Optimized design of control plans based on risk exposure and resources capabilities

Belgacem Bettayeb, Samuel Bassetto, Michel Tollenaere

Optimized design of control plans based on risk exposure and resources capabilities

PC-O-91

Belgacem Bettayeb[1], Philippe Vialletelle[2], Samuel Bassetto[1], Michel Tollenaere[1]
[1] Grenoble University, France, belgacem.bettayeb@grenoble-inp.fr
[2] STMicroelectronics, Crolles, France, philippe.vialletelle@st.com

Abstract – In this paper, we present a coherent method for quality control planning that tackles the limitations of traditional approaches when applied to an advanced high-mix fab like semiconductor manufacturing environment. The proposed approach consists of two stages and takes into account both the risk exposure, expressed in terms of the number of products potentially lost, and resources capabilities (process and measurement tools).

1. INTRODUCTION

In high mix semiconductor manufacturing lines, major scraps events are often issued from the growth, the expansion and the release of a bubble of uncertainty about products' health. Even if process control organization is supposed to protect the manufacturing system against these fearsome events, the monitoring of uncertainty is hardly effective operationally.

The numerous data sources and techniques applied today are necessary to master the process at the Angstrom level. However, the connection between production and quality control turns the management of material at risk in the line into a complicated and very often overwhelming task. As material at risks is directly linked to the plant competitiveness, the traditional process control approach [1] has to be strengthened. Whether defined according to FMEA or not, the control plan is loaded into MES (Manufacturing Execution System) through sampling rules. These rules are based on process frequency (i.e. measure one every ten), on events (Maintenance just achieved, out-of-control just happened, etc), on product or lot characteristics (experiment lot, so called rocket, bullet or ambulance lot) and on some exceptions (Run-to-run regulation loop, mandatory parameter for reporting, etc). Traditional approaches proposed in most existing MES are limited and valuable alternatives have been proposed as in [2], [3] and [4]. Nevertheless, in most cases, risks analyses are static and control plans adjustments are then driven by capacity limitations or productivity/cycle time improvement campaigns through so called non-value added steps reduction. Very few methods link risks analyses and actual control plan strategies in a detailed and efficient manner. From the risks analyses point of view, controls are often mentioned by a generic sentence like "control with SPC" or "perform a maintenance". To be fully operational these expressions have to be reworked by a specialist of the field. For example, "perform a maintenance" has to be detailed in the maintenance information system (label, spare parts, maintenance frequency, operating mode...).

In the remainder of the paper, the risk will be considered as number of uncertain products. The paper present first the risk based control plan design. It follows with an illustrative example and discussions. The paper concludes by outlining the future possible enhancements.

2. THE PROPOSED APPROACH

To master the bubble of uncertainty, the proposed approach (see Figure 1) consists of two stages:

- Stage 1: a risk based allocation model is used to define a minimum control plan that ensure a certain level of risk exposure during a considered horizon of production plan.

- Stage 2: the control plan defined in stage 1 is adjusted by partitioning the remaining (or the lacking) capacity according to a criterion related to process and metrology capabilities. In this stage, availabilities and capacities constraints of the control resources are also taken into account.

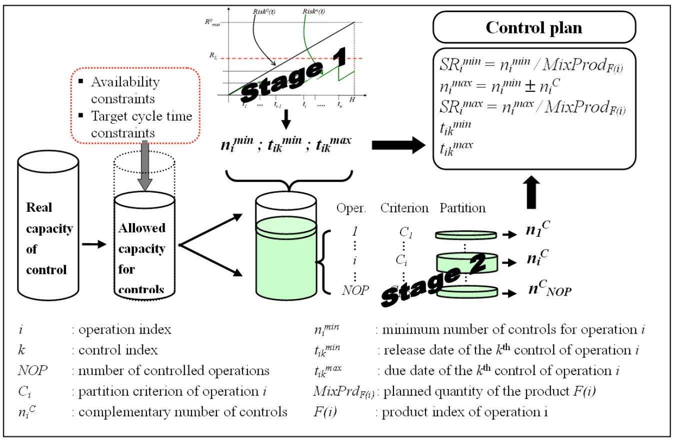

Figure 1. The proposed approach

2.1. Stage 1: Risk based minimum control plan

This proposition helps to move toward a more rational process control design. It can be understood as an insurance point of view for designing layers of control.

Notations

n: the number of controls
K: the set of available layers of controls on tools, processes, products and organization
k: index of individual layer of controls. $k \in K$
α_λ: the probability that the failure λ occurs.
H: the production horizon: the quantity of products manufactured during a rolling period.
i: The index of the control number
t_i: the date of the i^{th} control, $i \in \{1,2,...,n\}$
T: Vector of the dates of the n controls, $T=(t_1, t_2,...,t_i,...,t_n)$
$\rho_{k\lambda}$: the capture rate of the failure λ by the layer of control k.
R_L: the exposure limit.

$R^0_{\max}$: The maximum value of risk reached during the considered horizon H in a zero-control situation, $R^0_{\max} = \alpha_\lambda . H$.

$Risk^{n,K,T}(t)$: the risk function , $t \in [1,H]$

$R^{n,K,T}_{\max}$: The maximum value of risk reached during the considered horizon H in a situation when n controls are planned using the p layers of control $K=(k_1,k_2,...,k_p)$. It depends on the positions of these n controls $T=(t_1,t_2,...,t_n)$ along the considered horizon H.

$R^{n,K,T}_{\max} = \max_t Risk^{n,K,T}(t)$

$AV^{n,K,T}$: the added value of the n controls expressed in risks savings over the production horizon H using the layers of control defined in K, $AV^{n,K,T} = R^0_{\max} - R^{n,K,T}_{\max}$

Assumptions. In order to provide some insights and a first tractable model, the assumptions that give a simplified model are:

- a single layer of control k (example: the layer of defectivity control)
- a single particular failure mode λ is considered (for example: particles contamination).
- $\forall\ t_i \in [1,\ H],\ \alpha_l = \alpha = 1$ – every product is potentially impacted. The control acts only locally. No learning occurs after controls and the production of default remains unchanged. In order to provide general models, the term α will be conserved throughout the modelling process, even if we will not develop a statistical model.
- Controls are performed immediately. No delay between the decision of control and its execution.
- $R_L = Constant$. The budget allocated for insuring controls actions consequences is immediately refunded and each consumed capacity is automatically compensated.
- $\forall\ t_i \in [1,H],\ \rho_{k\lambda}(t_i)=1$. The capture rate of the layer k, regarding the actions are perfect and reset risks curves at 0.

These assumptions can represent following case: the production goes on until a systematic control of products. Passing R_L could lead to a major disruption (production, customer penalties…). A loss below this limit could be compensated internally or with a partner. The purpose is then to define (1) a strategy to ensure a minimum number of controls to remain below R_L and (2) their position in the production plan. In this frame, the risk can be illustrated as in Figure 2. In this illustration, it behaves in an increasing manner following the production throughput (as $\alpha=1$). It is reset at 0, each time a control is performed. In this figure, three controls have been planned in order to remain below R_L. As we consider only one layer, the added value can be reformulated as follow:

$$AV^{n,K,T} = AV^{n,T} = R^0_{\max} - R^{n,T}_{\max}$$

as the risk behaves in a linear increasing manner,

$$Risk^{n,T}(t_i) = \alpha(t_i - t_{i-1}) \quad \forall i \in \{1,...,n+1\}$$

with $t_0 = 0$ *and* $t_{n+1} = H$

then

$$AV^{n,T} = R^0_{\max} - R^{n,T}_{\max} = \max_t Risk^{n,T}(t)$$
$$= R^0_{\max} - \alpha . \max\{t_1;(t_2 - t_1);...;(t_n - t_{n-1});(H - t_n)\}$$

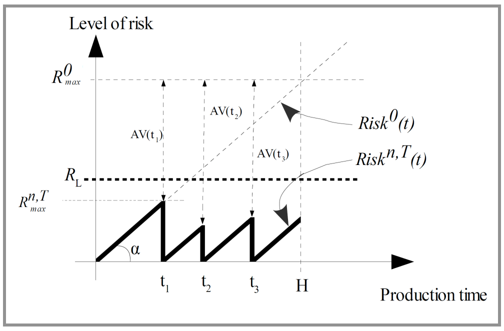

Figure 2. Risk evolution

Defining a control plan that ensure to stay below R_L, can be achieved by defining the number and positions of controls to maximize their added value. Let's note n^* the optimal number of controls and T^* the vector of their optimal positions. The problem is to find : n^* and T^* so that AV^{n^*,T^*} is maximum.

With these notations and assumptions the optimal positions of n planned controls can be determined when maximizing the added value as following

$$AV^* = \max_T AV^{n,T}$$
$$= R^0_{\max} - \alpha . \min_T\left(\max\{t_1;(t_2 - t_1);...;(t_n - t_{n-1});(H - t_n)\}\right)$$

It can be easily demonstrated that:

- the optimal position of controls is the uniform repartition $t^*_1 = (t^*_2 - t^*_1) = ... = (t^*_n - t^*_{n-1}) = (H - t^*_n) = \frac{H}{n+1}$
- The optimal number of controls is given by the formula $n^* = \left\lceil \alpha \frac{H}{R_L} - 1 \right\rceil$ where $\lceil x \rceil$: the first integer greater than or equal to x
- Depending on the decided number of controls n, there exist some allowances on the dates of controls that should be respected, in order to remain below R_L. Two cases are distinguished as following:
  - $n<n^*$ or ($n=n^*$ and $R_L = R^0_{max}/(n^*+1)$): No margin is available and the dates of the n controls should be $t^{\min}_i = t^{\max}_i = i.\frac{R^0_{\max}}{n+1} \quad \forall i \in \{1,2,...,n\}$
  - $n>n^*$ or ($n=n^*$ and $R_L > R^0_{max}/(n^*+1)$): A total margin of $(n+1).R_L/(\alpha-1)$ is available and the dates of the n controls should be as following $\max\left\{t_{i-1}; H-(n-i+1).\frac{R_L}{\alpha}\right\} \le t_i \le \min\left\{H; t_{i-1}+\frac{R_L}{\alpha}\right\} \ \forall i \in \{1,2,...,n\}$

This model is to be applied for each operation in the production plan and the number of controls for each operation is

$$n^{\min}_i = \left\lceil \alpha \frac{H_i}{R_L} - 1 \right\rceil$$

With $H_i = Mixprod_{F(i)}$ the quantity of products $F(i)$ to produce and $F(i)$ the product index of operation i.

2.2. Stage 2: Minimum control plan adjustment based on process and metrology capabilities

The minimum control plan based on risk exposure minimization do not take into account measurement capacity limitation. Regarding the available allowed capacity (*TOTALCAPA*) for control we distinguish two cases:

Case 1. the charge of risk-based control plan (CH_{RBCP}) is less than *TOTALCAPA*.
The remaining capacity $RCAPA=TOTALCAPA-CH_{RBCP}$ is then distributed among operations according to a repartition criterion C_i $i\in\{1,\dots,NOP\}$. In this case the number of controls of operation i in the final control plan is

$$n_i = n_i^{\min} + n_i^C$$

where n_i^C is the number of complementary controls of operation i. We used two variants of criterion related to process and measurement resources capabilities and processing times.

$$C_i^1 = \frac{CPM_i}{CP_i}; \quad C_i^2 = \frac{CPM_i}{CP_i}\frac{Pt_i}{Mt_i}$$

with
CPM_i: measurement capability of operation i
CP_i: process capability when executing operation i
Pt_i: processing time of operation i
Mt_i: measurement time of operation i
$MixProd_j$: quantity of product j to produce, $j\in\{1,\dots,NP\}$
$F(i)$: product index of operation

The choice of a criterion related to process and measurement tools capabilities (CP and CPM respectively) could be justified by the following: giving two operations with the same process tool capabilities, it is more efficient to allow more time to the control of the operation corresponding to the higher measurement tool capability. On the other hand, it is more efficient to allow more time to the control of the operation corresponding to the lower process capability if operations could be controlled with the same measurement tool capability.

Case 2. the charge of risk-based control plan (CH_{RBCP}) is greater than *TOTALCAPA*.
The over-charge $OCHAR = CH_{RBCP} - TOTALCAPA$ is then removed by releasing some controls on the different operations according to a criterion $C_i'=1/C_i$ and the number of controls of operation i in the final control plan is

$$n_i = n_i^{\min} - n_i^C$$

3. ILLUSTRATIVE NUMERICAL EXAMPLE AND DISCUSSION

The illustrative example presented in this section is based on a fictive instance generated by an expert person in the field of semiconductor manufacturing. The instance represent a mean production plan for one week. The production plan is composed of three products with its correspondent quantity noted by *MixProd* and its process flow model (see Figure 3 and Table 1). Each product is produced after a fixed number of successive operations (*NOP*). Each operation is processed on a tool characterized by its capability (*CP*) and controlled on a measurement tool also characterised by its capability (*CPM*) to detect the failure mode under surveillance.

In this illustration the measurement tools capacities are taken into account and the total charge of the control should not exceed a fixed limit of saturation noted by *OBJSAT*. In addition, *OOC%* of the measurement capacity is allocated to the additional measurements in the situations of out-of-control.

PRD	OPER	STEP	PTIME	TOOL	DTN	Dspecs	R2R	Recipe	CP	CPM	PROC?	Ptime Eff
A	2300	100	60	CVD	10			cvd1			1	60
A	2300	150	5	SATH	600	2000	N		3,33	10,00	1	5
A	2500	100	60	CVD	10			cvd1			1	60
A	2500	150	5	SATH	1000	1000	N		1,67	5,00	1	5
A	4000	100	60	CVD	10			cvd2			1	60
A	4000	150	5	SATH	400	4000	N		7,27	8,00	1	5
A	4200	100	120	CVD	10			cvd3			1	120
A	4200	150	10	SATH	600	200	N		0,59	2,00	1	10
A	4500	100	60	CVD	10			cvd3			1	60
A	4500	150	5	SATH	10	400	Y		1,18	4,00	1	5
A	4550	100	30	CMP	10			cmp1			1	30
A	4550	150	5	SATH	600	400	N		2,00	4,00	1	5
A	5500	100	60	CVD	10			cvd3			1	60
A	5500	150	5	SATH	10	500	Y		1,47	5,00	1	5
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

6 sigma process		
cmp1	200	avec R2R
cmp2	200	avec R2R
cvd1	600	
cvd2	550	
cvd3	340	
fur1	800	

R&R mesure	
cmp1	100
cmp2	120
cvd1	200
cvd2	500
cvd3	100
fur1	300

Figure 3. Abstract from the model of capacity/capability of the tested instance

Product	*A*	*B*	*C*
NOP	12	8	17
MixProd	1000	800	1200
Nr. Meas. Tools	*OBJSAT*	*Meas. Tools Availability*	*OOC%*
2	75%	70%	5%

Table 1. Parameters of the tested Instance. Real Meas. Tools Availability reaches 95%, but 20% to 25% is usually reserved to NPW (non Productive Wafer) and engineering tests

Two approaches are tested to compute the control plan where in the first one the stage 1 is omitted. The obtained results are presented Figure 4. The main remarks from these results are the following:

- The use of the risk based pre-allocation (stage 1) permit to master the outcome uncertainty by equilibrating the risk exposure among all the operations in the process flow. For example, we remark that the average sampling rate (*AVG SR*) for all the operations passes from 87.7% in the case where Stage 1 is omitted to 90.46% in the case where Stage1 is not omitted and R_L =1 and attain 91.1% when R_L=10.

- The value of AVG SR/Oper for each product and each process tool converge when R_L is large.

4. CONCLUSION AND PERSPECTIVES

In this paper, we presented an approach for control plan design based on the principle of mastering the risk exposure and optimizing resources utilization in the simple case of a single failure mode per operation and a single layer (resource) of control (or protection).

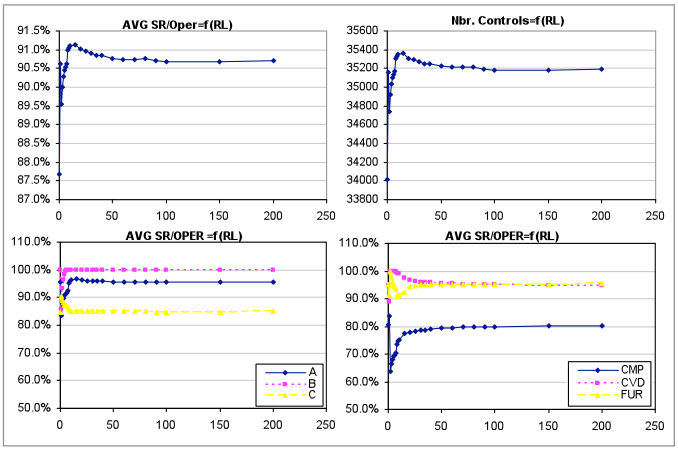

Figure 4. AVG SR/Oper = f(RL)

In real semiconductor manufacturing process there are several layers of protections also called layers of control against operational fearsome events (or failure modes) at every level of the manufacturing system: at the tool level, at the process level, at the product level and at the organization level ([5]). However, each of these layers can present locally several breaches because they are often designed independently and by separated organizations (quality, process engineering,...). A combination of breaches can occur inside these layers of protection (see Figure 5) that enables in some cases the possibility of non capture of major issues and the loss of thousand of products.

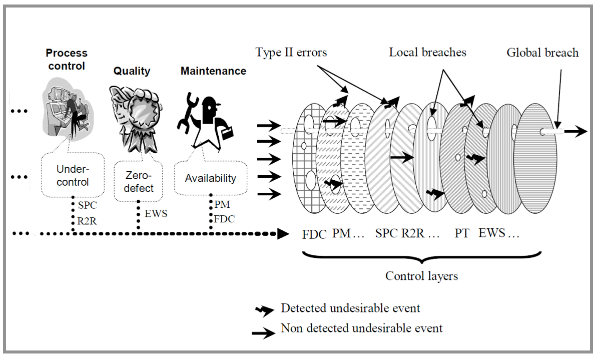

Figure 5. Local and Global breaches in layers of control

That is why, we seek, in the near future, to focus our work on the extension of the approach to a more realistic industrial situation where there are several failure modes, several layers of control, several control resources with different capture rates and different measurement depths.

REFERENCES

[1] G.S. May et C.J. Spanos, *Fundamentals of semiconductor manufacturing and process control*, New Jersey: Wiley-interscience, 2006.

[2] C. Mouli et M. Scott, "Adaptive Metrology Sampling techniques enabling higher precision in variability detection and control," *Advanced Semiconductor Manufacturing Conference, 2007. ASMC 2007. IEEE/SEMI*, 2007, pp. 12-17.

[3] M. Purdy, "Dynamic, Weight-Based Sampling Algorithm," 2007.

[4] A. Bousetta et A. Cross, "Adaptive sampling methodology for in-line defect inspection," *Advanced Semiconductor Manufacturing Conference and Workshop, 2005 IEEE/SEMI*, 2005, pp. 25-31.

[5] A.E. Summers, "Introduction to layers of protection analysis," *Journal of Hazardous Materials*, vol. 104, Nov. 2003, pp. 163-168.

AKNOWLEDGEMENTS

Authors are warmly grateful to STMicroelectronics for providing data and support for their research. This article describes the research under the context of the IMPROVE project, 'ImplementingManufacturing science solutions to increase equiPment pROductiVity and fab pErformance'. IMPROVE is a JTI Project supported by the ENIAC Joint Undertaking, contract N°12005

AUTHOR SHORT BIOGRAPHY

B. Bettayeb

P. Vialletelle…

S. Bassetto is associate professor at Grenoble Institute of Technology. His researches are mainly focused on process and quality control in manufacturing environment. He hold PhD and Engineering degrees from ParisTech and his MSc from University of Nancy.

M. Tollenaere, PhD, Ing, MSc is professor at Grenoble Institute of Technolgy. His researches are focused in industrial performance improvement. …