the knowledge of the client own processes, enhancing quality perception both from internal and external point of view.

To properly reflect the needs and requirements of the client, the Service department is organized in four main sub-departments and consequent procedures:

1. Service 1
2. Service 2
3. Service 3
4. Service 4

Key Performance Indicators are fundamental in order to monitor the performance of these sub-departments and to set proper corrective actions that can reflect the process targets, if issues occur.

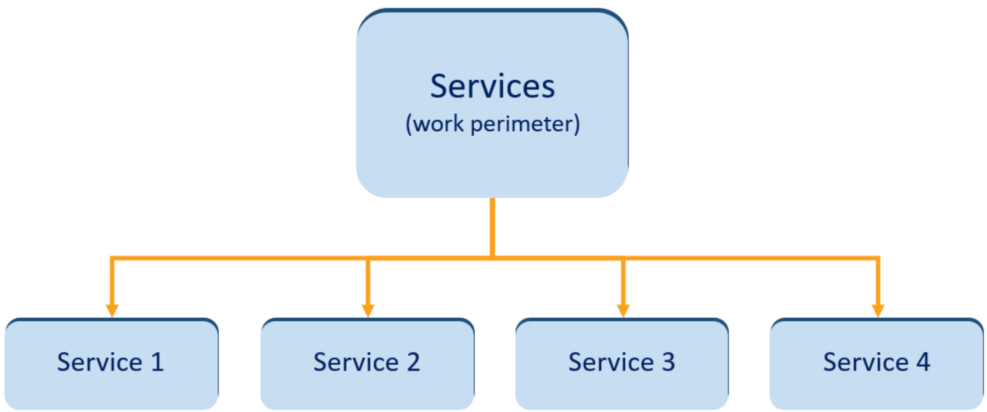

Figure 12: Services (S) - structure.

Service 1 - procedure

The aim of this procedure is to define the workflow that allow to release specific technical documents that contain product engineering information.

Service 2 - procedure

The aim of this one instead, is to define the workflow that leads to the developing of services based on customer vehicles remote data. This is fundamental, because by extracting value from raw vehicle data, it is possible to anticipate failures, reduce vehicle stop, reduce warranty cost, and limit troubleshooting operations.

Service 3 - procedure

This procedure aim is to define the workflow to produce a guided procedure that leads to the identification of the root cause of a vehicle problem, and to provide proper repairing instructions. The reduction of component replacement by identifying only when it’s necessary and consequent increased vehicle uptime, are key benefits related to the process in question.

Service 4 - procedure

Finally, the aim of this procedure is to define the workflow to develop a remanufactured product, which is a used product that through a remanufacturing process goes back to as-new condition. This process can allow the extension of the product life and reduction of costs, both for the customer and the producer.

Chapter 4

4. Services work perimeter - KPIs

Key Performance Indicators, as previously described, are part of the monitoring and control phase of project management workflow, and they allow to monitor the process performance in analysis, highlighting issues or gaps respect to the target and enabling the definition of proper corrective actions. These indicators are used throughout the entire process, and they can be suited to measure a specific phase or to monitor the overall performance.

This chapter highlights the relevance of KPIs implementation in the analysis of the processes related to the four Services sub-departments and related procedures previously described.

4.1 Service 1 - KPIs

To monitor and control this procedure workflow, two main Key Performance Indicators are used: Service1-A and Service1-B (called S1A and S1B for simplicity).

S1-A (Year 1)

- **Code:** S1-A.
- **Formula:**

$$S1A\ (\%) = \frac{Amount\ of\ documentation\ released}{Amount\ of\ documentation\ planned}$$

- **Explanation:** it helps to track the release of documents along the year, with a monthly frequency of data collection. The actual release of documentation is compared to the ones that are still to be released, considering both new and old ones. It could be possible that the numerator is higher than the denominator, in case the release of documentation is anticipated.
- **Monitoring frequency:** Monthly.
- **Feature:** Punctual.

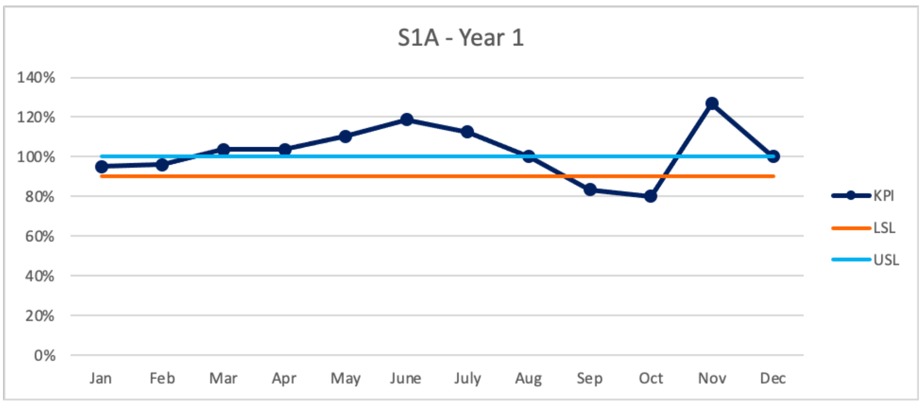

Figure 13: S1A - Year 1.

As shown in the chart above, there are two main Specification Limits, which are limits that are defined according to internal benchmarking or other client requirements:

- Upper Specification Limit (USL) = 100% → higher → over-achieved.
- Lower Specification Limit (LSL) = 90% → lower → to be improved.
- In between → achieved.

The overachievement shown by the indicator in question, from March to July, means that multiple documentation releases have been anticipated. This could be justified or by the fact that the workforce in question can deal with a higher demand independently by the demand complexity (which would highlight an underload situation) or that the demand complexity itself allowed this overachievement.

The decreasing trend from June to August could be physiological, but the underachievement in September and October instead, requires a why-analysis and could be explained for example by a change in the team workforce, with an improvement in November due to team capabilities adjustments.

During the second year, the LSL has been increased to 95% in order to test the team capabilities.

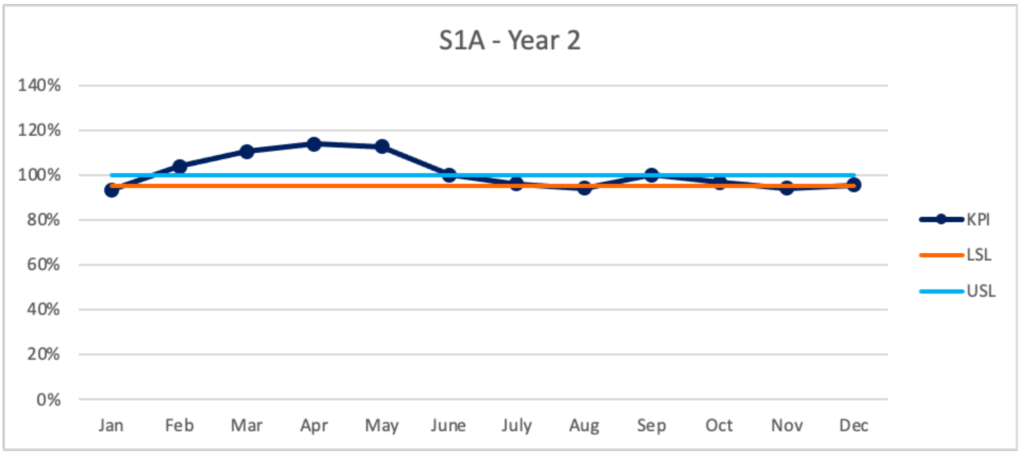

Figure 14: S1A - Year 2.

The over-achievement present from February to May, lead to an assessment that resulted in an underload condition, which means that the available resources were higher than the required ones, leading then to a stable performance from June to December due to team workforce adjustments.

S1B – Year 1 vs Year 2

Key Performance Indicators are constantly reviewed (to reflect specific needs and conditions), and for this reason they could be discarded or modified if the information that are meant to communicate is no more useful. This is precisely the case of the S1B (Year 1), that changed its structure from the first to the second year of application:

S1B – Year 1

$$S1B\ (\%) = \frac{Amount\ of\ claims\ solved}{Amount\ of\ claims\ to\ be\ solved}$$

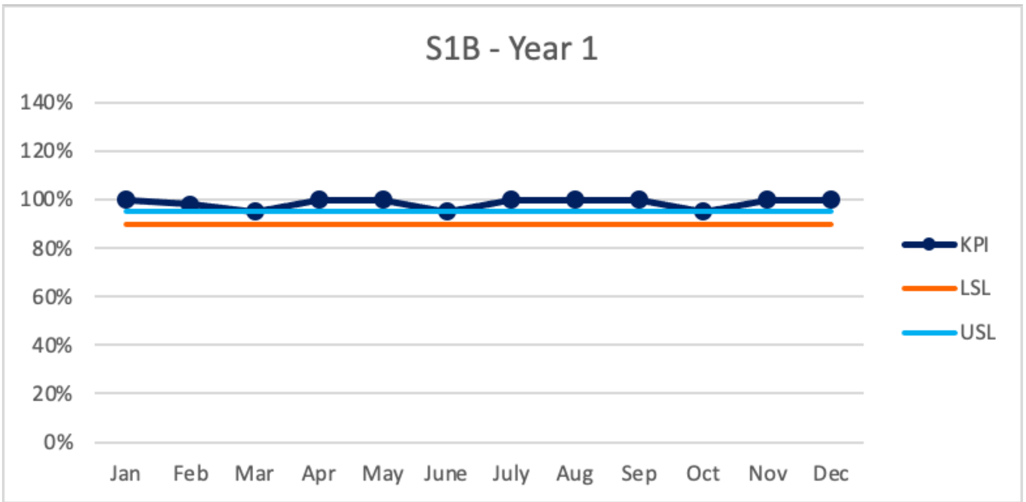

Figure 15: S1B - Year 1.

As the chart above shows, due to the constant overachievement results throughout the first year, this KPI has been modified in the second year, in order to communicate a different and adding-value information:

S1B (Punctual) – Year 2

$$S1B = \frac{Sum\ of\ working\ days\ used\ for\ each\ claim}{Number\ of\ claims\ solved}$$

Explanation: this KPI monitors the average claim response time.

Monitoring frequency: monthly.

In this specific KPI, the common position of the Specification Limits has been changed. The USL is now lower respect to the LSL, since the indicator monitors a parameter that the lower the better.

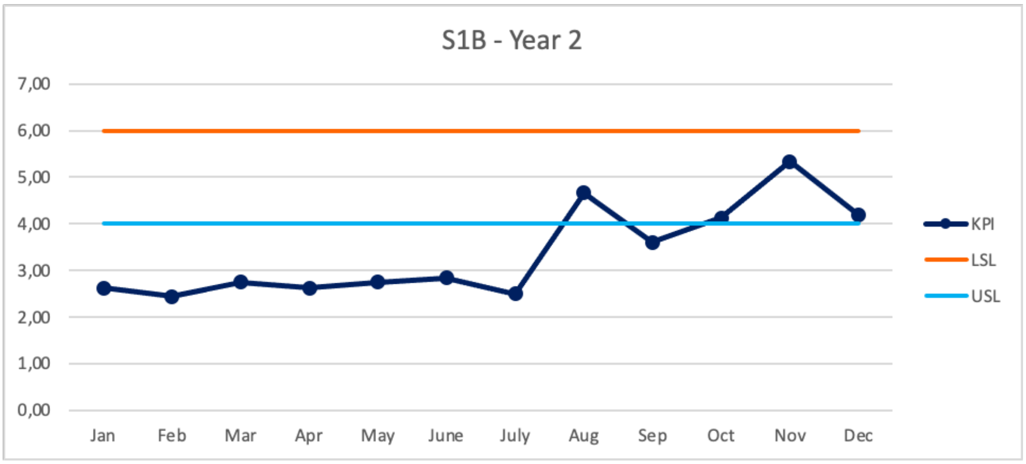

Figure 16: S1B - Year 2.

As shown in the chart above:

- LSL = 6 days needed to solve a claim on average → higher → to be improved.
- USL = 4 days needed to solve a claim on average → lower → over-achieved.
- In between = achieved.

The previously used language relation such as Lower Specification Limit with under-achievement condition and Upper Specification Limit with over-achievement has been maintained, even if the actual numeric position is now different.

4.2 Service 2 - KPIs

The aim of this procedure, as previously described, is to define the workflow that leads to the developing of services based on customer vehicles remote data.

To monitor and control this procedure workflow, three main Key Performance Indicators have been used: Service2-A, Service2-B, Service2-C, Service2-D (called S2A, S2B, S2C).

S2A

- **Code:** S2A.
- **Formula:**

$$S2A\ (\%) = \frac{Amount\ of\ milestones\ achieved\ on\ time}{Amount\ of\ milestones\ planned}$$

- **Explanation:** it helps to track the performance regarding the number of milestones reached on time respect to the planned ones.
- **Monitoring frequency:** Monthly.
- **Feature:** Punctual.

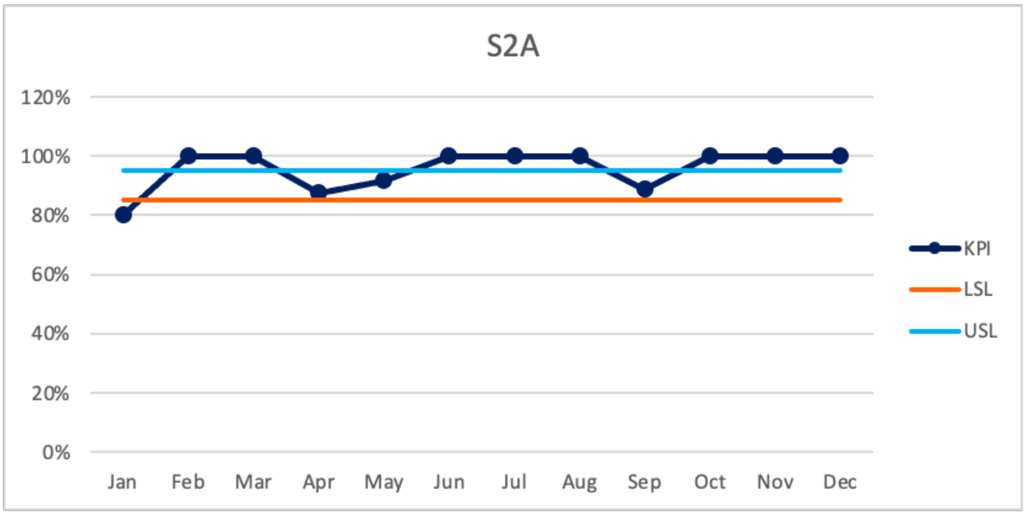

Figure 17: S2A data.

As shown in the chart above, in January, April, May and September there has been 1 milestone for each month not achieved on time. Still, the overall performance has been positive.

Two Specification Limits have been used:

- USL = 95% → higher → overachieved.
- LSL = 85% → lower → to be improved.
- In between = achieved.

S2B

- **Code:** S2B.
- **Formula:**

$$S2B\ (\%) = \left(2 - \frac{Sum\ of\ milestones\ delay\ weeks}{Amount\ of\ milestones\ in\ delay}\right) * 5 + 90$$

- **Explanation:** it helps to track the milestone average weeks delay, by setting a linear correlation between the value of average weeks delay per milestone and a performance percentage. Because of this structure, the higher the better.
- **Monitoring frequency:** Monthly.
- **Feature:** Cumulative.

Clearly there is a correlation between S2A and S2B, since the milestones not achieved on time are present in the denominator of S2B, counting the amount of delay weeks in question, in a cumulative way.

The Specification Limits in this case are referred to specific amount of weeks delay, and referred to the linear correlation previously mentioned:

- Between 0 and 2 weeks of average delay → overachieved (blue).
- Between 3 and 4 weeks of average delay → achieved (green).
- Between 5 and 20 weeks of average delay → to be improved (red).

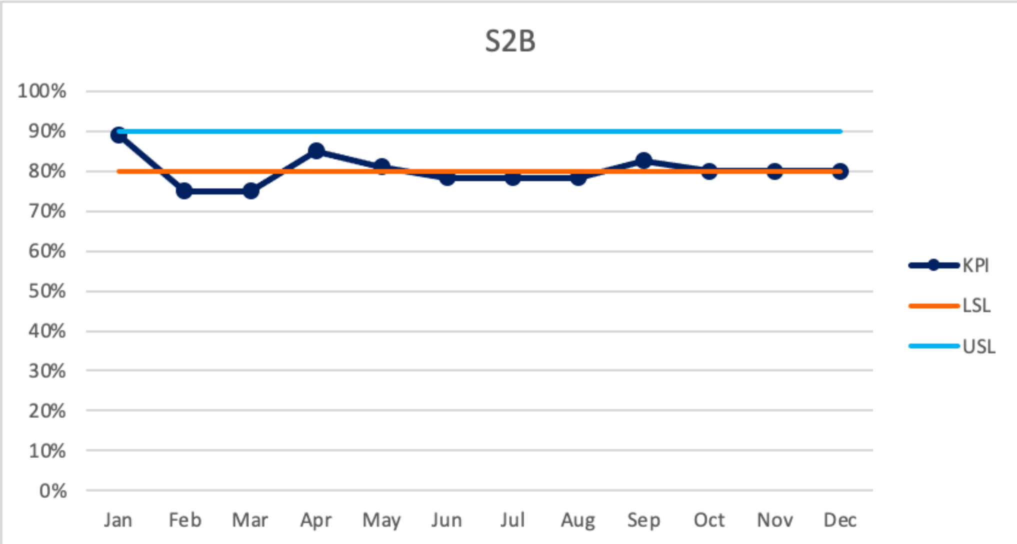

Figure 18: S2B chart.

Due to its cumulative nature, this Key Performance Indicator allows to monitor, at the end of the year, the overall weeks delay performance.

Peaks related to April and September are justified by the fact that due to its cumulative structure, when a milestone in delay is added, the denominator will increase and the ratio result could decrease, leading to a momentarily improvement. When the delay related to the new inserted milestone in delay increases, S2B starts to decrease again.

S2C

- **Code:** S2C.
- **Formula:**

$$S2C\ (\%) = \frac{Amount\ of\ issues\ solved}{Amount\ of\ issues\ to\ be\ solved}$$

- **Explanation:** it helps to track the performance regarding the number of issues resolution performance.
- **Monitoring frequency:** Monthly.
- **Feature:** Cumulative.

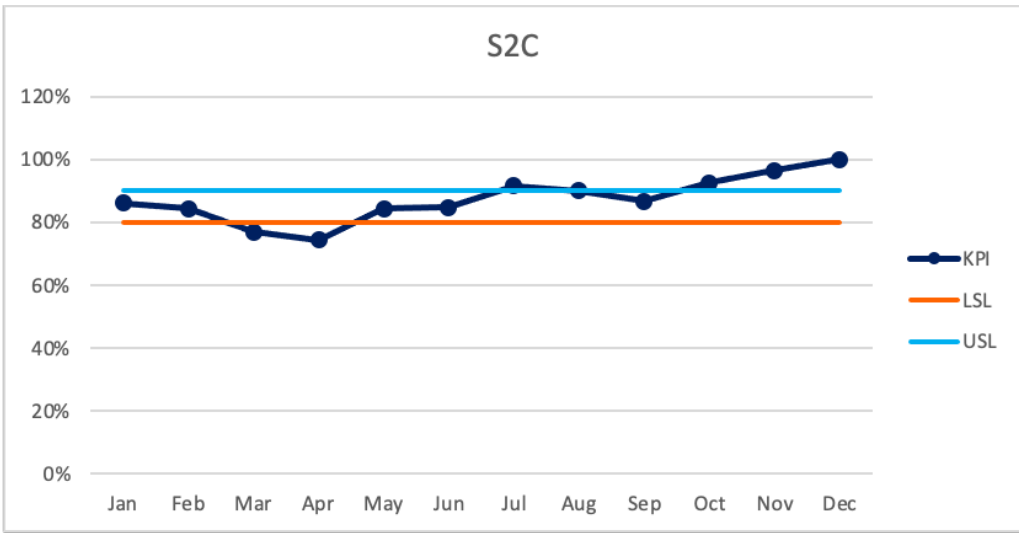

Figure 19: S2C chart.

As shown in the chart above, two Specification Limits have been used:

- USL = higher than 90% → overachieved.
- LSL = lower than 80% → to be improved.
- In between = achieved.

4.3 Service 3 – KPIs

The aim of this procedure, as previously described, is to define the workflow in order to produce a guided procedure to identify the root cause of the problem and to provide proper repairing instructions.

Part of this workflow is characterized by the interaction between the Product Engineering department of the simulated client in question (that produces the guided procedure) and the receiver client which must validate the procedure itself.

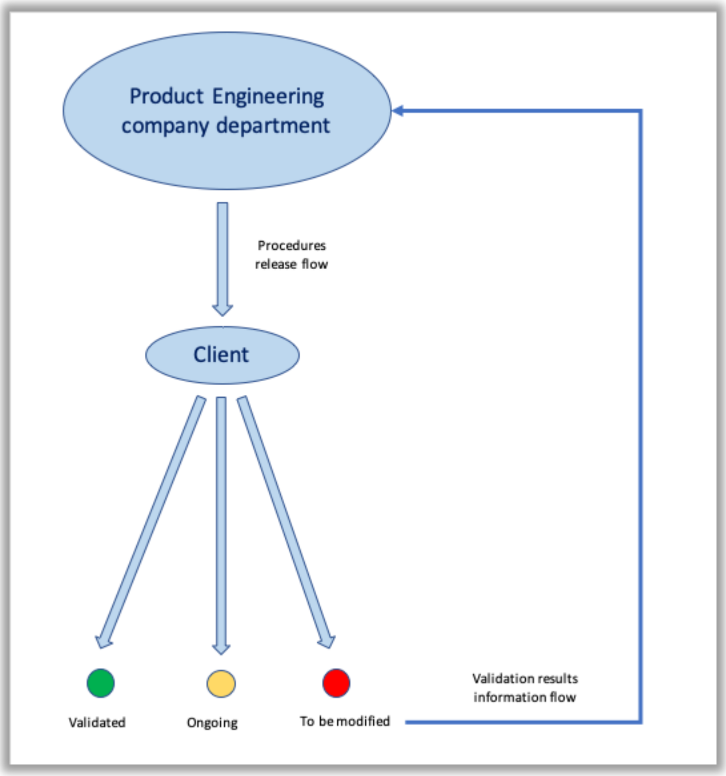

Figure 20: Part of the Service 3 workflow.

An exchange of information between the PE and the receiver client allows to understand the status of the validation process:

- If the validation process is successful → (procedure) validated.
- If the validation process is ongoing → ongoing.
- If the validation process shows that the procedure does not meet the requirements → to be modified (by the PE department).

To effectively monitor this part of the Service 3 workflow, four main Key Performance Indicators have been used.

Specifically:

- S3A monitors the PE procedures release performance.
- S3B monitors the validation status.
- S3C monitors the claim management performance.
- S3D the PE reworks performance.

S3A

- **Code:** S3A.
- **Formula:**

$$S3A\ (\%) = \frac{Procedures\ released}{Procedures\ planned\ to\ be\ released}$$

- **Explanation:** it helps to track the performance regarding the number of procedures released respect to the planned ones.
- **Monitoring frequency:** Monthly.
- **Feature:** Punctual.

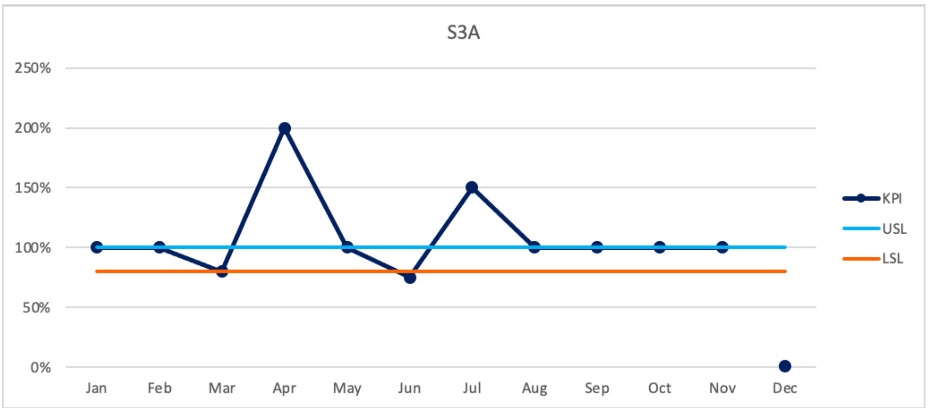

Figure 21: S3A chart.

As the chart above shows, the performance of the Product Engineering department has been positive throughout the year. The structure of S3A allows to understand when:

- Delayed releases have been released.
- Procedures releases have been anticipated.

In fact, the overachievement peaks in April and July are justified by the release of procedures that have been delayed respect to the previous month, in both cases, while in December there were no planned releases.

S3B

- **Code:** S3B.
- **Formula:**

$$S3B\ (\%) = \frac{Validated\ procedures}{Received\ procedures\ for\ validation}$$

- **Explanation:** it helps to track the performance regarding the number of procedures that have been successfully validated respect to the ones received.
- **Monitoring frequency:** Monthly.

- **Feature:** Cumulative.

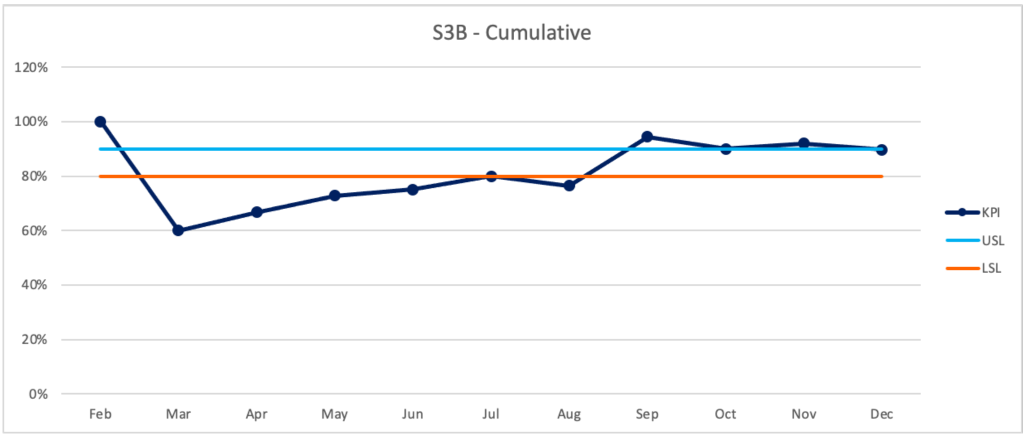

Figure 22: S3B cumulative - chart.

The cumulative performance allows to understand at the end of the year, the overall situation and in this case, almost 90% of procedures released have been validated. Regarding the "to be improved" performance in the first months of the year, by analyzing the status of the validation process from the information flow, there was a relevant quantity of procedures with ongoing validation status.

Cumulative Key Performance Indicators tend to dampen negative performance in the long term (if specific conditions are present), but they allow to highlight the overall process performance.

S3C

- **Code:** S3C.
- **Formula:**

$$S3C\ (\%) = 1 - \frac{Amount\ of\ claims\ that\ actually\ lead\ to\ a\ rework}{Amount\ of\ received\ claims}$$

- **Explanation:** it helps to track the performance of claims management department, tracking the total amount (%) of claims that did not need a rework. For this reason, S3C tracks a positive performance, since high percentage values mean that among all the claims received, only few lead to a rework.
- **Monitoring frequency:** Monthly.
- **Feature:** Cumulative.

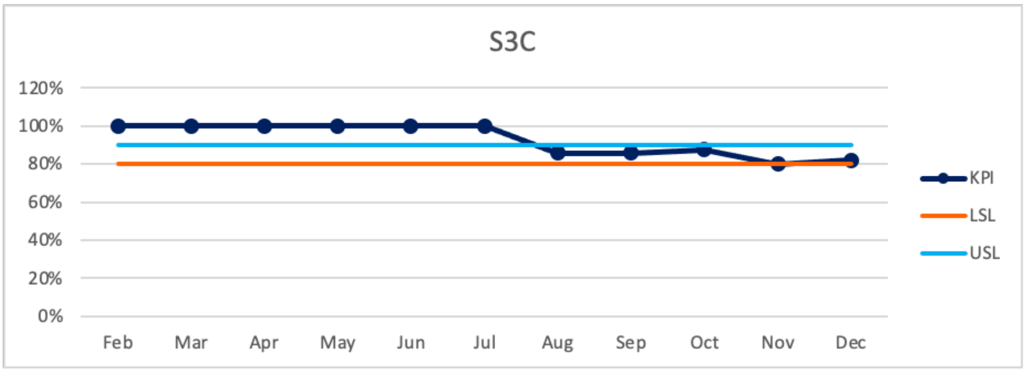

Figure 23: S3C chart.

S3D

- **Code:** S3D.
- **Formula:**

$$S3D\ (\%) = 1 - \frac{Total\ amount\ of\ reworks}{Total\ amount\ of\ received\ procedures}$$

- **Explanation:** as the previous KPI, S3D tracks the PE performance, because it monitors the total amount of procedures that did not need a rework compared to the ones received by the receiver client. High percentage values mean that only few procedures needed a rework.
- **Monitoring frequency:** Monthly.
- **Feature:** Cumulative.

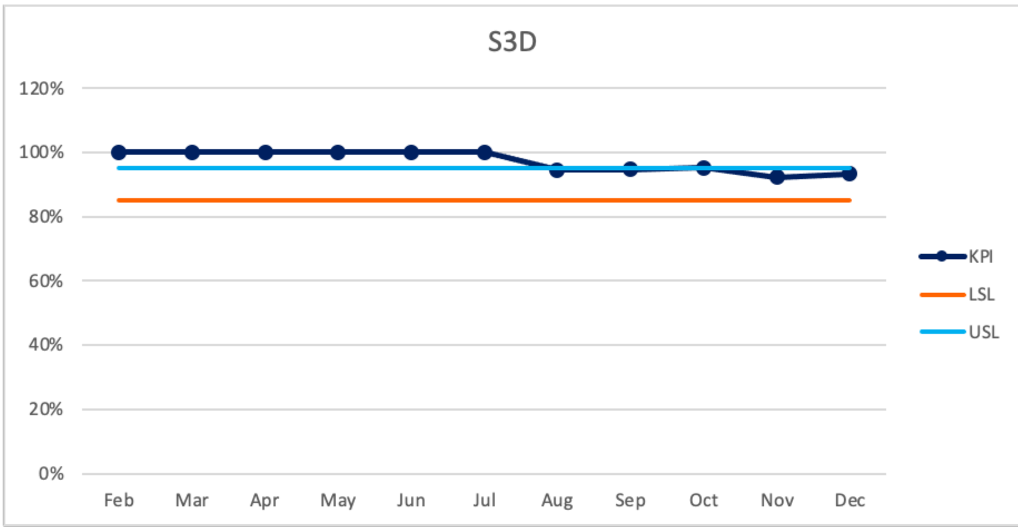

Figure 24: S3D chart - PE performance.

The structure of this KPI is cumulative, which means that highlights the overall performance and not the punctual one. However, as the chart shows, the overall performance has been steadily positive, since only few procedures needed to be modified.

4.4 Service 4 – KPIs

The aim of this procedure, as previously described, is to define the workflow to develop a remanufactured product, which is a used one that through a remanufacturing process goes back to as-new condition.

To monitor and control this procedure workflow, two main Key Performance Indicators have been used: S4A and S4B.

S4A

- **Code:** S4A.
- **Formula:**

$$S4A\ (\%) = \frac{Total\ amount\ of\ managed\ requests}{Total\ amount\ of\ requests\ to\ be\ managed}$$

- **Explanation:** this KPI allows the monitoring and control of the requests management performance, by considering at the denominator not only the ones that are planned for that specific month but also the old ones still to be managed.
- **Monitoring frequency:** Monthly.
- **Feature:** Punctual.

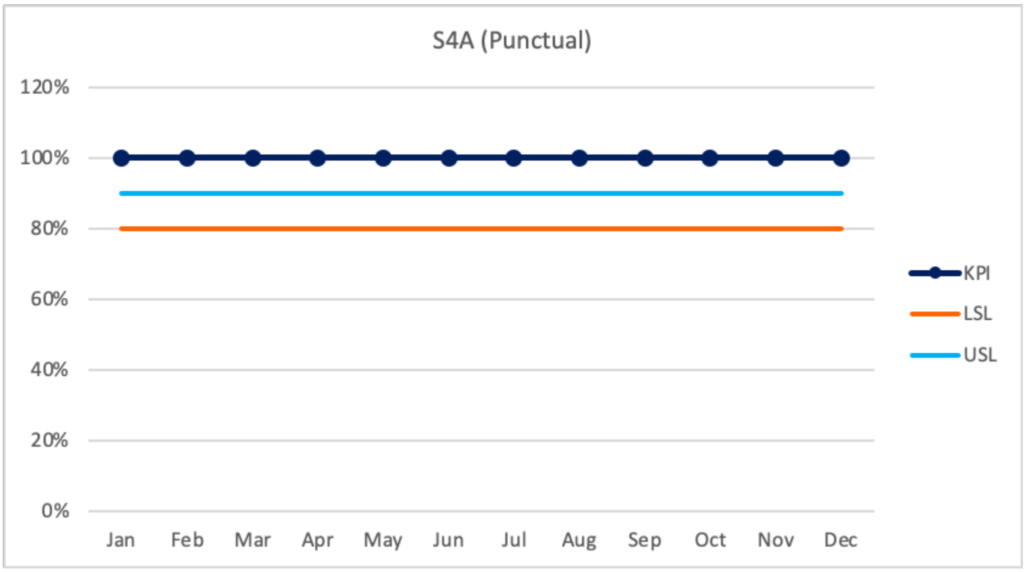

Figure 25: S4A chart.

Two Specification Limits have been used:

- USL = higher than 90% → overachieved.
- LCL = lower than 80% → to be improved.
- In between = achieved.

As the chart above shows, the performance has been steadily positive throughout the year.

S4B

- **Code:** S4B.
- **Formula:**

$$S4B\ (\%) = \frac{Sum\ of\ working\ days\ for\ each\ request}{Total\ amount\ of\ received\ requests}$$

- **Explanation:** this KPI allows the monitoring and control of the average response time performance, by setting a linear correlation between the S4B numeric result and performance percentages. The higher the better, because of this linear correlation.
- **Monitoring frequency:** Monthly.
- **Feature:** Punctual.

As in the previous examples, due to a % convertor and since the average working days have always been under 7 days, the result of this KPI has been constantly overachieved.

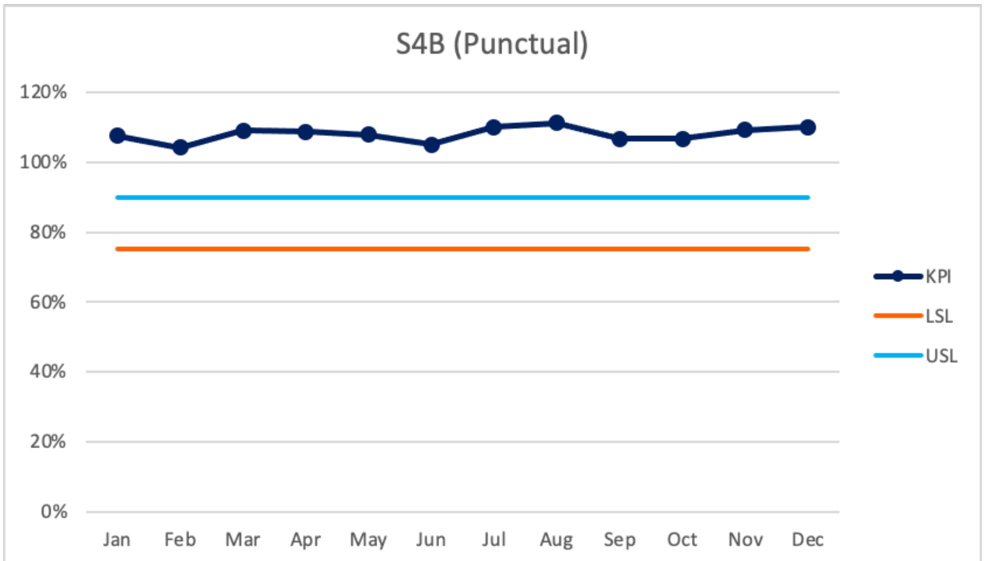

Figure 26: S4B chart.

As described, two Specification Limits have been used:

- USL = 90% (equal to 7 average working days) → lower amount of average working days → overachieved.
- LCL = 75% (equal to 10 average working days) → higher amount of average working days → to be improved.
- In between = achieved.

As shown in the chart, the performance has been positively steady throughout the year.

Chapter 5

5. Control Charts implementation proposal

Control Charts were invented by Walter Shewhart in 1920 and they are defined as statistical tool that can monitor the stability of a process, by setting Control Limits that represent the thresholds that contain the predictable range of the process variability.

These charts are traditionally used in manufacturing production lines, as a punctual and real-time monitoring and analysis tool. In fact, they can be used not only for real-time process monitoring, but also for historical analysis.

The goal of this chapter is to present an implementation proposal of Control Charts on the previously described KPIs monitoring method, in order to acquire potential advantages that could be useful to promote why-analysis or define proper corrective actions if needed.

5.1 Control Charts definition

Control Charts, as previously described, are an effective tool, and through a graph, they show how the process changes over time.

There are different types of Control Charts, but in general the parameter to be monitored is reported on the Y-axis, while the X-axis is characterized by the time intervals or the progressive element/sample number with a sequential order.

A Control Chart is composed of three main elements, computed through historical data, defined as:

- Control Limits.
- Central Line (average).
- Parameter to be monitored.

Control Limits in particular, allow to graphically highlight the predictable variability range of the process in question and consequently to point out when the variable has overcome these thresholds. Generally, they are symmetric respect to the Central Line and called: Upper Control Limit (UCL) and Lower Control Limit (LCL).

If computed as shown in the formulas below, the interval between these two limits can contain up to 99,73% of the events regarding the population (statistics definition), but only if the process in question is in statistical control.

$$UCL = \bar{X} + 3 * \sigma$$

$$LCL = \bar{X} - 3 * \sigma$$

The image below shows an example of Control Chart.

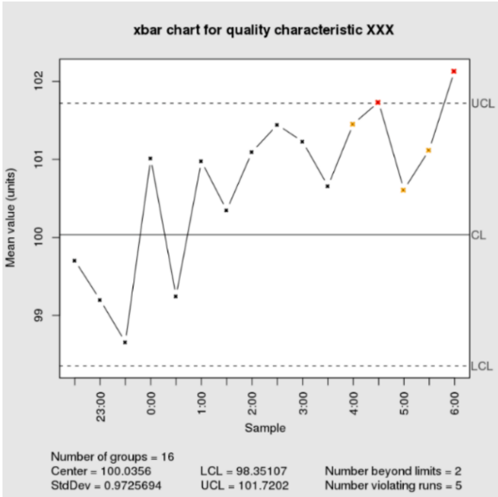

Figure 27: Example of Control Chart.

Control Charts generally highlight two sources of variation:

- Common causes variation: this type of variation is inherent in the process itself because it refers to all the causes which effects are of small-scale type and which management is difficult at singular level. Each singular cause contributes to the overall process variability. If the process is characterized by only common causes, it is defined as stable.
  In this case, it would be optimal to reduce the overall variability of the process, by studying all the data and acquiring a better understanding of the process itself.

- Special causes variation: they are unpredictable, and they can be identified by punctual variations of the monitored parameter that are beyond the variability present on the process. When presents, the process is unstable, and they must be identified and removed to allow the process to acquire its previous predictable inherent variability.

5.2 Control Charts typologies

As previously stated, there are different types of Control Charts, and they are characterized by two main categories such as:

- Control Charts for continuous data (Normal distribution).
- Control Charts for discrete data (Binomial and Poisson distribution).

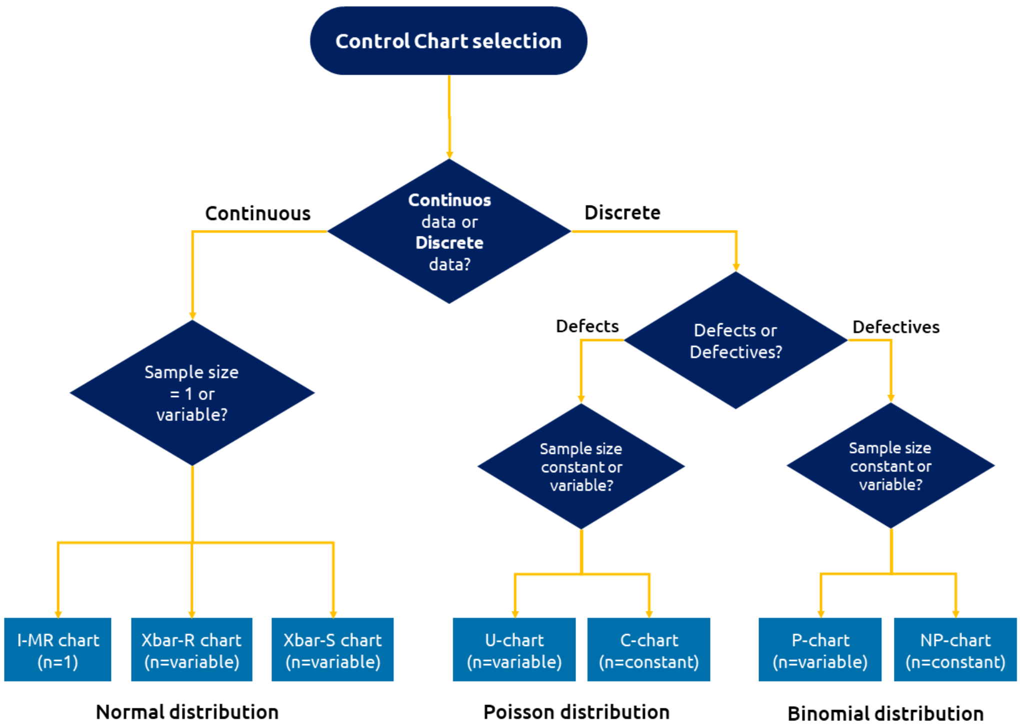

Figure 28: Control Charts typologies.

Control Charts for attributes refer to qualitative characteristics, and they require precise definition criteria for the defect to be monitored, in order to unequivocally establish which product or parameter is characterized by a defect or not, or as defective or not.

Control Charts for variables instead, refer to quantitative characteristics and as for attributes, they require precise definition criteria for the defect in question.

The main Control Charts used for this implementation proposal are:

- Individuals (Variables).
- Xbar – R (Variables).
- P (Attributes).
- NP (Attributes).

Formulas and constants related to Control Charts, are shown in the tables below.

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Tables of Constants for Control charts								
	Table 8A - Variable Data				ref : AIAG manual for SPC			
	X bar and R Charts				X bar and s charts			
	Chart for Averages	Chart for Ranges (R)			Chart for Averages	Chart for Standard Deviation (s)		
	Control Limits Factor	Divisors to Estimate σ_x	Factors for Control Limits		Control Limits Factor	Divisors to estimate σ_x	Factors for Control Limits	
Subgroup size (n)	A_2	d_2	D_3	D_4	A_3	c_4	B_3	B_4
2	1.880	1.128	-	3.267	2.659	0.7979	-	3.267
3	1.023	1.693	-	2.574	1.954	0.8862	-	2.568
4	0.729	2.059	-	2.282	1.628	0.9213	-	2.266
5	0.577	2.326	-	2.114	1.427	0.9400	-	2.089
6	0.483	2.534	-	2.004	1.287	0.9515	0.030	1.970
7	0.419	2.704	0.076	1.924	1.182	0.9594	0.118	1.882
8	0.373	2.847	0.136	1.864	1.099	0.9650	0.185	1.815
9	0.337	2.970	0.184	1.816	1.032	0.9693	0.239	1.761
10	0.308	3.078	0.223	1.777	0.975	0.9727	0.284	1.716
15	0.223	3.472	0.347	1.653	0.789	0.9823	0.428	1.572
25	0.153	3.931	0.459	1.541	0.606	0.9896	0.565	1.435

	Centerline	Control Limits		σ_x
X bar and R Charts	$CL_{\overline{X}} = \overline{\overline{X}}$	$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$	$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$	$\frac{\overline{R}}{d_2}$
	$CL_R = \overline{R}$	$UCL_R = D_4\overline{R}$	$LCL_R = D_3\overline{R}$	
X bar and s Charts	$CL_{\overline{X}} = \overline{\overline{X}}$	$UCL_{\overline{X}} = \overline{\overline{X}} + A_3\overline{S}$	$LCL_{\overline{X}} = \overline{\overline{X}} - A_3\overline{S}$	$\frac{\overline{s}}{c_4}$
	$CL_s = \overline{s}$	$UCL_s = B_4\overline{s}$	$LCL_s = B_3\overline{s}$	

Figure 29: Control Chart tables - 1.

Tables of Constants for Control charts

Table 8B Variable Data — ref : AIAG manual for SPC

	Median Charts				Charts for Individuals			
	Chart for Medians	Chart for Ranges (R)			Chart for Individuals	Chart for Moving Range (R)		
	Control Limits Factor	Divisors to Estimate σ_x	Factors for Control Limits		Control Limits Factor	Divisors to Estimate σ_x	Factors for Control Limits	
Subgroup size	$\tilde{A}_2$	d_2	D3	D4	E_2	d_2	D_3	D_4
2	1.880	1.128	-	3.267	2.660	1.128	-	3.267
3	1.187	1.693	-	2.574	1.772	1.693	-	2.574
4	0.796	2.059	-	2.282	1.457	2.059	-	2.282
5	0.691	2.326	-	2.114	1.290	2.326	-	2.114
6	0.548	2.534	-	2.004	1.184	2.534	-	2.004
7	0.508	2.704	0.076	1.924	1.109	2.704	0.076	1.924
8	0.433	2.847	0.136	1.864	1.054	2.847	0.136	1.864
9	0.412	2.970	0.184	1.816	1.010	2.970	0.184	1.816
10	0.362	3.078	0.223	1.777	0.975	3.078	0.223	1.777

	Centerline	Control Limits	
Median Charts	$CL_{\tilde{X}} = \bar{\tilde{X}}$	$UCL_{\tilde{X}} = \bar{\tilde{X}} + \tilde{A}_2\bar{R}$	$LCL_{\tilde{X}} = \bar{\tilde{X}} - \tilde{A}_2\bar{R}$
	$CL_R = \bar{R}$	$UCL_R = D_4\bar{R}$	$LCL_R = D_3\bar{R}$
Charts for Individuals	$CL_X = \bar{X}$	$UCL_X = \bar{X} + E_2\bar{R}$	$LCL_X = \bar{X} - E_2\bar{R}$
	$CL_R = \bar{R}$	$UCL_R = D_4\bar{R}$	$LCL_R = D_3\bar{R}$

Figure 30: Control Charts tables - 2.

Tables of Formulas for Control charts

Table 8 C Attribute Data — ref : AIAG manual for SPC

	Centerline	Control Limits	
p chart for proportions of units in a category	$CL_p = \bar{p}$	Samples not necessarily of constant size	
		$UCL_{p_i} = \bar{p} + 3\frac{\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n_i}}$	$LCL_{p_i} = \bar{p} - 3\frac{\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n_i}}$
		If the Sample size is constant (n)	
		$UCL_p = \bar{p} + 3\frac{\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$	$LCL_p = \bar{p} - 3\frac{\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$
np chart for number / rate of units in a category	$CL_{np} = n\bar{p}$	$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}$	$LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}$
c chart for number of incidences in one or more categories	$CL_c = \bar{c}$	$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$	$LCL_c = \bar{c} - 3\sqrt{\bar{c}}$
u chart for number of incidences per unit in one or more categories	$CL_u = \bar{u}$	Samples not necessarily of constant size	
		$UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n_i}}$	$LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n_i}}$
		using average sample size	
		$UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{\bar{n}}}$	$UCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{\bar{n}}}$
		If the sample size is constant (n)	
		$UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$	$UCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$

Figure 31: Control Charts tables - 3.

5.3 I-MR charts (variables) - overview

I-MR Control Charts are adopted when it's not possible or not convenient to collect and organize the data in subgroups or when the production of data is so slow that creating subgroups would delay the monitoring process itself.

It is usually used in combination with the Moving Range chart, but for the purpose of this implementation the MR chart has not been used. Individual control charts allow to monitor the process variation over time through a graphical method.

The image below shows an example of I-MR charts created by using Minitab.

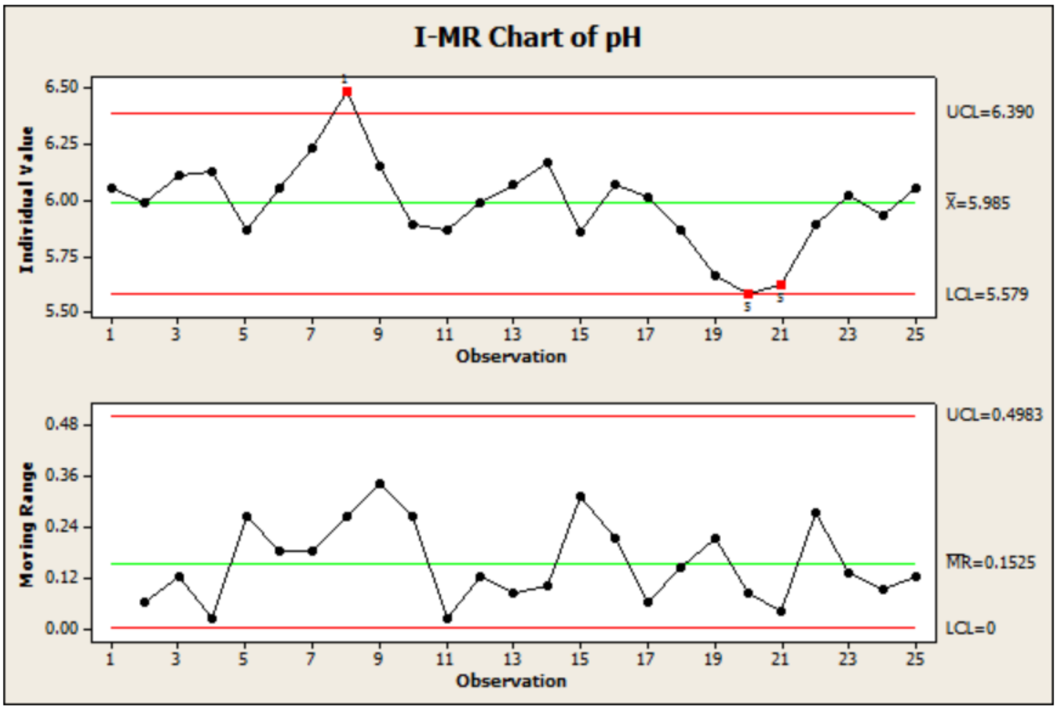

Figure 32: I-MR Control Charts example.

5.3.1 I-MR Chart – Data considerations

To ensure the validity of the results, it is essential to consider specific requirements before collecting data and implementing this type of Control Chart.

Data should be:

- **Continuous.**
- **In time order:** it should be considered the order related to the data collection itself, with the oldest data at the beginning.
- **Collected at appropriate time intervals:** equally spaced time intervals must be considered, and the time length should be defined in order to highlight specific changes of the process.
- **Individual observations that are not collected in subgroups.**
- **At least 100 observations:** with fewer number of observations, the Control Chart can still be used but the results are preliminary because the Control Limits may not be precise, so a re-estimation should be considered when at least 100 observations are reached.
- **Data should be moderately normal:** in case of moderate departures from normality, the results should not be significantly affected, but if there are severe departures from normality, false out-of-control signals could increase in number. In fact, in presence of very skewed data, a Box-Cox transformation is suggested in order to correct the non-normal condition and then apply the Control Chart.
- **Observations should not be correlated with each other.**

5.4 Xbar-R charts (variables) – overview

Xbar-R Control Charts are used to monitor the performance of a process characterized by continuous data and collected in subgroups. They are characterized by two main parameters, monitored in the Xbar and R chart respectively:

- Average (Xbar).
- Moving Range (R).

These types of Control Charts are often used in the manufacturing sector which is characterized by high volumes and continuous flow of production. They allow to monitor the stability of the process and detect the occurrence of special causes variations or other alarming trends, leading then to the setting of proper corrective actions in order to restabilize the process.

Data are assumed to be normally distributed and its availability is larger respect to the I-MR Control Chart typology, allowing then to use subgroups without delaying the monitoring process.

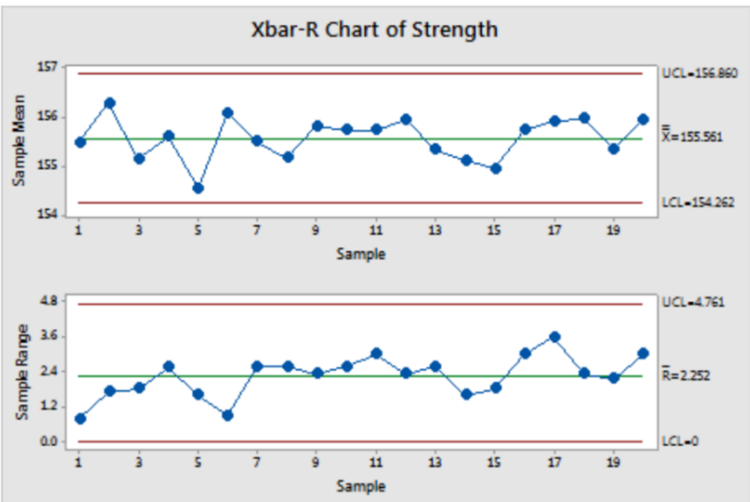

Figure 33: Xbar-R Control Charts example.

5.4.1 Xbar-R charts – Data considerations

To ensure the validity of the results, it is essential to consider specific requirements before collecting data and implementing this type of Control Chart.

Data should be:

- **Continuous.**
- **In time order:** it should be considered the order related to the data collection itself, with the oldest data at the beginning.
- **Collected at appropriate time intervals:** equally spaced time intervals must be considered, and the time length should be defined in order to highlight specific changes of the process.
- **In rational subgroups:** which is defined as a small sample of items that are similar and produced under the same conditions in a short period of time, representative of the process output.
- **The subgroup size should be 8 or fewer observations:** in case of 9 or more observations, it is suggested to use the Xbar-S Chart.
- **Appropriate amount:** the proper amount of data contained in the subgroups depends on the subgroups size itself:
    - If the subgroup size is less than or equal to 2, at least 100 observations.
    - If the subgroup size is 3, at least 80 observations.
    - If the subgroup size is 4 or 5, at least 70 observations.
    - If the subgroup size is 6 or greater, at least 60 observations.
    - In case of fewer than recommended number of observations, Control Charts can still be used, but the results are preliminary, and the Control Limits may not be precise. It is

then suggested to re-estimate them after the recommended quantity of observations has been collected.

- **Data do not need to be normally distributed:** even if most Control Charts for variables data are formally based on the assumption of normality, it is possible to obtain good results with non-normal data if collected in subgroups. In case of very skewed data, it is then possible to apply a Box-Cox transformation in order to correct the non-normal condition and then apply Control Charts, comparing the results before and after the Box-Cox transformation.
- **The observations within each subgroup should not be correlated with each other:** if consecutive data points are correlated, there could be some in-control points shown as out of control, due to narrow Control Limits.

5.5 P and NP charts (attributes) – overview

P Control Chart considers the binomial distribution, in fact it is used for attributes and by focusing on the "defectives", which means that it considers the proportion of units (defectives) in a sample. This type of chart is linked to process monitoring over time and regarding binary events with variable sample size, for example by assessing if alarming patterns or out of control events occurs and consequently taking corrective actions in order to remove the causes in question and to restabilize the process.

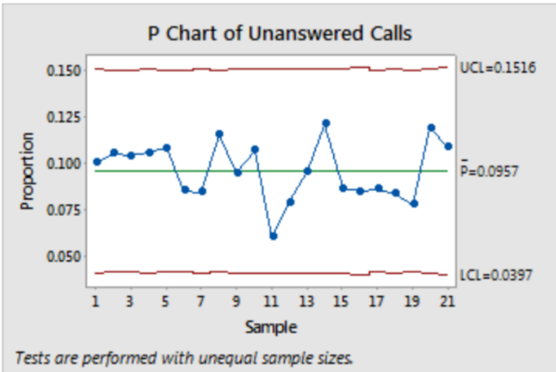

Figure 34: P Control Chart example.

NP Control Chart considers also the binomial distribution, but it considers the number of defective items, instead of the percentage and it is usually used when the sample size is constant.

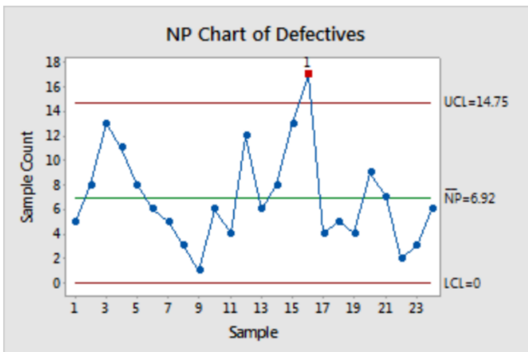

Figure 35: NP Control Chart example.

5.6 Implementation proposal

The standard monitoring method described in the previous chapters, is based on threshold limits, that are not statistically computed, called: Specification Limits.

These thresholds are based on client requirements or internal benchmarking, and they need to be flexible in order to allow customer requests adjustments or internal team ones. Because of this intrinsic feature, they cannot strictly monitor the process variability.

Control Chart instead, with Control Limits based on statistics as previously described, can highlight special causes variations or alarming trends that could damage the stability of the process, consequently promoting why-analysis and eventually corrective actions.

Another key difference between the standard monitoring method and the Control Charts one, is that the latter strictly uses punctual data instead of cumulative ones, allowing a better process analysis since cumulative perspective tends to dampen negative punctual data in the long term if relevant positive ones are already present.

The implementation proposal in question, considers the application of specific Control Chart types on the data presented in the previous chapters with the standard method, in order to highlight potential monitoring advantages.

This implementation considers specific KPIs previously described, with the goal to prove the effectiveness of the implementation itself.

5.6.1 S1B (Year 2) – Control Charts implementation

The S1B (Year 2) KPI, as explained in one of the previous chapters, monitors the average claim response time with a monthly frequency.

$$S1B = \frac{Sum\ of\ working\ days\ used\ for\ each\ claim}{Number\ of\ claims\ solved}$$

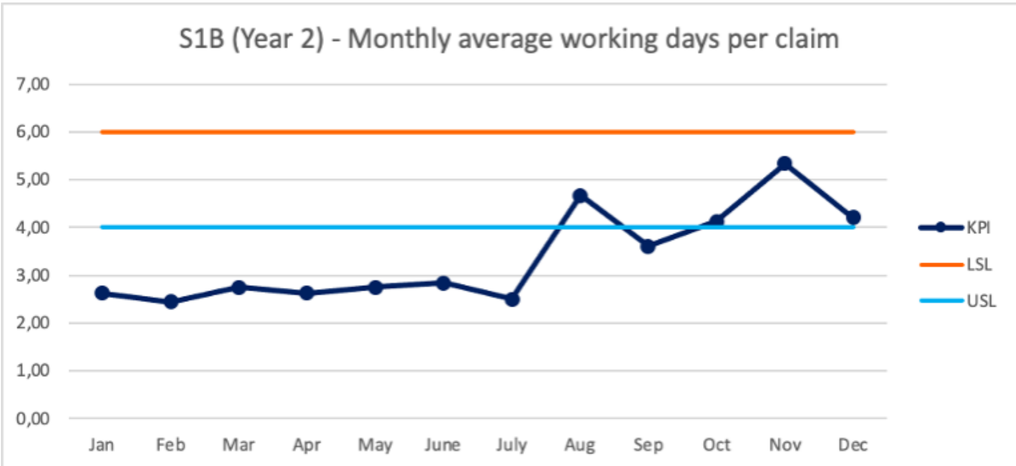

Figure 36: S1B (Year 2) - Standard monitoring method.

As previously explained, the Specification Limits (USL and LSL present in the chart above) used in the standard KPIs monitoring method, cannot strictly monitor the variability of the process.

To do that and considering as a first case the unavailability of raw data, such as the individual amount of days used to solve each of the single claim, it is possible to apply the Individuals Control Chart type, in order to seek for preliminary potential advantages in process monitoring.

As previously explained, data for Individuals Control Chart should be moderately normal, but moderate departures from normality do not significantly affect the results of the chart.

In this case, the histogram shows that data are moderately right skewed (with a skewness of 0,90). Since these data are the averages of subgroups related to all the claims received to that specific month and because of the Central Limit theorem, they will tend to reflect the behavior of a normal distribution. It is important to state that the KPI in question measures the averages amount of days used to solve a claim, which means that it will not present negative (sign) data, which means that there is an intrinsic wall that push to a right skewed data configuration.

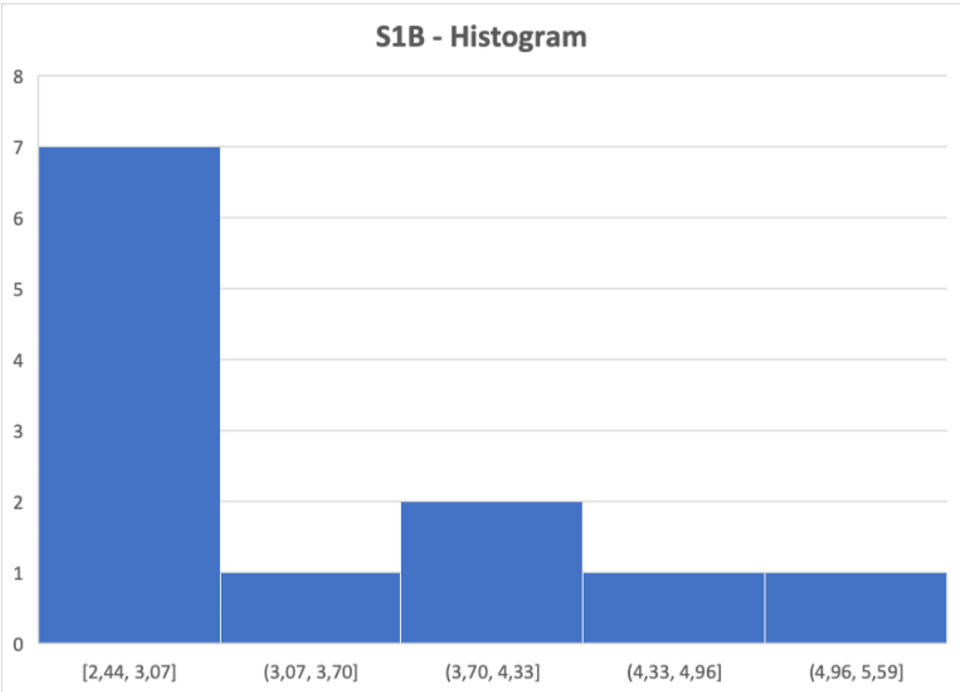

Figure 37: S1B histogram.

However, considering also that there are only 12 available individual observations in total (100 observations recommended), the results of the

Individuals Control Chart implementation are preliminary, and the Control Limits may not be precise.

The results of this first implementation, using MATLAB, is shown in the image below:

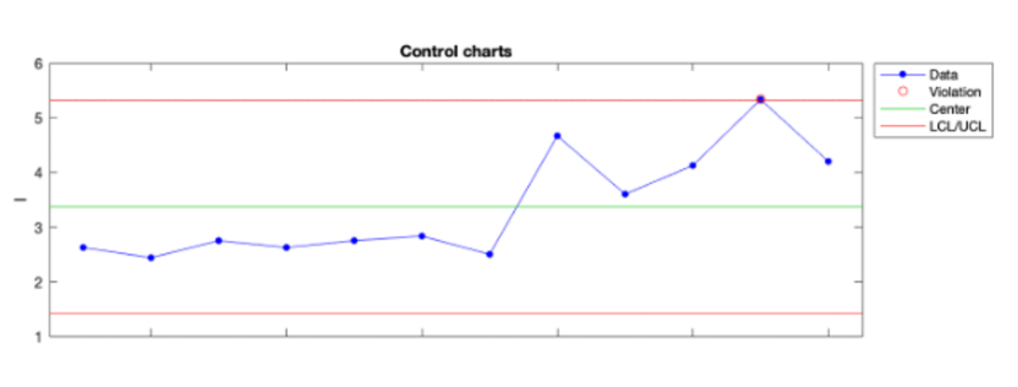

Figure 38: S1B - Individuals Control Chart.

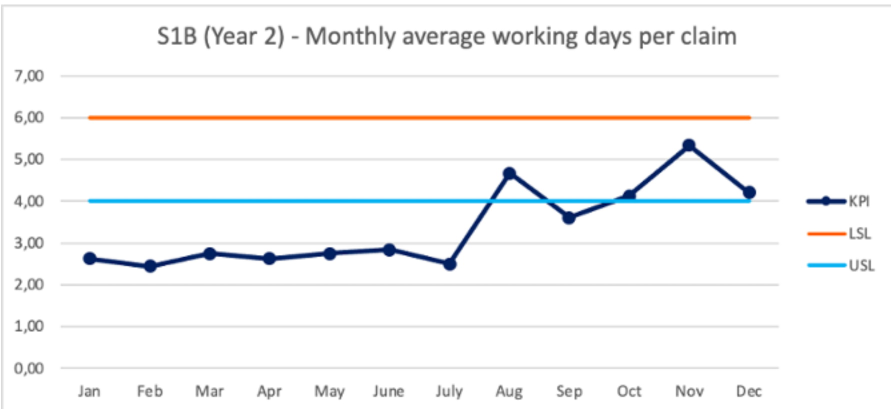

Figure 39: S1B (Year 2) - Standard monitoring method.

As shown in the comparison above, the main advantage of Control Charts implementation is that they allow to have a different monitoring view of the process.

For example, if we consider August and November data:

- In the standard monitoring method, they are in the allowed area between the two Specification Limits, and since they consider the Process Client perspective, these data are acceptable.
- In the Control Chart, August is near the Upper Control Limit and November is out of the limit, so it should be appropriate to promote a why-analysis into the raw data, in order to understand the root-cause of these two peaks.

By looking then at the raw data, focusing on the relation between the monthly total amount of claims received and the monthly total amount of days spent, it is possible to understand the cause of the out-of-control November data.

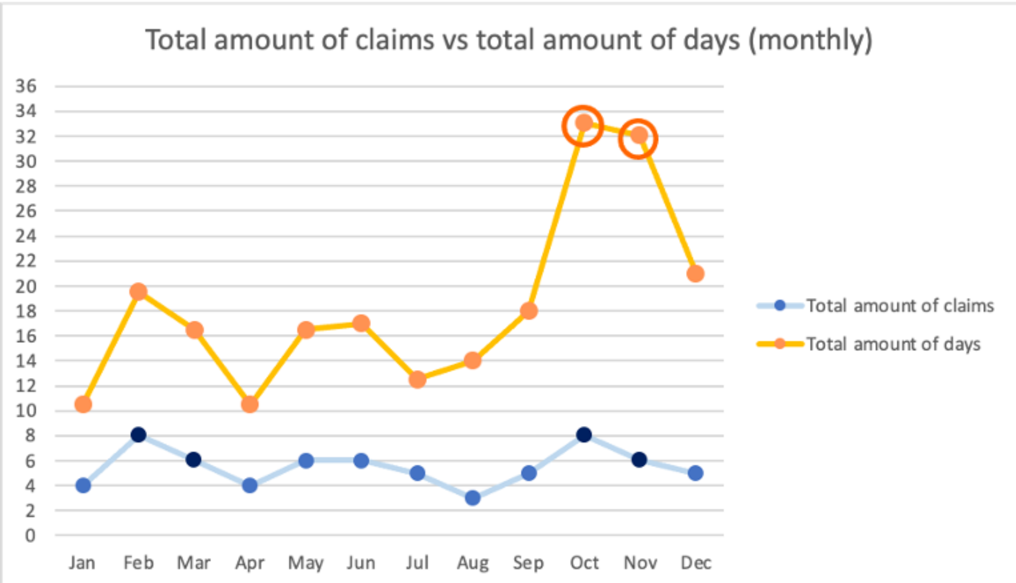

Figure 40: S1B data analysis.

Even if in October and November, the number of claims received has been equal respectively to February (8 total claims) and March (6 total claims), the total amount of days spent to solve them has been relevantly higher as shown in the chart above, causing the upper trend that led to the out-of-control data in November.

Consequently, the advantage of this analysis promoted by the Control Chart implementation, could be useful in order to further understand why such several days have been used to solve those claims.

- February: 8 claims received, and 19,5 days spent.
- March: 6 claims received, and 16,5 days spent.
- October: 8 claims received, and 33 days spent.
- November: 6 claims received, and 32 days spent.

Still, it is possible to improve the monitoring process by using raw data, such as the individual number of days used to solve each claim individually per month, but using the Xbar-R Control Chart type, in order to have better monitoring results.

The main advantage of the Xbar-R Control Chart type, respect to the Individuals one, is that it allows to filter out-of-control data present in the Individuals chart, with better statistic precision.

It is important to highlight the fact that due to the different number of claims received between different months, this implementation is characterized by samples (months) of different size and consequently variable Control Limits.

The results of the Xbar-R charts implementation are shown in the image below:

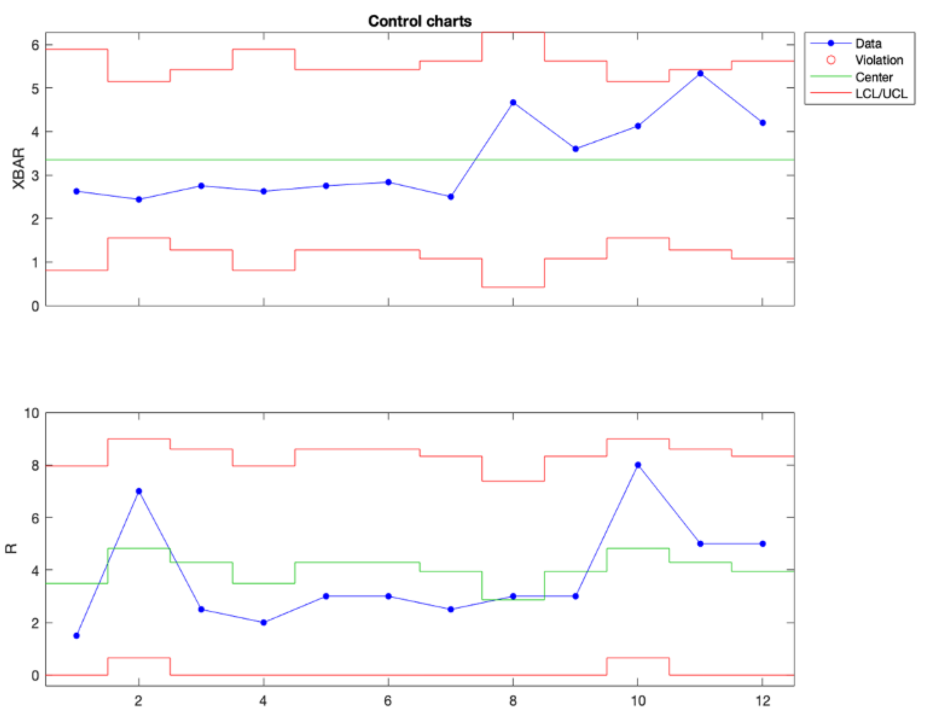

Figure 41: S1B - Xbar-R Control Charts implementation.

As shown in the chart above and as explained previously, the November data that was above the Upper Control Limit in the Individuals chart, it is now slightly below the Upper Control Limit, due to better statistics precision. Still, this result promotes why-analysis.

To further improve the process analysis, it possible to categorize the solved claims by using weights such as: light, medium and heavy. By analyzing the result of this categorization, in case of alarming trends or out of controls punctual data, there could be a better understanding of the root cause.

Finally, another improvement proposal could be:

1) Categorize the solved claims by Light, Medium and Heavy.
2) Implement the Xbar-R chart for each category.

In this way it possible to monitor the process performance for each category.

KPI	Weight	Control Chart applied
Average claims response time	Light	Xbar - R
	Medium	Xbar - R
	Heavy	Xbar - R

Figure 42: Improvement proposal based on weights.

5.6.2 S2A and S2C Control Chart implementation

Due to the analytical definition of S2A and S2C, it is possible to apply the P Control Chart type in order to search for advantages in the process monitoring.

The S2A KPI, as explained in one of the previous chapters, helps to track the monthly (punctual) performance regarding the number of milestones achieved on time respect to the planned ones.

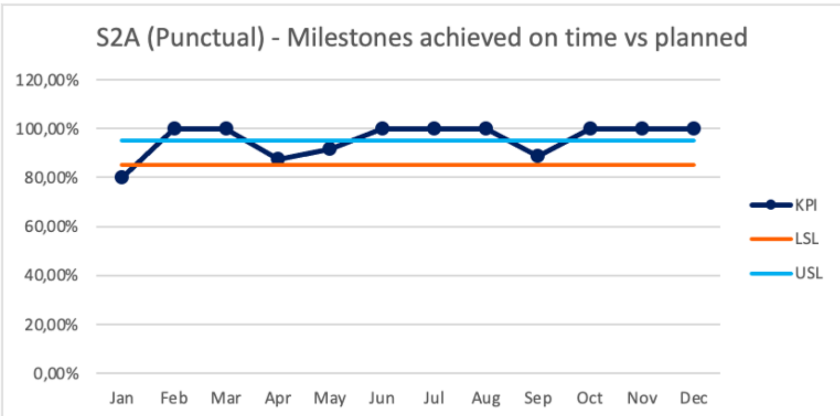

Figure 43: S2A (Punctual) - Standard monitoring method.

The result of the P Control Chart type implementation is shown in the image below.

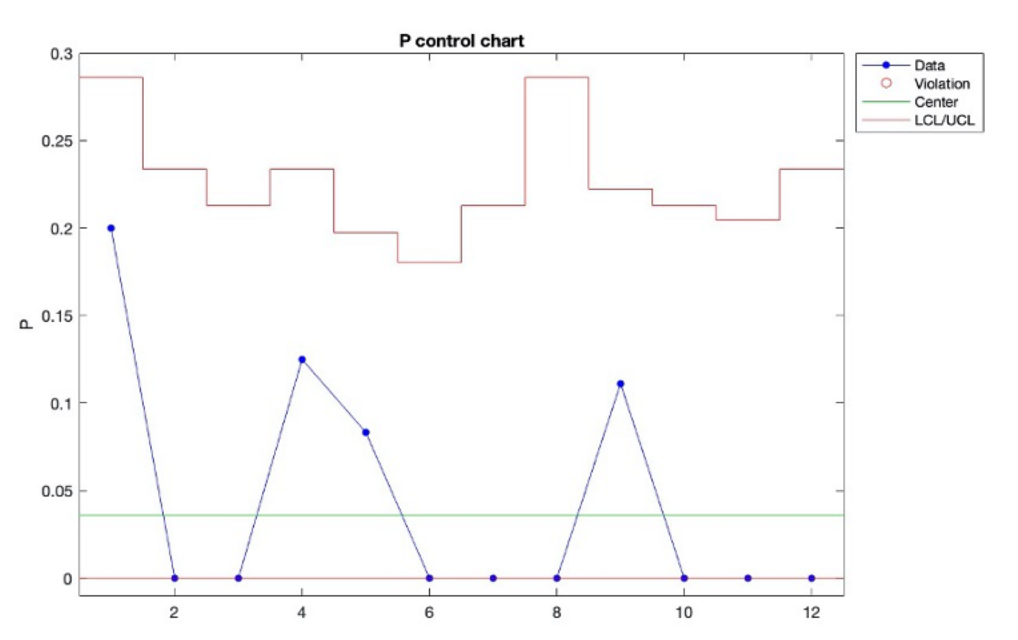

Figure 44: S2A - P Control Chart implementation.

The P chart in question, uses the monthly data of the number of milestones not achieved respect to the planned ones, so the lower the better because it essentially monitors the milestone not achieved performance. In this case there are no out-of-control data.

The S2C KPI (standard monitoring method) instead, helps to track the performance regarding the number of solved issues (issues solved respect to ones to be solved), with a cumulative structure.

It considers also the issues remained unsolved in the previous year and it is shown below in the standard monitoring method.

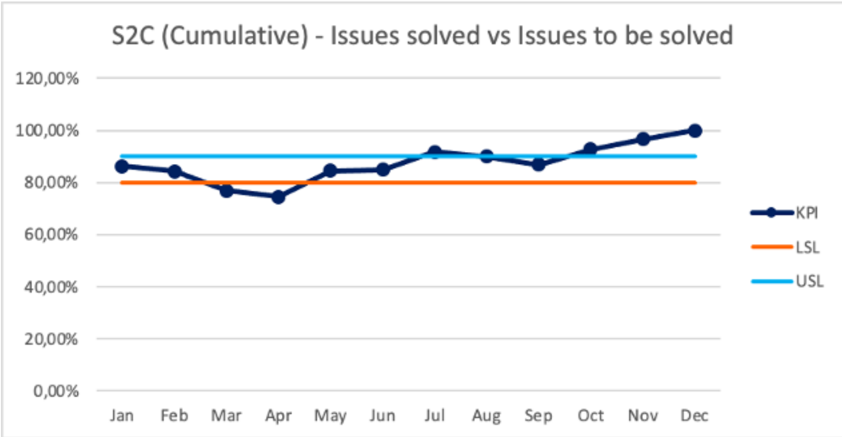

Figure 45: S2C - Standard monitoring method.

(S2C - Cumulative) Issues solved / Issues detected	Month	Num	Den
	Dec	24	29
	Jan	25	29
	Feb	27	32
	Mar	30	39
	Apr	32	43
	May	38	45
	Jun	39	46
	Jul	44	48
	Aug	45	50
	Sep	46	53
	Oct	50	54
	Nov	55	57
	Dec	59	59

Figure 46: S2C data.

In order to improve the monitoring process, it is possible to re-define the structure of this KPI in a punctual way, by considering the following analytical structure:

$$S2C\ (punctual) = \frac{Total\ issues\ remained\ unsolved}{Total\ issues\ present\ in\ a\ month}$$

$$Total\ issues\ present\ (monthly) = unsolved\ issues + new\ ones$$

S2C - P chart punctual data	Lot (Month)	Monthly issues not solved %	Issues remained unsolved per month	Monthly issues solved	Issues to be solved (unsolved + new ones)
	Jan	80,00%	4	1	5
	Feb	71,43%	5	2	7
	Mar	75,00%	9	3	12
	Apr	84,62%	11	2	13
	May	53,85%	7	6	13
	Jun	87,50%	7	1	8
	Jul	44,44%	4	5	9
	Aug	83,33%	5	1	6
	Sep	87,50%	7	1	8
	Oct	50,00%	4	4	8
	Nov	28,57%	2	5	7
	Dec	0,00%	0	4	4

Figure 47: S2C - P Control Chart data.

In this way it is possible to track the negative performance of remaining unsolved issues in a punctual way and the implementation of the P Control Chart on this re-defined structure is shown in the image below.

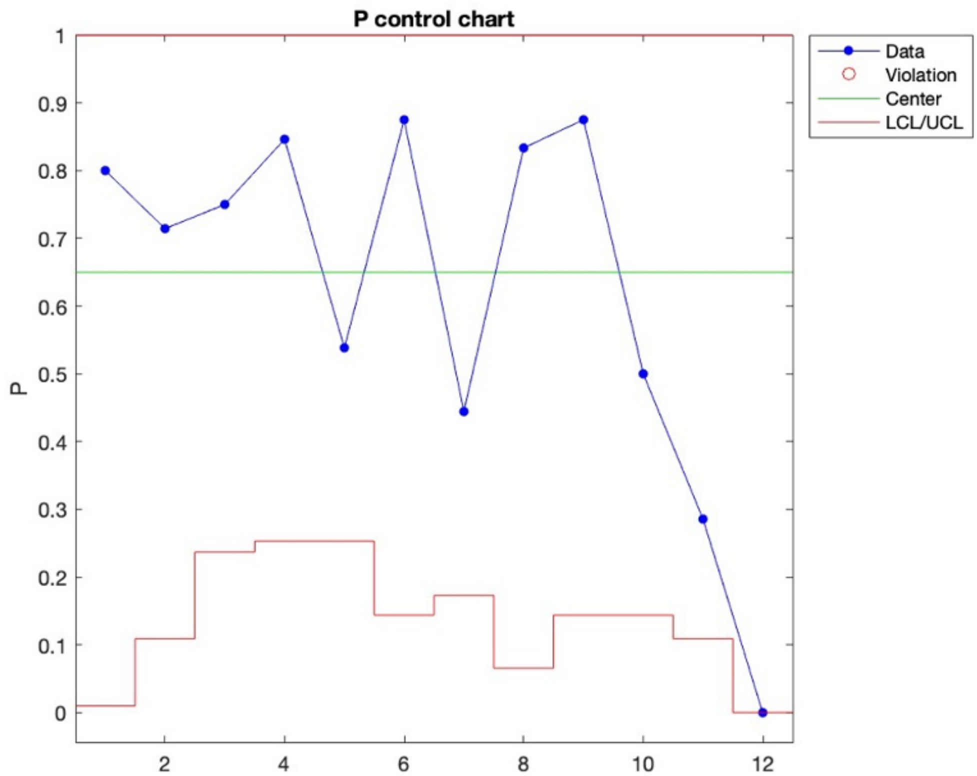

Figure 48: S2C - P Control Chart implementation.

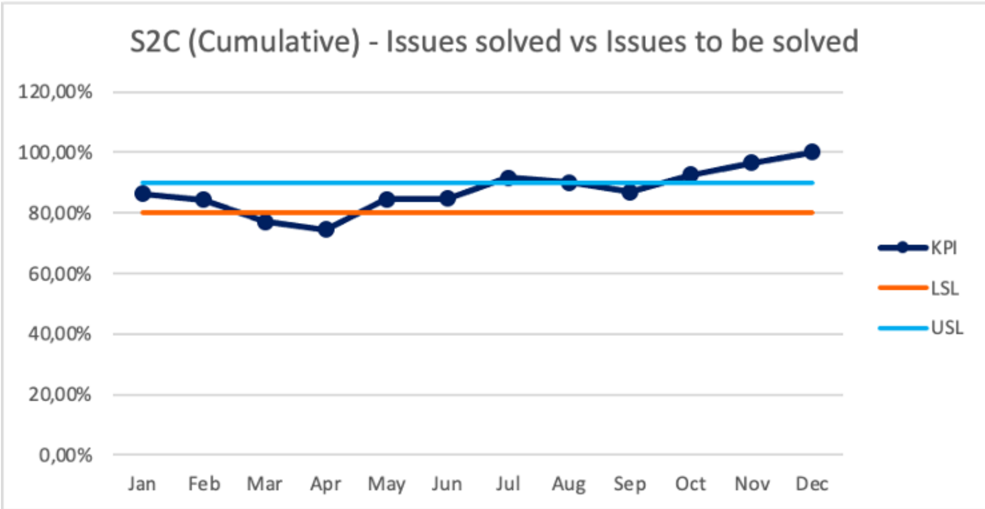

Figure 49: S2C - Standard monitoring method.

Since P chart considers the issues remained unsolved divided by the issues to be solved, monthly, the lower the KPI the better it is. Ideally, we would like to have a result equal to zero, which would mean that all the issues of that related month have been solved.

The punctual performance described by the P Control Chart, shows an important number of monthly unsolved issues in most of the year, with a positive drastic change from October to December, in which all the issues have been solved.

The three peaks of unsolved issues in April, June and August-September highlighted by the P Control Chart, are explained by the fact that in those months, there were few issues solved respect to the number of issues to be solved.

These considerations promote a why-analysis in order to explain those results.

The S2C standard cumulative view tends to hide negative performance in the long term, due to the cumulative format itself. For example, the peak in April is matched with an out of Specification Limit in the cumulative view, but the other two such as June and August-September are dampened by the cumulative format.

For this reason, the P Control Chart and the punctual re-definition of the S2C formula, offer an improved perspective to monitor the performance of remaining unsolved issues respect to the cumulative standard version, that dampens the influence of negative performance peaks.

5.6.3 S2B – Control Chart implementation trade-off considerations

S2B instead, is structured in such a way that could potentially allow the implementation of an Individual Control Chart type. Specifically, as explained in the previous chapters, S2B monitors the average amount of delay weeks related to milestone achievement, in a cumulative way and by using a specific performance linear correlation, this cumulative numeric parameter is transformed into a percentage one.

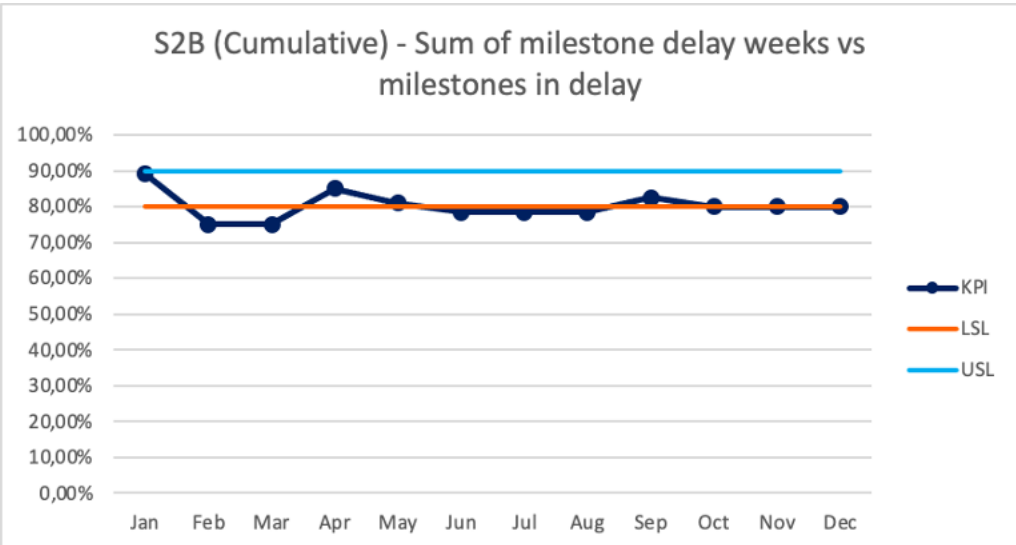

Figure 50: S2B chart.

The main issue related to the structure of this KPI, lies in its cumulative structure, that allows data peaks, such as in April and September that are not related to a better performance, but are since in those months a new milestone in delay is added, consequently increasing the denominator, and decreasing the cumulative parameter.

Before implementing Control Charts, a tradeoff must be pursued in order to understand if advantages are present. In this specific case, it would be useful to implement an Individual Control Chart on the total individual amount of delay weeks per milestone, in order to analyze statistically and punctually the department performance on each milestone achievement.

5.6.4 Service 3 – Considerations

Regarding the Service 3 sub-perimeter, in order to have a clearer view of the intrinsic process performance, it would be optimal to introduce a punctual view of S3B that considers the monthly number of validated procedures respect to the ones that needs to be validated (both new and old ones), beside its P chart implementation.

The overall process that S3B monitors already, in its standard monitoring structure, does not focus only on the company performance, but also on the client one, since the client itself must validate the procedures that the company department produces.

Cumulative indicators tend to dampen negative performance in the long term (if specific conditions are present) respect to their punctual version that considers the monthly perspective.

In this case, since the punctual view of S3B considers at the denominator not only the new procedures to be validated for that specific month, but also the ones that are still to be validated, the difference respect to the S3B cumulative version could be more highlighted.

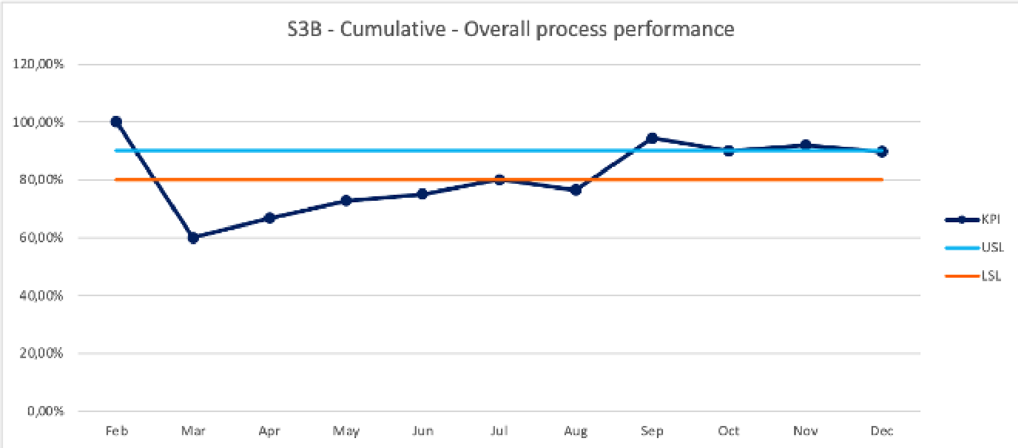

Figure 51: S3B - Cumulative structure.

Even if the S3B cumulative version (that considers client requirements through Specification Limits), shows a positive overall performance at the end of the year with almost 90% of procedures fully validated, the punctual version highlights an under-performing validation performance, considering internal benchmarking requirements.

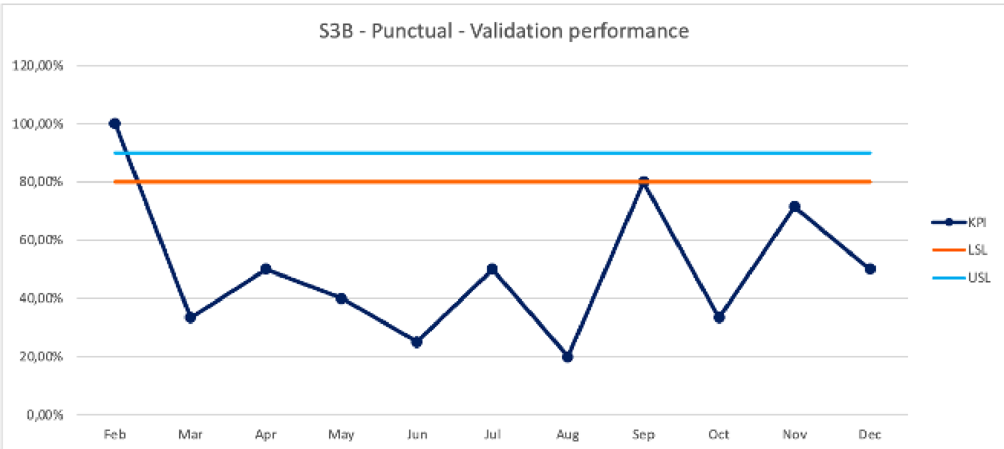

Figure 52: S3B - Punctual structure.

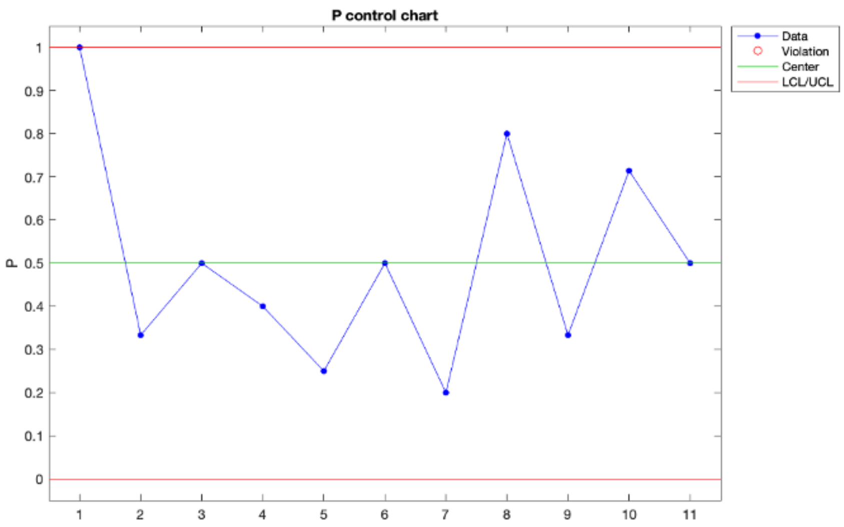

Figure 53: S3B - P chart implementation.

The P chart above confirms that the performance has been steadily under-performing throughout the year, and it needs to be improved. This is an example where the P chart is used not to monitor a negative process aspect by considering the "defective number of items", but the opposite one.

Regarding the S3B punctual results, in order to understand if they are related to the company Product Engineering department performance or to the Client validation process, it is important to analyze intrinsically the Client response.

This can be practically expressed by the number of not validated procedures with a real time indicator that considers the ones that are still not validated because of client on-going validation process and the ones that are still not validated because they need to be modified by the company Product Engineering department.

This real time indicator is shown in the chart below:

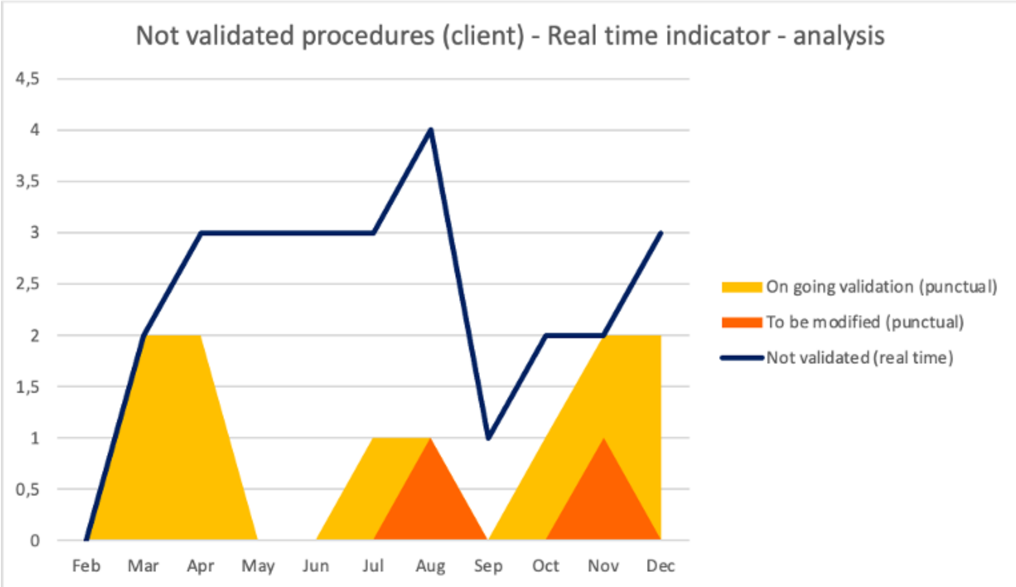

Figure 54: Not validated procedures - Real time indicator.

As this indicator shows, the main amount of not validated procedures is related to the on-going validation process of the client, and not to the company Product Engineering, with the overall percentages shown in the chart below.

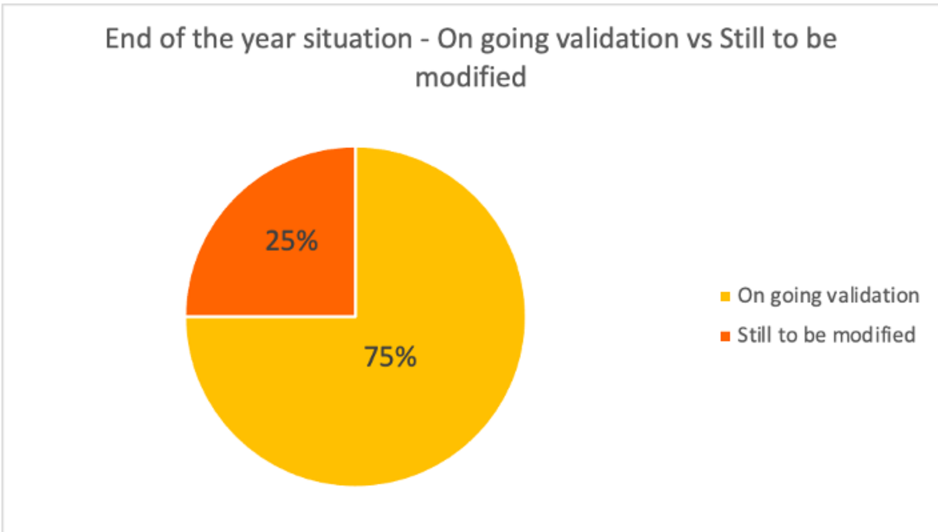

Figure 55: Not validated procedures overall analysis.

5.6.5 S4B – Individuals and Xbar Control Charts implementation

Finally, S4B is another type of indicator that can be used beside its Control Chart implementation. As previously explained, S4B monitors the monthly sum of working days spent for each request respect to the total amount of received ones for that specific month.

If monthly raw data (individual number of days spent for each request) is not available, an Individual chart can be implemented:

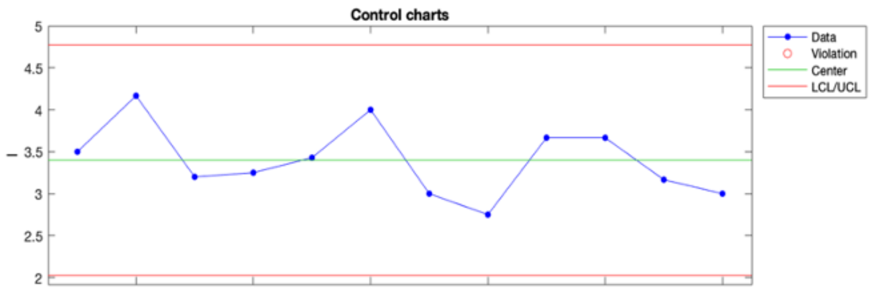

Figure 56: S4B - Individuals chart.

Otherwise, Xbar-R charts can be used:

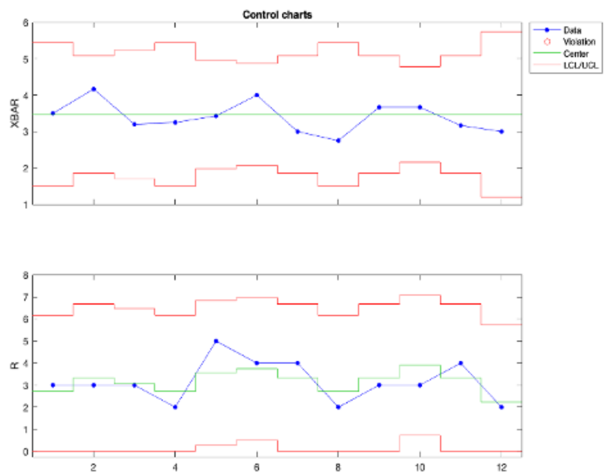

Figure 57: S4B - Xbar-R charts.

5.7 Conclusions

The described KPI standard monitoring method, with only Specification Limits, allows to consider client requirements or internal benchmarking, but it cannot strictly monitor the process variability from a statistical point of view.

The implementation described in the improvement proposal above, focused on 4 main types of Control Charts, such as Individuals, Xbar-R and P.

Other types of charts have not been considered not only because of technical reasons, but to maintain the implementation itself as simple and effective as possible.

In conclusion, by using Control Charts beside the standard monitoring method, it possible to acquire a better understanding of the overall process performance and allow data-driven why-analysis, promoting processes continuous improvement.

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Figure References

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