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CAPABILITY STUDIES AS A KEY DRIVER FOR PRODUCT AND PRO-CESS QUALITY ASSURANCE IN INDUSTRIALIZATION PROCESS

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Abstract: Customer satisfaction has long been an important concern for most organizations aiming to provide and ensure excellent quality products. To offer an appropriate level of quality assurance, it is necessary to have implemented a robust quality assurance system. Nowadays, mere customer satisfaction is not sufficient for organizations to sustain a mutually beneficial relationship. There has arisen a necessary requirement to go beyond customer satisfaction, aiming primarily to achieve a level of so-called cus-tomer delight. To attain sustainable product and process quality assurance and, consequently, customer delight, we must address process capability. This includes gauges, machines, and the overall process and product capability, with a specific emphasis on the design and development process, product reali-zation, and the initial flow. This also includes data gathering from the utilization stage of product opera-tion. This article deals with the capability study during the industrialization process of a new product into serial production, using chosen Key Performance Indicators (KPIs), particularly Capability indices and their sequence, to ensure the appropriate level of quality guarantee and customer delight. The article aims to broaden the existing set of Key Performance Indicators (KPIs) by incorporating crucial metrics from the quality domain, with a particular emphasis on Capability indices.
Keywords: Quality, Quality Guarantee, Customer Satisfaction, Customer Delight, Capability

1. INTRODUCTION

The aim of the study is to emphasize the importance of going beyond mere customer satisfaction and achieving “customer delight” by implementing a robust quality assurance system. The article suggests that, to ensure sustainable product and process quality assurance, organizations should conduct capability studies during the industrialization process of a new product into serial production. The article specifically discusses using Key Performance Indicators (KPIs), particularly Capability indices, to measure and ensure the appropriate level of quality guarantee and customer delight. The ultimate goal is to broaden the set of KPIs by incorporating crucial metrics from the quality domain.

According to the well-known definition of quality stemming from the ISO 9000:2015 standard, quality is the ability of a set of inherent characteristics of a product, system, or process to meet the requirements of customers and other interested parties (ISO 9000:2015). The question raised is to what extent, meaning what level of quality can lead to customer satisfaction. We must not subject our products to customer testing, i.e., deliver products and wait to see their impact. Instead, we need to ensure, before handing over the product, that it meets the needs and requirements of the customer. Quality assurance cannot be guaranteed without proper control. Critical characteristics, including parameters mandated by law, those most important to the user, and considerations related to the environment and safety, are of outmost importance. These critical parameters are defined as CTQ (Critical to Quality), and the article introduces the term CSE (Essential Monitored Characteristics).

The worst manifestation of a non-functional or failed quality assurance system is typically a recall campaign. A few industry examples include Toyota`s recall of 3.37 million automobiles in 2016 and 2017 due to airbag and emission failures. In 2016, Samsung`s Galaxy Note 7 faced issues with battery self-ignition or explosion. Reflecting on the profound failure of Volkswagen in 2015, which affected Audi, Skoda, Mercedes-Benz, Nissan, Mitsubishi, Fiat-Chrysler, Renault, Peugeot, and Citroën, and culminated in the grounding of the Boeing 737 Max due to a part crack, emphasizes the critical need for a re-evaluation of contemporary quality approaches. One of the root causes appears to lie outside the quality assurance system itself — the moral qualities of management, which are reflected in the quality assurance system. There has long been a necessity for the reconsideration of the definition of quality based on ISO 9000:2015. It should encompass a morality and reliability approach at each step or stage of the manufacturing process, extending to the entire business process, including organizational culture, vision, and strategy. This should be grounded in daily management, which includes CSE management. Implementing a robust quality assurance system helps prevent these types of failures mentioned above, ensuring products and services meet the required standards and customer expectations. As mentioned earlier, customer satisfaction alone is not sufficient. To generate profits, we need not just satisfied but delighted customers. In a market saturated with options, selling becomes a more significant challenge than production. An unsatisfied or even a satisfied customer has numerous opportunities to buy elsewhere. Being satisfied with ISO 9000:2015 is not enough; we still incur losses. That´s why we need Total Quality Management (TQM) from top management and the so-called third level of quality, which involves Customer delight through unexpected quality advancements, meeting customers´ unspoken (latent) requirements (Kano, 2019).

Furthermore, our discussion has focused solely on quality so far. On the other hand, a crucial characteristic from a practical standpoint is reliability. According to ISO 9000:2015 and IEC 50 (191) standards, reliability is defined as the probability of trouble-free operation. This entails the object`s ability to perform the required function in given conditions and within a specified time interval. Reliability is a fundamental product property, ensuring the performance of required functions while maintaining specified operating parameters within given limits and adhering to technical conditions. It represents the product`s ability to sustain inherent quality traits over its useful life. In a narrower sense, reliability is a collective term encompassing availability and related factors (reliability, maintainability, and maintenance security). Simply put, reliability is an expression of quality over time, influencing product costs and processes. It`s an intrinsic aspect of product design affecting performance. Achieving a reliable product involves applying reliability disciplines during the early stages of product conception and design for cost-effective activities. Like other engineering disciplines, reliability must be managed to deliver high-value products to customers. Broadly, reliability reflects user confidence in a product`s usability by ensuring satisfaction with its capability, readiness for on-demand service, and minimizing the cost of acquisition and ownership throughout its lifecycle. Moreover, the aforementioned approach would not succeed without a continuous improvement strategy and tools properly implemented at all stages of manufacturing (Mazur, 2019; Kozeń, 2019).

2. CUSTOMER DELIGHT BEYOND CUSTOMER SATISFAC-TION AND THE IMPORTANCE OF KPI`S

In the context of industrialization, our organization must guarantee the most crucial product and process characteristics and, naturally, achieve a level of quality that delights. It`s imperative to focus on key stages in the life cycle, specifically: 1. Design and development, 2. Pre-serial production, 3. Serial production, and 4. Utilization or product performance; other stages are not included. KPI (Key Performance Indicator) is defined as a predetermined indicator used to evaluate whether tasks assigned to a department, or an individual are carried out as planned, serving as input for developing corrective actions (Kano, 2019). The definition replaces “Control item” with KPI (Kano, 2019) at the JUSE MC Terminology Review Subcommittee of JUSE 1988. A KPI is an indicator that shows whether business activities are conducted in a way that produces the intended results (Kano, 2019). Importantly, note that a KPI is not just an individual indicator; rather, a set of KPIs tells the entire story, as individual fragments can be misleading. Crucially, one must consider the trend of KPIs in relation to targets in the overall organizational strategy and quality policy. This involves understanding which KPIs are lagging or leading, whether they are sufficient, and which one(s) require necessary improvement. This involves understanding which of them is behind or ahead, whether it is sufficient, or which one(s) need necessary improvement (Cieśla, 2021). All manufacturing processes around the world deal with variation, regardless of their design, manufacturing process, and exploitation. Variability affects the process and can divert it from producing products or implementing services to meet customer specifications. Knowing the capability of a process allows us to gain insight into whether the process will be able to meet the customer`s requirements or not. A process capability study can help determine the uniformity of a product around the target value. By reducing variability and creating consistent quality, the viability of predicting future process behavior can be increased. The capability of the process is determined based on the behavior of individual products in relation to the specification.

The capability of a process is assessed through what is known as capability indices. These indices compare the prescribed permissible variability, as defined by the limit values, with the actual achieved variability of the quality characteristic. The two most commonly used types of capability indices are the Capability Index Cp and the Critical Capability Index Cp_k. The Capability Index, Cp, can only be calculated when both limit values of the monitored quality parameter are specified. It compares the permissible and actual variability of values, irrespective of the location of the values within the tolerance field.

While its value characterizes the potential capabilities of the process, it does not provide insights into how these capabilities are utilized. On the other hand, the Critical Capability Index, Cp_k, can be calculated when both or only one of the specifications is specified. Unlike the Cp index, the Cp_k index considers the location of the values within the tolerance field. Thus, its value characterizes the actual ability of the process to comply with the prescribed limits, offering insight into the guarantee we provide for quality. The entire concept of capability indices stems from Genichi Taguchi`s philosophy of target-oriented quality indicates that the further a product deviates from the target value, the more severe the loss. Building on Genichi Taguchi`s Loss Function philosophy, the Cp, Cp_k indices approach, and the SPC technique converge (Chaloupka, 2008; Mitra, 2016, Dian, 2018). Understanding Taguchi`s loss function philosophy becomes crucial during the machinery design preparation stage when the future machine`s ability/capability is determined with respect to customer specifications. The Cp and Cp_k process capability indices are mathematical ratios quantifying the ability of a process to produce products within the specifications (Tab. 1).

Table 1.
The Capability indices as the important KPI´s

Capability of product	**Capability of machine**	**Capability of Gauge**
$C_p = \frac{USL - LSL}{6s}$	$C_m = \frac{\frac{3}{4}\,(USL - LSL)}{6\,s_M}$	$C_g = \frac{0.15\,(USL - LSL)}{6\,s_g}$
$C_{Pk} = \frac{USL - \bar{X}}{3s}$	$C_{mkU} = \frac{\frac{3}{4}\,(USL - \overline{X_M})}{3\,s_M}$	$C_{gkU} = \frac{(T + 0{,}075\Delta) - \overline{X_g}}{3\,s_g}$
$C_{Pk} = \frac{\bar{X} - LSL}{3s}$	$C_{mkL} = \frac{\frac{3}{4}\,(\overline{X_M} - LSL)}{3\,s_M}$	$C_{gkL} = \frac{\overline{X_g} - (T - 0{,}075\Delta)}{3\,s_g}$
$C_{Pk} = min(C_{pkU;}C_{pkL})$	$C_{mk} = min\,(C_{mkU}; C_{mkL})$	$C_{gk} = min\,(C_{gkU}; C_{gkL})$

Source: (Fabian et al., 2007)

Here, Cp is the Capability Index, defined as the ratio of the tolerance (USL – LSL, where USL is the Upper Specification Limit and LSL is the Lower Specification Limit) to 6s (where s represents the standard deviation). On the other hand, Cp_k is the Critical Capability Index, defined as the ratio of the minimum of (USL - $\bar{X}$) and ($\bar{X}$ - LSL) to 3s, where $\bar{X}$ is the mean value. The “min” (minimum) indicates that the more appropriate value is the lesser of the two calculated values, representing worse process behavior. The Cp is generally considered as the potential of the process, while Cp_k reflects how effectively we can utilize this potential. Cp_k is also referred to as the “Quality Guarantee” index. The “m” index represents machine, “g” index represents gauge, “L” stands for lower, and “U” stands for upper. The real values of USL and LSL are determined based on agreed customer specifications. The parameter “s” in the denominator, representing the standard deviation, is calculated from measurements of at least 30 manufactured pieces taken from a real production line. The prerequisite for utilizing capability indices is to perform a normality test to determine whether the set of data shows a normal distribution. For practical capability studies, Cp_k is considered the most important, as it immediately indicates the current Quality Guarantee (refer to Table 2).

Table 2.
The Capability indices as the important KPI´s and their mutual relation

When: $C_p \geq C_{pk} \geq 1$	Then: $C_m \geq C_{mk} \geq 1.33$
$C_p \geq C_{pk} \geq 1.33$	$C_m \geq C_{mk} \geq 1.67$
$C_p \geq C_{pk} \geq 1.67$	$C_m \geq C_{mk} \geq 2$

Source: (Fabian et al., 2007, Chaloupka, 2008)

3. CAPABILITY STUDIES DURING INDUSTRIALIZATION PRO-CESS

Based on customer expectations during pre-serial production, all dimensions on the customer's drawing were measured and capabilities analyzed (see Fig. 1). Immediate corrective actions were taken to prevent discrepancies. After the SOP, a set of CSE characteristics was chosen (Tab. 3), and the development of their capabilities studies is presented in Fig. 1. Following the initial flow stage, the SPC was implemented using regulation diagrams (Fig. 2), and reporting took the form of a dashboard (Fig. 3) that was put into use.

The industrialization process is a crucial component of the overall approach to introducing a new product to the market. It commences with research and development, extending through industrial production. Capability studies, integral to ensuring product quality, commence well before the Start of Production (SOP), beginning with the design and prototype stages. They continue through pre-serial production, the initial flow stage, and must be sustained throughout the entire period of serial production.

Table 3.
An example of chosen CSE characteristics based on customer requirements and Control plan

CSE Characteristics Steering Column		Nominal value	Tolerance	Control plan limit	Frequence & means of control
1	Lower bearing crimping	5	+0.5/-2	3 - 5.5	5/consequent pieces Caliper
2	Bearing extraction force (75 dents fork)	2000	min	1800 min	3/shift special gauge
3	Bearing extraction force (44 dents fork)	2000	min	1800 min	3/shift special gauge
4	Bearing extraction force (cardan fork)	2000	min	1800 min	3/shift special gauge
5	Bearing extraction force (telescopic shafts)	2000	min	1800 min	5/consequent pieces Caliper
6	Securisation of plastic sleeve	0.7	± 0.25	0.45 - 0.95	5/consequent pieces Caliper
7	Handle locking force	60	+10/-15	45–70	5/consequent pieces Push Pull meter
8	Extraction force of telescopic shafts	300	min	300 min	1/shift /Instron
9	Securisation of 44 dents fork	1	+0/-0.4	0.6–1.0	5/consequent pieces High gauge
10	Securisation of telescopic shafts	1.2	+0.3/-0.2	1.0	5/consequent pieces High gauge

Source: (Own Study)

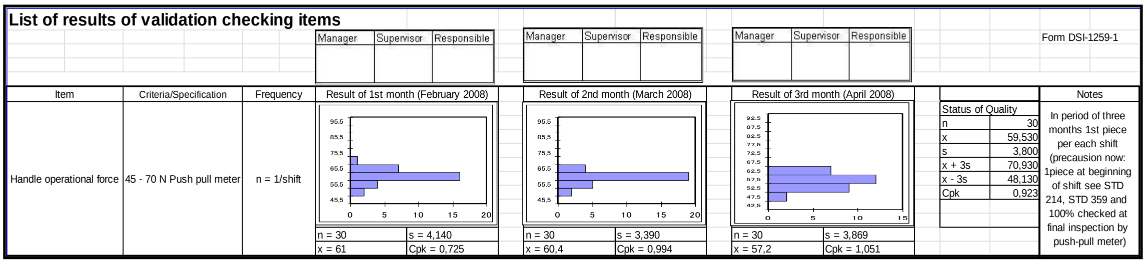


Fig. 1. Capability report from Initial flow of serial production - CSE parameter (Source: Own Study)

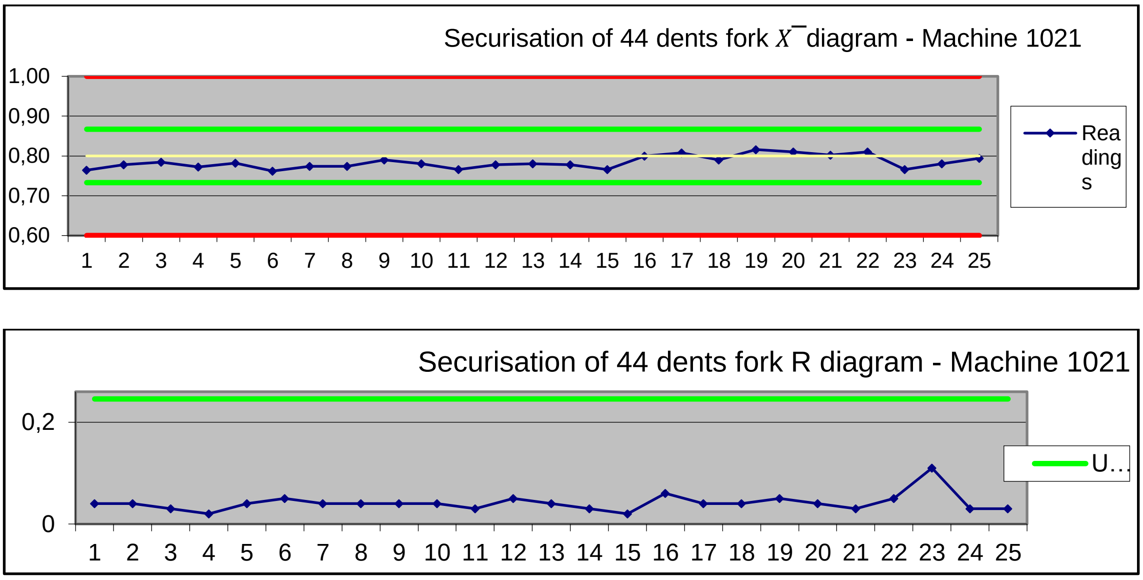
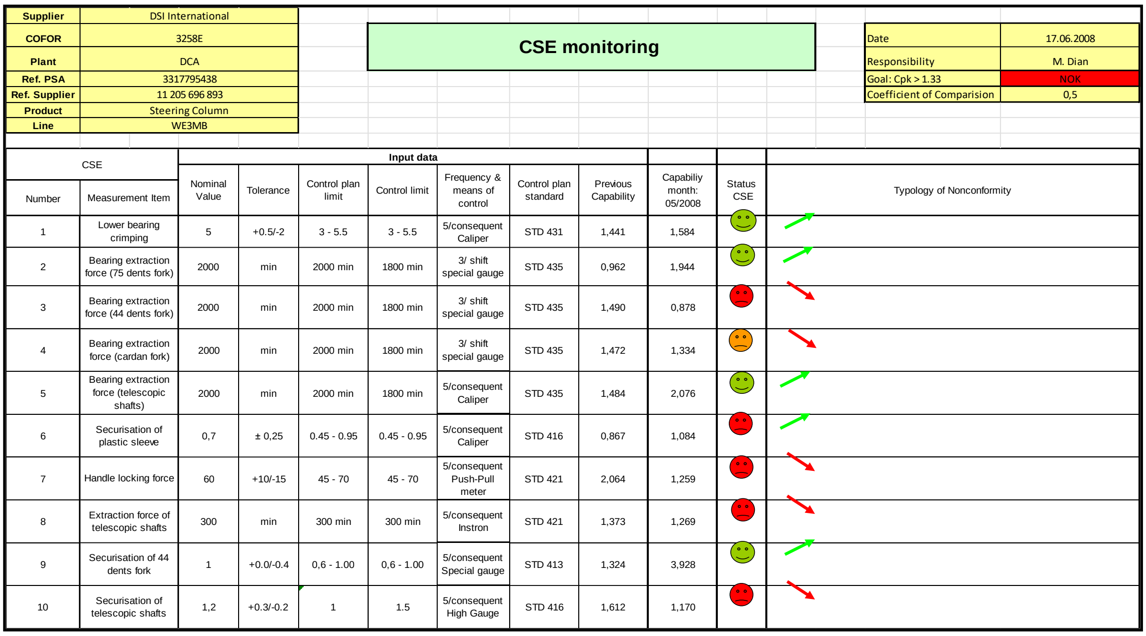


Fig. 2. SPC $\bar{X}$-R chart implemented on CSE characteristic in serial production (Source: Own Study)



CSE monitoring

Supplier	DSI International
COFOR	3258E
Plant	DCA
Ref. PSA	3317795438
Ref. Supplier	11 205 696 893
Product	Steering Column
Line	WE3MB

Date	17.06.2008
Responsibility	M. Dian
Goal: Cpk > 1.33	NOK
Coefficient of Comparision	0,5

CSE		Input data									
Number	Measurement Item	Nominal Value	Tolerance	Control plan limit	Control limit	Frequency & means of control	Control plan standard	Previous Capability	Capabiliy month: 05/2008	Status CSE	Typology of Nonconformity
1	Lower bearing crimping	5	+0.5/-2	3 - 5.5	3 - 5.5	5/consequent Caliper	STD 431	1,441	1,584		
2	Bearing extraction force (75 dents fork)	2000	min	2000 min	1800 min	3/ shift special gauge	STD 435	0,962	1,944		
3	Bearing extraction force (44 dents fork)	2000	min	2000 min	1800 min	3/ shift special gauge	STD 435	1,490	0,878		
4	Bearing extraction force (cardan fork)	2000	min	2000 min	1800 min	3/ shift special gauge	STD 435	1,472	1,334		
5	Bearing extraction force (telescopic shafts)	2000	min	2000 min	1800 min	5/consequent Caliper	STD 435	1,484	2,076		
6	Securisation of plastic sleeve	0,7	± 0,25	0.45 - 0.95	0.45 - 0.95	5/consequent Caliper	STD 416	0,867	1,084		
7	Handle locking force	60	+10/-15	45 - 70	45 - 70	5/consequent Push-Pull meter	STD 421	2,064	1,259		
8	Extraction force of telescopic shafts	300	min	300 min	300 min	5/consequent Instron	STD 421	1,373	1,269		
9	Securisation of 44 dents fork	1	+0.0/-0.4	0,6 - 1.00	0,6 - 1.00	5/consequent Special gauge	STD 413	1,324	3,928		
10	Securisation of telescopic shafts	1,2	+0.3/-0.2	1	1.5	5/consequent High Gauge	STD 416	1,612	1,170		

Fig. 3. Example of CSE Management weekly report in serial production (Source: Own Study)

The early phases of capability studies are seamlessly integrated into the Advanced Product Quality Planning (APQP, 2008) process, supported by a well-established system of Essential Monitored Characteristics (CSE) management. The industrialization process itself is comprised of three essential stages from a quality perspective.

The first phase involves preparing for production, which includes reminding the customer of rules and requirements for the industrialization phase at the supplier`s end. It also involves managing the acceptance of supplied parts through IT tools, encompassing management, planning, and evaluation with targeted outcomes. Special attention is given to reporting documents, which must be updated monthly. The second stage, known as the Pre-serial Off-Line stage, involves the delivery of parts from final tools intended for assembly approximately 50 weeks before the Start of Production (SOP), contingent on quality status. During this stage, the focus is on achieving prescribed targets for Aspect quality indicators, Functional quality indicators, Dynamic tests, and ABCD defects. This stage serves as an opportunity to fine-tune the tools, with the objective of permanently freezing the product definition by the phase`s end. The last deliveries in this stage initiate product pre-qualifications.

In terms of quality, a prompt reaction to nonconformities is required (within 48 hours) along with an 8D report. Confirmation of the transition from the Pre-serial Off-Line phase to the Pre-serial On-Line phase is conditional on achieving the quality targets. By the end of the Pre-serial Off-Line phase, 100% of the product pre-qualifications must be acquired for each function. The next phase (the third one), the Pre-serial On-Line phase, is intended for the development of industrial means to guarantee the conformity of deliveries in a repeatable way at full speed. This stage marks the transition to series operating modes. All industrial resources must be in series from the start of the Pre-serial Off-Line phase, and by the end, all product qualifications and process approvals must be acquired. The conclusion of this phase is the moment to switch from pre-serial to serial operating functioning in a form called Ramp Up (refer to Table 4).

Throughout the aforementioned stages of industrialization, a weekly list of parts with a significant impact on quality (Aspect, Functional, Dynamic, ABCD faults) has been reported regularly, including quality Key Performance Indicators (KPIs) such as Capability Indices. Since the Start of Serial Production (SOP), the importance of monitoring capability remains significant. This is why a monitoring system, referred to as “Initial Flow Management,” is implemented at intervals between 3 to 6 months, depending on the quality level and the associated quality guarantee. Subsequently, CSE management continues throughout the entire serial production of the product.

Table 4.
An Example of check list within industrialization process

The supplier uses supplier quality manual on the B2B Portal
The monthly progress report has been released
The Industrialization Timing Plan has been released
The Essential Characteristics CSE List has been released
The Tooling progress Report has been released
The Control Plan has been released
The Control Report has been validated
Contact List has been filled in (in the presented file)
Contact with customer is operational
The sales and delivery contract are signed
Logistic data are available (in the presented file)
Target dates for run at rate days are defined
The Ramp-up is validated

Source: (Group PSA, 2021)

The continual surveillance of CSE parameters is crucial for several reasons. Monitoring these parameters helps prevent risks to the final customer, guarantees the functionalities required by the customer and other stakeholders, and ensures the integration of the component chain in the vehicle. Achieving appropriate levels of capability indices (Cp_k = 1.33 or 1.67) not only meets customer satisfaction but can even lead to customer delight. To attain excellent or targeted results in terms of capability indices during serial production, it is imperative to prepare various aspects such as the product, process, machinery, tools, gauges, equipment, and personnel. In other words, creating the right conditions is necessary to reach the set targets. Awareness of critical points is crucial to avoid potential issues that may arise later, preventing unpleasant surprises and ensuring the fulfillment of quality commitments. One significant issue is the possibility of design changes and material or supplier changes during the pre-serial or qualification process. The second issue pertains to machinery design, including parameters setting possibilities, precision, and the capabilities of the chosen technology, including tools. It`s essential to be aware that some production lines may face challenges in reaching targeted capability levels, even if they are brand new. The third issue to consider is the chosen methods and measurement equipment and their ability (R&R) to reach prescribed targets, accompanied and influenced by the human factor. During capability evaluation in the pre-serial stage, a short-term capability approach is used, while in the initial flow stage and serial production within CSE management, the long-term capability is employed (Simion, 2017; Dian, 2017, 2018). Based on the known and previously described methodology, the first step of the Capability study process is the determination of the most important characteristics of the product, the CSE (Tab. 3). The following figure (see Fig. 4) illustrates the preliminary capability performed before entering pre-serial production. All characteristics on the drawing must comply with required values (standards). In case of any discrepancy, appropriate action must be taken.

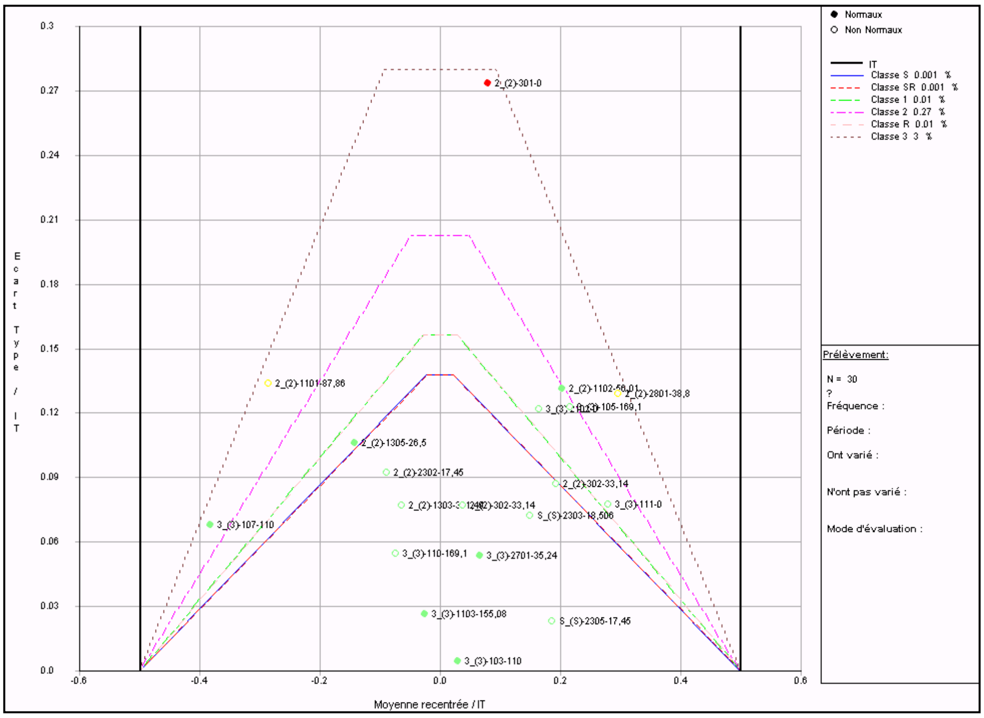
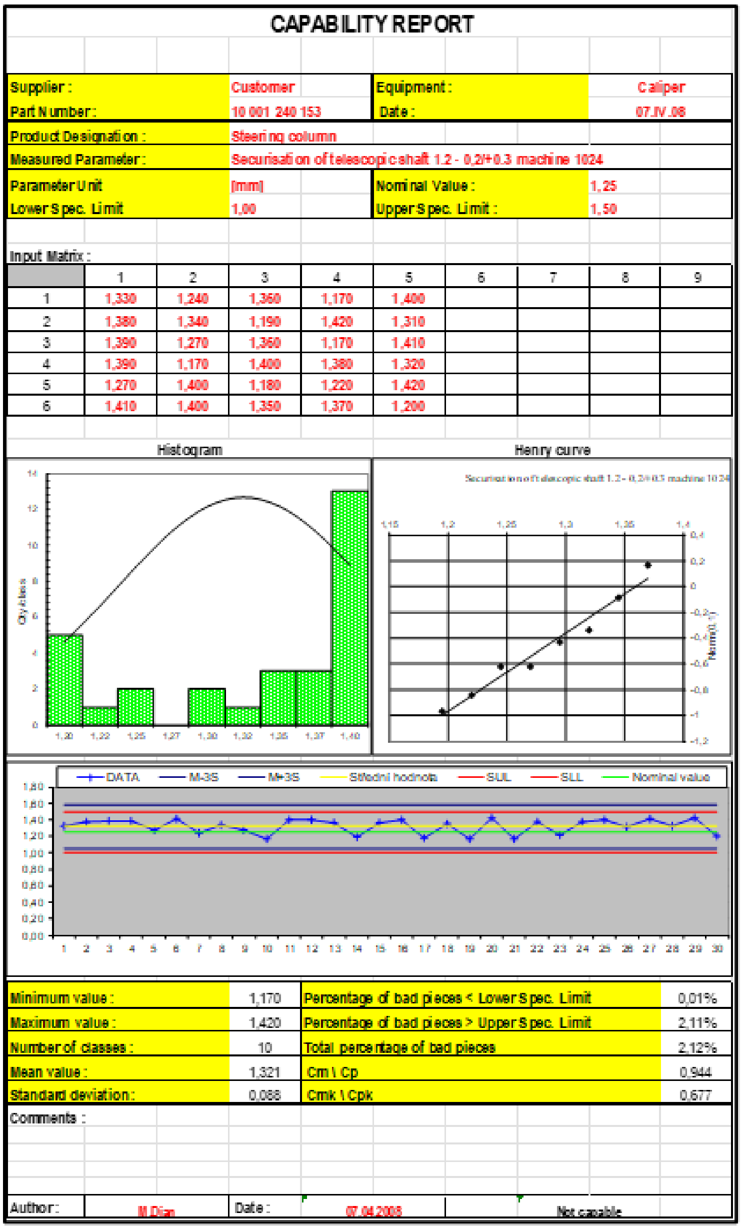


Fig. 4. Synthesis of Capability study from pre-serial stage of production (TAG software) (Source: Own Study)



CAPABILITY REPORT

Supplier :	Customer	Equipment :	Caliper
Part Number :	10 001 240 153	Date :	07.IV.08
Product Designation :	Steering column		
Measured Parameter :	Securisation of telescopic shaft 1.2 - 0,2/+0.3 machine 1024		
Parameter Unit	[mm]	Nominal Value :	1,25
Lower Spec. Limit	1,00	Upper Spec. Limit :	1,50

Input Matrix :

	1	2	3	4	5	6	7	8	9
1	1,330	1,240	1,360	1,170	1,400				
2	1,380	1,340	1,190	1,420	1,310				
3	1,390	1,270	1,360	1,170	1,410				
4	1,390	1,170	1,400	1,380	1,320				
5	1,270	1,400	1,180	1,220	1,420				
6	1,410	1,400	1,350	1,370	1,200				

Minimum value :	1,170	Percentage of bad pieces < Lower Spec. Limit	0,01%
Maximum value :	1,420	Percentage of bad pieces > Upper Spec. Limit	2,11%
Number of classes :	10	Total percentage of bad pieces	2,12%
Mean value :	1,321	Cm \ Cp	0,944
Standard deviation :	0,088	Cmk \ Cpk	0,677

Comments :

Author : M.Dian Date : 07.04.2008 Not capable

Fig. 5. Detailed Capability report of one of the CSE parameters in pre-serial production (Source: Own Study)

During the previously mentioned periods of the industrialization process, each specific controlled characteristic can be calculated using MINITAB or Excel software at regular intervals. The obtained results are analyzed and presented to the customer in a specific format for each CSE parameter (Fig. 3). The initial flow is maintained to enhance and stabilize serial or mass production, essentially representing the final phase of maintaining quality assurance (Fig. 1). To ensure that all CSE characteristics are continuously maintained at the required levels and to react promptly in case of any issues, Statistical Process Control (SPC) must be implemented (Fig. 2 and Fig. 3).

5. SUMMARY AND CONCLUSION

In conclusion, the article highlights a crucial and powerful quality tool essential for monitoring manufactured products across various phases, from industrialization through serial production to sustained quality. Drawing inspiration from the Japanese approach, the Capability of a product emerges as a pivotal Key Performance Indicator (KPI), demanding continuous monitoring, reporting, and maintenance. The article underscores the critical importance of effective communication and collaboration between designers and technologists to avoid discrepancies arising from tight tolerance limits that might exceed current technological capabilities. Failure to address these discrepancies could jeopardize the achievement of quality commitments and guarantees, as represented by the Cp_k values of 1.33 or 1.67. Moreover, the article meticulously details the industrialization process, emphasizing the role of Capability indices and their impact on chosen CSE/CTQ characteristics in real manufacturing processes. It shares insights from the manufacturing sector, identifying and addressing potential obstacles to enhance awareness and prevent challenges. The provided sequence of documents, including the Synthesis of capability before pre-serial production, pre-serial stage, validation phase, Initial flow approach, and ongoing monitoring with daily based corrective actions and weekly reporting, offers a comprehensive guide. The success of the described system hinges on trained personnel supported by the principles of Daily Management rooted in Total Quality Management (TQM) approaches. The article concludes by serving as a practical guide for quality professionals, aiding them in establishing and maintaining a robust quality assurance system. It emphasizes the use of the mentioned KPIs and approach to not only meet but exceed customer expectations, ultimately achieving customer delight and improving and sustaining the production process..

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