Management and Production Engineering Review
Volume 3 • Number 4 • December 2012 • pp. 69–79
DOI: 10.2478/v10270-012-0035-8

MEASUREMENT OF EFFECTIVENESS OF NEW PRODUCTS IMPLEMENTATION PROCESS ACCORDING TO APQP/PPAP REQUIREMENTS – PROPOSITION OF INDICES

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Received: 29 October 2012
Accepted: 26 November 2012

Abstract
One of the requirements of the process approach is to identify the methods and evaluation criteria for process measurement. The effectiveness described as the ability to execute scheduled tasks and the objectives may be the measure used to evaluate processes. The article presents a few concepts of efficiency indicators that can be used in assessing the activities carried out within the framework of the implementation of new projects, according to APQP&PPAP guidelines. This paper proposes four concepts of indicators to assess the effectiveness of the above-described process, including index based on the Taguchi loss function.

Keywords
APQP, PPAP, Flow Chart, FMEA, Taguchi, Loss Function.

Supplier quality assurance through PPAP procedure

Quality of the final product no longer depends solely on its manufacturer. It has become the outcome of the quality of its components supplied by numerous subcontractors.

In automotive industry, a considerable complexity of the product structure combined with a high pace of implementation of manufacturing processes (usually accompanied by requirements to assure on – time deliveries) created a narrow specialization of suppliers. OEMs suppliers along with their suppliers, etc., create a supply chain – complicated and difficult to manage [1]. Transferring of production from manufacturers premises to suppliers caused great limitations with respect to controlling of processes. Moreover, one can notice a considerable shortening of the product life cycle, not only in automotive industry. Products used to be manufactured without any changes for several decades. This is no longer possible in contemporary market. Currently, the life cycle of any car model amounts up to several years [2]. Such a situation is a reason of frequent implementations of new manufacturing processes at OEMs and their sub-contractors. This has raised an important issue of controlling sub-contractors processes to assure quality of the products and timely deliveries. As the remedy formal quality management systems were developed – ISO 9001 [3] and its extension for automotive industry – ISO/TS 16949 [4]. However, the requirements contained in these documents do not sufficiently protect interests of car manufacturers in terms of quality and timely deliveries, therefore the great American car manufacturers: Chrysler, Ford and General Motors have developed additional requirements for suppliers, the so called quality manuals, including among others: APQP (Advanced Product Quality Planning) [5] and its comple-

ment – the PPAP procedure (Production Part Approval Process) [6]. Others manuals cover methods like FMEA, MSA, SPC – extending and describing in detail requirements of APQP and PPAP.

The PPAP procedure is an essential part of preparation phase of production process. It contains a number of guidelines for suppliers, who are obliged to present a set of qualitative evidences proving readiness for SOP (Start of Production). This means that the supplier, before starting deliveries, is required to develop and submit a particular documentation for the customer for his approval. The required documents answers 18 requirements imposed by PPAP manual, cited in Table 1.

All requirements have been specified together with customer-supplier agreed level of submission. It determines which of the evidences (documents) shall be submitted (presented) to a customer as default and which of the evidences should be submitted on customer's demand. The most frequently used level of submission is level 3, the so-called full PPAP. After completing the required documents, a PSW (Part Submission Warrant) is filled and all are sent to a customer together with reference samples. A customer makes a decision about submitted documents notifying supplier of PPAP approval, temporary approval or PPAP rejection.

To get a PPAP approval on time a process of acquisition and development of PPAP required evidences should be planned, monitored, measured, evaluated and systematically improved on the basis of obtained results. However, authors experience show that applying basic PDCA cycle for PPAP is hardly a case. The paper is hoped to be a contribution to efforts aiming at changing this situation.

Table 1
PPAP requirements for suppliers [6].

REQUIREMENTS – PPAP ELEMENTS	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1. Design Record	R	S	S	*	R
- for proprietary components/details	R	R	R	*	R
- for all other components/details	R	S	S	*	R
2. Engineering Change Documents, if any	R	S	S	*	R
3. Customer Engineering Approval **	R	S	S	*	R
4. Design FMEA	R	R	S	*	R
5. Process Flow Diagrams	R	R	S	*	R
6. Process FMEA	R	R	S	*	R
7. Control Plan	R	R	S	*	R
8. Measurement System Analysis	R	R	S	*	R
9. Dimensional Results	R	S	S	*	R
10. Material, Performance Test Results	R	S	S	*	R
11. Initial Process Studies	R	R	S	*	R
12. Qualified Laboratory Documentation	R	S	S	*	R
13. Appearance Approval Report (AAR) **	S	S	S	*	R
14. Sample Product	R	S	S	*	R
15. Master Sample	R	R	R	*	R
16. Checking Aids	R	R	R	*	R
17. Records of Compliance with Customer-Specific Requirements	R	R	S	*	R
18. Part Submission Warrant (PSW)	S	S	S	*	R
Bulk Material Checklist	S	S	S	*	R

Required way of presenting the evidence to customer:

S	The organization shall submit to the customer and retain a copy of records or documentation items at appropriate locations
R	The organization shall retain at appropriate locations and make available to the customer upon request
*	The organization shall retain at appropriate locations and submit to the customer
**	If required / applicable

Justification of the need to measure the PPAP effectiveness

ISO 9000:2005 [7] defines the process as a set of interrelated activities which interact and transform inputs into required outputs. Tasks required by PPAP (no mention its name) implies that it is a process, therefore it is necessary to:

- define it as a sequence of activities,
- assign each activity its input and output with specific requirements (goals),
- identify and assure necessary resources,
- assign responsibility for each activity.

PPAP treated as a process can be presented as a flowchart (Fig. 1) defining the order of activities aiming at obtaining evidences for PPAP submission.

At the PPAP input a supplier has to gather and review all engineering data and records defining requirements for a product a supplier is supposed to deliver (design, manufacture), including technical changes (if any) and evidence of customers technical approval. Special attention should be paid to principles of GD&T. Engineering data at PPAP input is usually delivered in electronic format (CAD, CAM).

At the output of the PPAP process a customer's approval status of the submitted PPAP documents is obtained.

Each process is designed and controlled in order to meet objectives, to add value. If it does so, a process can be described as effective. People in charge of processes need to know and report to what degree set targets are achieved by a process in order to control and improve it. This might be a fairly vague task if process targets definitions do not comply with the so called SMART rule. It recommends that objectives should be defined as Specific, Measurable, Ambitious, Reasonable and should have a designated Time horizon. This rule should be met also in case of PPAP process.

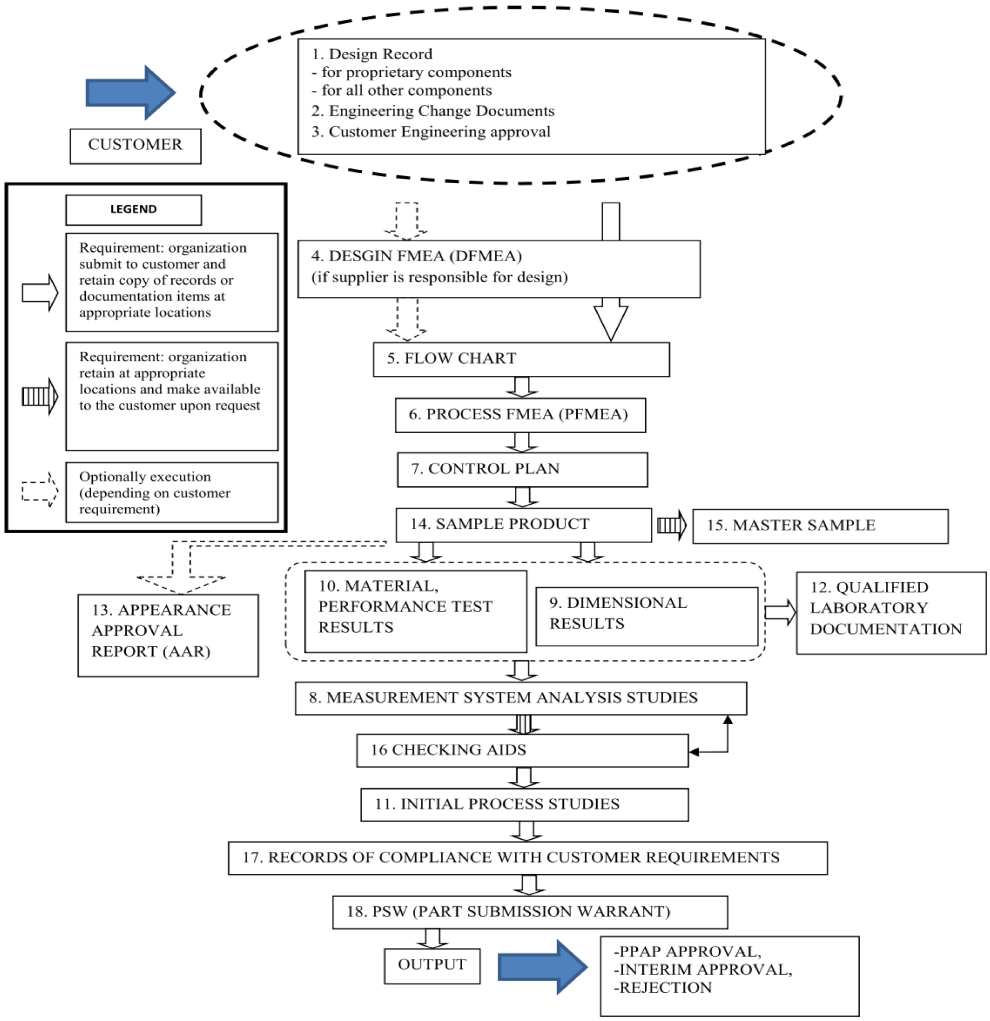


Fig. 1. The flow chart of preparing PPAP documentation at level 3 [1].

PPAP main objective, as was mentioned earlier, is to obtain customer approval in time (before SOP) or even on time (on planned time, before SOP). To achieve this goal, each PPAP step needs to be accomplished in time (or even on planned time). Obviously, this requires that PPAP process be carefully planned, with documented schedule, taking into consideration complexity of product affecting PPAP steps, SOP date and possible risks. Assuming such a schedule is developed, PPAP objectives, deployed down to PPAP scheduled steps, are:

- specific (technical requirements referring to each quality evidence are set by customer or by standard [5, 6]),
- ambitious (PPAP interim approvals or rejections happens),
- reasonable (PPAP approvals happens more often than interim approvals or rejections), and
- have time constraints (assuming detailed PPAP schedule).

PPAP objectives in terms of obtaining specific results of individual PPAP steps (e.g. PFMEA – acceptable risk indices, MSA – acceptable measurement system capability indices, SPC – acceptable process capability indices) are apparently measurable with results reviewed, reported and often undergoing continuous improvement.

PPAP objectives in terms of meeting deadlines scheduled for each PPAP step and for PPAP as a whole (obtaining final approval) are measurable, but apparently no measures are performed, no indices are reviewed, reported, no mention continuous improvement, which is hardly possible in terms of effectiveness of meeting deadlines.

Repeatability of PPAP process (steps and objectives for new products) makes it reasonable to think of PPAP process continuous improvement. To achieve this goal (so obvious for many processes in any manufacturing company), authors of this paper see the need to:

- determine time objectives of PPAP (schedule, down to PPAP steps),
- develop relevant indices for PPAP process monitoring and evaluation in terms of meeting scheduled deadlines.

The paper discusses a few concepts of PPAP indices, with an assumption made, that a company develops a detailed PPAP schedule before starting activities necessary to submit and obtain PPAP approval.

It will be necessary for personnel responsible for PPAP to identify and acquire all the required information to calculate proposed indices. This means the necessity of gathering additional quality records which should include information about the course (history), performance and conditions of the PPAP actions (steps).

Applying proposed indices should enable to measure PPAP effectiveness in terms of meeting scheduled PPAP deadline. This is necessary for PPAP process control and PPAP effectiveness improvement. This, in long term, would mean cost reduction and higher probability of:

- readiness for serial production in time,
- obtaining PPAP approval right the first time.

Proposed indices of PPAP effectiveness – general outline

Effectiveness of a process relates to a degree it meets its objectives. Effectiveness index should be defined as a function comparing an objective (or a set of objectives) with actual process performance. The paper introduces four concepts of effectiveness indices for PPAP process taking into consideration timely and successful execution of a whole PPAP and PPAP steps, as an objective (i.e. in accordance with a schedule, obtaining customer approval). The last of the presented indices is based on a concept of Taguchi loss function.

Each concept allows to evaluate both the effectiveness of each step of the PPAP process individually and the global effectiveness of the PPAP process. For the latter case the so-called OPE index (Overall PPAP Effectiveness) has been introduced, which can be calculated in two ways:

- as a product of each PPAP step effectiveness index (alike OEE), or
- as a global PPAP success index (treating PPAP as a whole, without going into effectiveness indices of PPAP steps).

The paper focused on effectiveness of major PPAP steps (of developing evidence to be submitted) such as DFMEA, Flow Chart, PFMEA, Control Plan, MSA, SPC. However, if following the analogy, the proposed indices can be used for any other PPAP step (Fig. 1).

PPAP effectiveness indices – the concept number 1 (linear)

For the purpose of further discussion, the following terms and symbols have been introduced:

t_d – actual delay in accomplishing of a given step of PPAP (compared to a scheduled deadline),

t_{d0} – critical (predefined) delay in accomplishing of a given step of PPAP; can be calculated basing

on exact contractual date of full PPAP approval (or re-approval after resubmission) or SOP date agreed with a customer; the critical delay may also take into consideration a risk of not meeting PPAP submission deadline,

t_p – actual period of time devoted to development of a given PPAP step (or a whole PPAP),

t_{start} – planned (scheduled) time (e.g. date) for starting development of a given PPAP step,

t_{plan} – planned (scheduled) time (e.g. deadline date) for finishing development of a given PPAP step or a whole PPAP,

T_{plan} – planned (scheduled) period of time for development of a given PPAP step or of a whole PPAP,

t_{SOP} – planned (scheduled) start of production time (e.g. date), according to a project schedule,

i – id. no. of (i-th) PPAP step (e.g. PFMEA),

Es – effectiveness index,

Esi – effectiveness index for i-th step of PPAP.

Assumptions for the concept no. 1:

I. index is expected to be a linear function of delay,
II. effectiveness for $t_d = 0$ is expected to be 100%,
III. effectiveness for $t_d = t_{d0}$ is expected to be 0%,
IV. effectiveness for $t_d > t_{d0}$ should decrease below 0% (negative),
V. effectiveness for negative delays ($t_d < 0$) is expected to grow starting from the value of 100%.

Basing on above assumptions, a formula for Es index as a function of a delay (t_d) can take a form of a linear function:

$$Es = a \cdot t_d + b. \tag{1}$$

The above function can be represented as a bunch of lines shown in Fig. 2 (with slope depending on t_{d0} value).

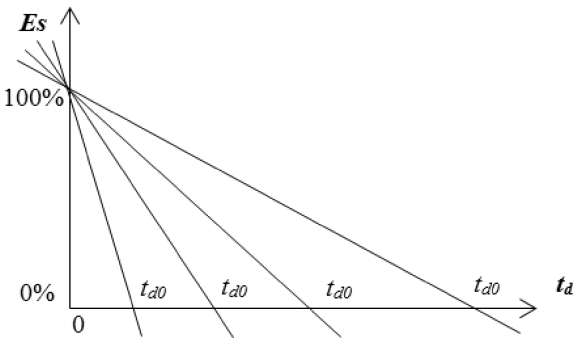


Fig. 2. Effectiveness (Es) vs delay (t_d) and critical delay (t_{d0}).

According to assumptions I-V formula (1) takes the following, general form:

$$Es = \left(1 - \frac{t_d}{t_{d0}}\right) \cdot 100\%. \tag{2}$$

which referenced to a given PPAP i-th step, gives:

$$Es_i = \left(1 - \frac{t_{d_i}}{t_{d0_i}}\right) \cdot 100\%. \tag{3}$$

In the same way one can perform a calculation of the effectiveness index for PPAP as a whole:

$$Es_{PPAP} = 100\% \left(1 - \frac{t_{dPPAP}}{t_{d0PPAP}}\right), \tag{4}$$

where t_{dPPAP} – delay of PPAP completion (compared to a scheduled deadline), t_{d0PPAP} – critical PPAP delay.

An example of Es calculation with critical delay

A person responsible for PPAP, during planning phase, decided critical Flow Chart delay to be 10 days (taking into consideration PPAP submission deadline and risk of missing it due to Flow Chart delays). During PPAP the Flow Chart was prepared with 2 days delay compared with a schedule. Thus, according to agreed terms and abbreviations:

$$t_d = 2, \tag{5}$$

$$t_{d0} = 10. \tag{6}$$

The effectiveness index of PPAP step: Flow Chart, by substituting (5), (6) to (2), gives:

$$Es_{Flow\ Chart} = 80\%. \tag{7}$$

OPE – Overall PPAP Effectiveness

Figure 3 shows the concept of Overall PPAP Effectiveness index (OPE), which is a product of all PPAP steps effectiveness indices, e.g.:

$$OPE = Es_{FlowCh} \cdot Es_{PFMEA} \cdot Es_{CtrlPlan} \cdot Es_{MSA} Es_{SPC}. \tag{8}$$

In general:

$$OPE = \prod_{i=1}^{n} Es_i, \tag{9}$$

where n – number of PPAP steps (pieces of evidence to be submitted).

This approach and formula were also used within the other two concepts of PPAP effectiveness, presented in the following parts of this paper.

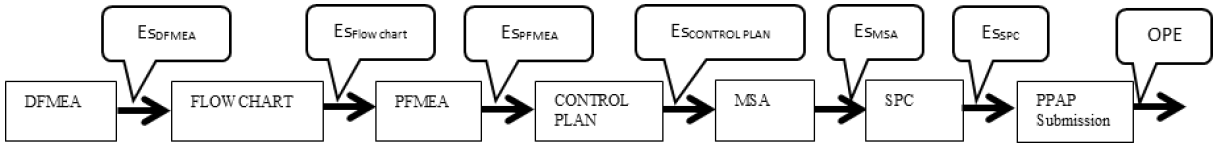


Fig. 3. Comparison of a single PPAP step effectiveness and Overall PPAP Effectiveness.

PPAP effectiveness indices – the concept number 2 (linear with SOP)

This concept is a special case of the concept described in 3.1 with the assumption that the critical delay coincides with a required start of production (SOP) date. This means that the critical delay in development of a given PPAP step (or PPAP as a whole) can be expressed as:

$$t_{d0} = t_{SOP} - t_{plan}. \tag{10}$$

Assumptions for the concept no. 2:

I. index is expected to be a linear function of delay,
II. effectiveness for $t_d = 0$ is expected to be 100%,
III. effectiveness for $t_d = t_{d0} = t_{SOP} - t_{plan}$ is expected to be 0%,
IV. effectiveness for negative delays ($t_d < 0$) is expected to grow starting from the value of 100%,
V. effectiveness for $t_d > t_{SOP} - t_{plan}$ should decrease below 0% (negative).

On the basis of the above assumptions it can be seen that this indicator is a special case of the indicator described above (Subsec. 3.1).

Basing on above assumptions, a formula for Es index as a function of a delay (t_d) can take a form of a linear function:

$$Es = a \cdot t_d + b. \tag{11}$$

The function $Es = f(t_d)$ is illustrated in Fig. 4.

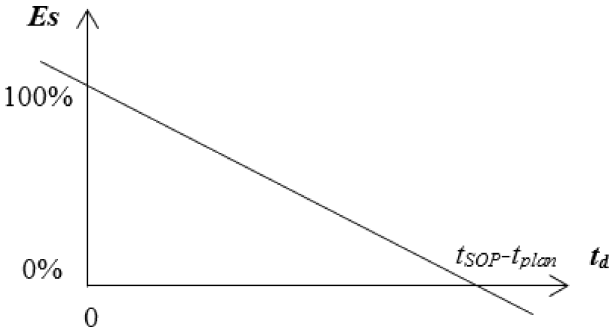


Fig. 4. Effectiveness (Es) vs delay (t_d) and SOP.

According to assumptions I–V (allowing to calculate parameters a and b) formula (11) takes the following, general form:

$$Es = \left(1 - \frac{t_d}{t_{SOP} - t_{plan}}\right) \cdot 100\% \tag{12}$$

which referenced to a given PPAP i-th step, gives:

$$Es_i = \left(1 - \frac{t_{d_i}}{t_{SOP} - t_{plan_i}}\right) \cdot 100\%. \tag{13}$$

In the same way one can perform a calculation of the effectiveness index for PPAP as a whole:

$$Es_{PPAP} = \left(1 - \frac{t_{d_{PPAP}}}{t_{SOP} - t_{plan_{PPAP}}}\right) \cdot 100\%, \tag{14}$$

where t_{dPPAP} – delay of PPAP completion (compared to a scheduled deadline), $t_{planPPAP}$ – planned (scheduled) time of development of a whole PPAP.

An example of Es calculation with SOP

On 3.01.2012 a person responsible for PPAP initiates a PFMEA. Completion date of this activity (meant as obtaining acceptable risk for a new manufacturing process) was scheduled on 31.01.2012. The start of production (SOP) date, according to a customer project schedule, was scheduled on 29.02.2012. Due to some unexpected problems, the PFMEA was completed 5 days after planned deadline – on 05.02.2012. Thus, according to agreed terms and abbreviations:

$$t_{SOP} = 29.02, \tag{15}$$

$$t_{d\_PFMEA} = 05.02\text{–}31.01 = 5 \text{ days}, \tag{16}$$

$$t_{plan\_PFMEA} = 31.01, \tag{17}$$

$$t_{SOP} - t_{plan\_PFMEA} = 29 \text{ days}. \tag{18}$$

The effectiveness index of PPAP step: PFMEA, by substituting (15)–(18) to (13), gives:

$$Es_{PFMEA} = 82.8\%. \tag{19}$$

OPE – Overall PPAP Effectiveness

Having calculated Esi indices (as described above) for each i-th PPAP step, the OPE (Overall PPAP Effectiveness) index can be calculated in a way described in clause 3.1.2.

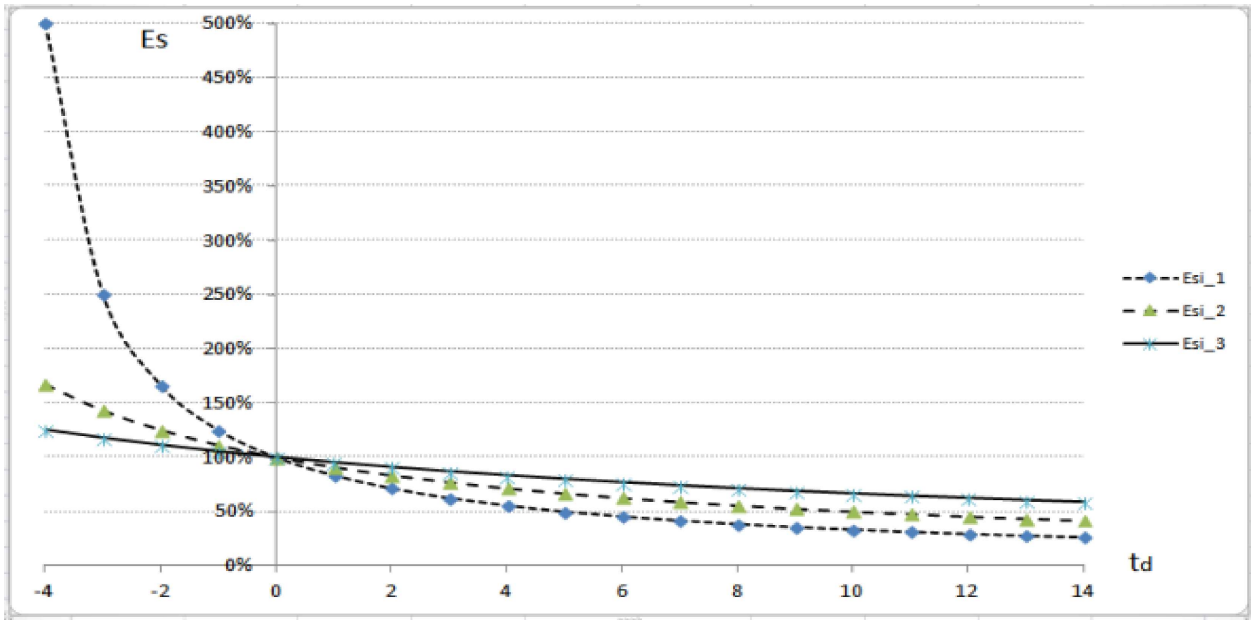


Fig. 5. Assumed nonlinear dependence of the effectiveness Es from the delay t_d (own work).

PPAP effectiveness indices – the concept number (nonlinear)

Assumptions for the concept no. 3 are as follow:

I. index is expected to be a nonlinear function of delay, decreasing with t_d, initially significantly, then slower as t_d increases,
II. effectiveness should depend on delay t_d in relation to a scheduled planned period t_{plan}, i.e. the smaller is $(t_{plan} - t_{start})$ period, the smaller should the Es be for a given t_d,
III. effectiveness for $t_d = 0$ is expected to be 100%,
IV. effectiveness for $t_d \to \infty$ should asymptotically approach 0,
V. effectiveness for negative delays $(t_d < 0)$ should increase from value 100% .

Basing on above assumptions, a formula for Es index as a function of a delay (t_d) can take a form of a nonlinear function (with parameters a and b):

$$Es = \frac{a}{t_d + b}. \tag{20}$$

The function $Es = f(t_d)$ is illustrated in Fig. 5.

According to assumptions I–V (allowing to remove parameters a and b) formula (20) takes the following, general form:

$$Es = \frac{T_{plan}}{t_d + T_{plan}} \tag{21}$$

which referenced to a given PPAP i-th step, gives:

$$Es_i = \frac{T_{plan_i}}{t_{d_i} + T_{plan_i}} \tag{22}$$

In the same way one can perform a calculation of the effectiveness index for PPAP as a whole:

$$Es_{PPAP} = \frac{T_{planPPAP}}{t_{dPPAP} + T_{planPPAP}}, \tag{23}$$

where t_{dPPAP} – delay of PPAP completion (compared to a scheduled deadline), $T_{planPPAP}$ – planned (scheduled) period of development of a whole PPAP.

An example of Es calculation

According to PPAP schedule, PFMEA was planned to be finished after 70 days. However, the document ready for submission was prepared with two weeks delay. Using formula (22) and considering:

$$t_d = 14, \tag{24}$$

$$T_{plan} = 70 \tag{25}$$

one obtains:

$$Es_{PFMEA} = 83.3\%. \tag{26}$$

OPE – Overall PPAP Effectiveness

Having calculated Esi indices (as described above) for each i-th PPAP step, the OPE (Overall PPAP Effectiveness) index can be calculated in a way described in clause 3.1.2.

Indicator of effectiveness based on Taguchi loss function

Assumptions for the concept no. 4 are as follow:

I. All steps of PPAP have been planned in optimal way – optimal in terms of PPAP submission deadline, product and process quality goals and consumed resources.
II. Each PPAP step should be performed on planned time.
III. Finishing any PPAP step before planned time incurs risk of not meeting customer quality requirements.
IV. Finishing any PPAP step after planned time incurs risk of not meeting PPAP submission deadline.
V. All above mentioned risks are difficult to estimate in terms of probability and costs (effects and losses).
VI. Potential, total losses (L) depend on the delay t_d, the function $L(t_d)$ being described rather as quadratic than linear relation to t_d.
VII. The potential risks and losses tend to increase as SOP date comes closer during PPAP development.

This implies that the potential loss related to each PPAP step can be described with Taguchi loss function [8], in which the loss is proportional to the square of the departure from target (here: delay t_d). Moreover, if $L(t_d)$ parabola is "calibrated" so that it gets steeper as SOP date gets closer (see: assumption VII), the Taguchi loss function seems to be a best function, addressing above assumptions I–VII.

As a result of the above assumptions and reasoning, effectiveness index can be expressed as a loss function for a given PPAP step:

$$L_i = k \cdot t_{d_i}^2, \tag{27}$$

where L_i – a potential loss incurred by a considered i-th PPAP step, k – coefficient (the slope of the parabola), t_{d_i} – delay of the PPAP step ("departure" from schedule); independent variable of the loss function.

Basing on the assumptions (I–IV) one obtains the following characteristic values of the loss function L_i (t_{di}):

$$L_i(0) = 0, \tag{28}$$

$$L_i(t_{SOP} - t_{plan}) = L_0. \tag{29}$$

Equation (28) can be explained on the basis of the assumption I (i.e. according to a PPAP schedule, only a planned time of execution of considered PPAP step yields no loss).

Equation (29) can be understood by noticing that for delay large enough to miss SOP date (for considered PPAP step) potential loss achieves critical value L_0, which can be estimated and then used for parabola "calibration" (see: assumption VII), i.e. determination of k value (27).

The critical loss L_0 can be estimated through possible losses, resulting from not submitting PPAP (early enough to be approved) before the SOP date.

Having estimated L_0, coefficient k (slope of the parabola) can be calculated by formula (30), obtained by substituting (28) and (29) to (27):

$$k = \frac{L_0}{(t_{SOP_i} - t_{plan_i})^2}. \tag{30}$$

In conjunction with (27) it gives the final formula for the loss function of a considered PPAP step:

$$L_i = \frac{L_0}{(t_{SOP_i} - t_{plan_i})^2} t_{d_i}^2 \tag{31}$$

The L_0 value requires estimation of somewhat arbitrary value of possible losses resulting from not submitting the required PPAP before the start of production. The examples of the proposed concepts for determining the L_0 value are as follow:

a. An "aggressive approach": L_0 is a planned (potentially lost) profit of the whole project (taking into account the expected life cycle of the project).
b. A "conservative approach": L_0 is a cost of the whole PPAP development (planned expenses).

Basing on (31), having calculated L_i values for all PPAP steps, it is possible to calculate the total PPAP loss, which is the sum of all losses of PPAP steps:

$$L_{PPAP} = \sum L_i. \tag{32}$$

L_i for each PPAP step can be compared with the total loss L_{PPAP} (32) in order to identify those elements of PPAP, which incur the highest, potential losses (risks) and thus should be given the highest priority at planning and then during realization phase. Effectiveness index based on Taguchi loss function is given by the following formula:

$$\%L_i = \frac{L_i}{L_{PPAP}} \cdot 100\%. \tag{33}$$

Example of application of the concept of Taguchi loss function to measure the effectiveness of PPAP

At the company manufacturing stamped parts, a new project manager, responsible for preparing

Table 2
Summary of data and calculations related to above example.

PPAP Component	t_{plan} [days]	t_d [days]	t_{SOP} [days]	$k\ \left[\frac{\text{EUR}}{\text{day}^2}\right]$	Li [EUR]	$\%Li$ [%]
DFMEA	30	0	120	864	0	0
Flow Chart	5	1	90	969	969	0.1
PFMEA	20	5	85	1 657	41 420	4.41
Control Plan	5	5	65	1 944	48 611	5.18
MSA	10	5	60	2 800	70 000	7.46
SPC	20	10	50	7 777	777 778	82.85
L_{PPAP} – total loss EUR		93 8778				

PPAP documentation, initiates the action for the ongoing project. He starts 120 days before the start of production. He determines the optimal execution time of a Control Plan – t_{plan}. However, during the preparations some delays have appeared (t_d). Let T_{SOP} value represent the number of days from the beginning of the PPAP step development till SOP date. The following table presents: t_{plan}, t_d and t_{SOP} values for a few steps.

Sales department together with a financial department have estimatde losses that the company may suffer from as a result of not submitting PPAP draft till the particular deadline – SOP. It is important to consider that this is the project for a newly-acquired customer. In order to consider the financial scale of the project, it has been decided to use an aggressive approach in the calculation of the losses (L_0). The basis for calculating the L_0 value is the potential loss of profit for the entire 5-year life of the project ($L_0 = 7000000$ EUR).

Taking into consideration the above assumptions, the k coefficient was calculated for considered PPAP steps (components). Then, formula (31) was used to calculate the potential loss of given PPAP steps (components). The sum of all losses gives the total loss. Then, using formula (33) effectiveness indices $\%L_i$ were calculated for considered PPAP steps (components). Results are shown in Table 2.

Summary and conclusions

For PPAP process to work effectively and produce the expected results, good PPAP (APQP) planning and its effective execution is of course necessary. PPAP as a process should undergo PDCA cycle (Plan, Do, Check, Act) to assure continuous improvement of PPAP (APQP) process.

Table 3 and 4 summarize four concepts of indices which can be used to assess the efficiency of the PPAP process, necessary for the "Check" stage of PDCA cycle.

- Presented concepts of effectiveness indices allow to assess the effectiveness (in terms of timeliness) of development of any evidence necessary for PPAP submission. They allow also to calculate the global effectiveness OPE of the PPAP process. Results can be a starting point for improving the PPAP process.
- Overall effectiveness of PPAP (OPE) is calculated as the product of the effectiveness indices of all PPAP steps considered.
- Global PPAP effectiveness is calculated by considering PPAP as the whole process with one deadline.
- In case of problems with quality of PPAP management, to improve the effectiveness of PPAP process, it is essential to identify PPAP steps (activities) that are most responsible for the low effectiveness of PPAP. For this purpose, the effectiveness indices for individual stages of PPAP has been proposed.
- According to the concept 1 (linear), to calculate effectiveness indices it is necessary to assume a critical delays (t_{d0}).
- In the concept 2 (linear with SOP), Start of Production date has been adopted as a base for critical delay (t_{d0}). This seems reasonable and natural from a practical point of view, because starting a production without having approved PPAP is not acceptable.
- In the concept 3 (nonlinear), for effectiveness indices to be calculated, it is not necessary to establish any critical delay (t_{d0}). In this concept, the effectiveness indices significantly depends on the delay already for small values of delays. The effectiveness index, reaching the lower value (below 100%), becomes less dependent on increasing delays. This may well reflect actual impact of PPAP steps delays on certain projects.
- Effectiveness indices ($\%L_i$) based on the concept of Taguchi loss function, describes in fact also efficiency of PPAP process, taking into consideration

possible loss resulting from departure from optimal, planned schedule of PPAP steps. This approach implies that there is a need for a optimally designed PPAP (APQP) process.

Table 3
Comparison of the presented concepts of PPAP performance indicators excl. Taguchi.

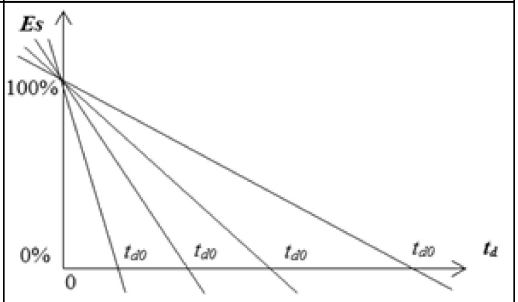
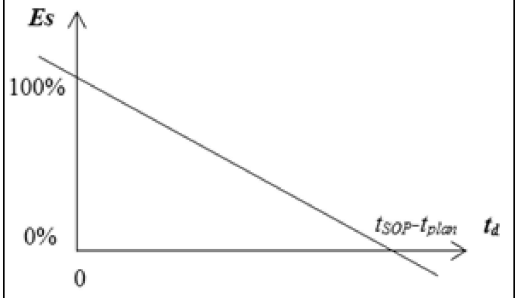
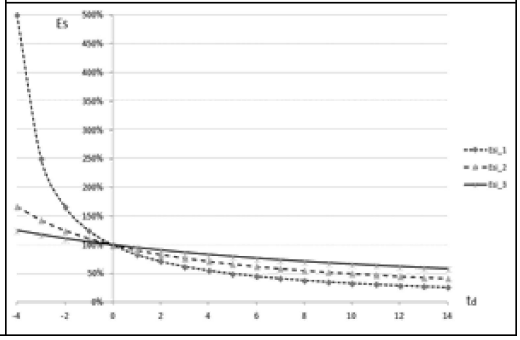
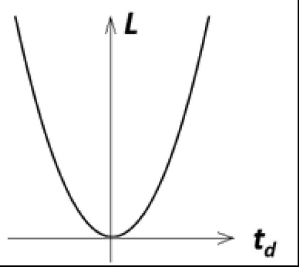
Lp	Es_i / Es_{PPAP}	OPE	Graph
1	$Es_i = \left(1 - \frac{t_{d_i}}{t_{d0_i}}\right) \cdot 100\%$	$OPE = \prod_{i=1}^{n} Es_i$	
	$Es_{PPAP} = 100\% \cdot (1 - \frac{t_{dPPAP}}{t_{d0PPAP}})$		
2	$Es_i = \left(1 - \frac{t_{d_i}}{t_{SOP_i} - t_{plan_i}}\right) \cdot 100\%$		
	$Es_{PPAP} = \left(1 - \frac{t_{d_{PPAP}}}{t_{SOP_{PPAP}} - t_{plan_{PPAP}}}\right) \cdot 100\%$		
3	$Es_i = \frac{t_{plan_i}}{t_{d_i} + t_{plan_i}}$		
	$Es_{PPAP} = \frac{t_{planPPAP}}{t_{dPPAP} + t_{planPPAP}}$		

Table 4
PPAP performance indicator based on Taguchi loss function concept.

L_i	L_{PPAP}	$\%L_i$	Graph
$L_i = \frac{L_0}{(t_{SOP_i} - t_{plan_i})^2} \times {t_{d_i}}^2$	$L_{PPAP} = \sum L_i$	$\%L_i = \frac{L_i}{L_{PPAP}} \times 100\%$	

Final conclusion

The above presented concepts may be found useful to evaluate effectiveness of any process which consists of defined, interrelated steps with planned deadlines. However, authors focused on process of product quality planning (APQP / PPAP) as its effectiveness influence on quality of manufactured products cannot be overestimated. Too often cost reduction requirements put quality objectives into jeopardy. If company is not aware which step of production preparation process is performed (or planned) ineffectively, it is impossible for the company to learn from failures and achieve improvement in quality planning for a new project. It is high time that some manufacturing companies realized how important for designed product and process quality is the stage of quality planning and validation. The basic approach this paper recommends is to measure effectiveness of the whole PPAP process (and its components). A more advanced concept could use Taguchi loss function to address effects of ineffectiveness of the PPAP process (and its components) on efficiency (expected losses) of a new manufacturing project being introduced. Using proposed indices could replace application of complex quality costs models and time-consuming data recording, which, if thoroughly done, would prove managers that, at the end of the day, prevention is much cheaper than detection and correction. It is a truism, it is easy to say, but business and manufacturing reality has shown that it is difficult to manage processes in line with effective preventive policy. Further research is planned in order to elaborate guidelines for selecting best PPAP effectiveness indices for a given situation. The guidelines will be based on observed correlations between PPAP effectiveness indicators and manufacturing process performance indices.

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