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A GENERIC VMI MEASUREMENT AND APPLICATION IN THE SEMICONDUCTOR INDUSTRY

Hans Ehm
Frederic Jankowiak
Veronika Filser
Tim Lauer

Infineon Technologies AG
Am Campeon 1-15
Neubiberg, Bavaria, GERMANY

Anh Nguyen

Hogeschool van Arnhem en Nijmegen
Ruitenberglaan 27
Arnhem, Gelderland, THE NETHERLANDS

ABSTRACT

Vendor managed inventory (VMI) is a widespread supply chain collaboration model. To avoid product shortage and excessive stocks, various measurement approaches defining minimum and maximum inventory levels have been designed. None of the known approaches take up the aspect of responsibility regarding the status of the inventory levels. This is especially important in industries facing long process times, short product life cycles and volatile demand patterns, such as the semiconductor industry and their downstream customers. Within this work, a VMI classification checklist is established to build a basis for a common understanding of this collaboration model. This is followed by a generic VMI measurement approach including a process to assign responsibilities for poor performance. The novel process distinguishes from other measures, as it is of a bilateral nature and parameters can be fitted uniquely to the needs of different VMI partnerships.

1 INTRODUCTION

Semiconductor manufacturers are facing high levels of complexity in Supply Chain Management (SCM). Their supply chains can be considered global fabs since not only customers and suppliers are located all over the world, but also the complex and exceptionally expensive internal production is spread globally (Ehm et al. 2011). The manufacturing process of semiconductors is divided into front-end and back-end production and includes up to 1,200 process steps (Ehm and Lachner 2016). This can result in lead times of up to 6 months for front-end production only. The complexity is increased by the rapid evolution of semiconductor technology as described by Moore’s Law leading to a significant decrease in the value of the products (Moore 1965).

VMI, which has been established in various industries to manage complex supply chains, shifts the replenishment decision from customer to supplier (Kamalapur et al 2013). There are predefined conditions connected to every VMI system, commonly including minimum and maximum inventory levels (Simchi-Levi and Kaminsky 2008). In the semiconductor industry, due to long production cycle times, it is common practice that the customer sends a rolling demand forecast to the supplier at an early stage which is updated regularly. VMI allows the supplier to satisfy the demand independently, as long as the pulls of the customer are within a certain range. Overall, it brings diverse benefits to both suppliers and customers, such as better supplier service levels and optimization of production plans, capacity utilisation rates and transportation costs on the suppliers side (Marquès et al. 2010).

VMI requires constant monitoring and evaluation in order to enable participants to monitor, analyse and optimize its performance. In the semiconductor industry, customers develop and apply measurement

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approaches for supplier evaluation (Continental AG 2010) and suppliers serving multiple customers, use their individual approach to measure their own performance.

Since the replenishment decision is shifted to the supplier, the common understanding is that the supplier is solely responsible for the performance of the VMI system (Odette International, 2004). However, if the customer's forecast is not accurate (e.g. unpredicted pull of all available stocks), the supplier is not necessarily able to adjust the replenishments immediately due to its long production cycle time. In this case, the poor performance is based on the customer's behaviour. This aspect of shared responsibility for the success of VMI has not been addressed in academic or industrial publications yet.

2 LITERATURE REVIEW AND RESEARCH BACKGROUND

2.1 Supply Chain Collaboration – Background of VMI

The well-known bullwhip effect described by Forrester (1961) and taken up by Lee et al. (1997), explains how the variability of demand increases upstream at each level of the supply chain. It causes several inefficiencies, including excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules (Lee et al. 1997). According to Simchi-Levi et al. (2008) long lead times are magnifying this effect.

A widely discussed and accepted solution to mitigate the bullwhip effect is the application of supply chain collaboration models. Within supply chain collaboration models independent companies maintain relationships characterized by openness and trust where risks, rewards and costs are shared between parties (Li et al. 2010). Although the majority of publications mention how visible, accurate measurements can improve collaboration via increased trust, no literature was found on applying measurements including split responsibility to the concept of VMI.

2.2 VMI Characterization

The literature study revealed that there is no consensus on the definition of VMI. The term is commonly mentioned in comparison to other business models such as consignment stock or in regards to a combination of VMI and consignment stock.

To begin with, the basic specifications of VMI, include information sharing, as well as location and ownership of the inventory. In general and commonly among all publications, VMI describes the shift of replenishment responsibility to the supplier: the supplier is refilling the customer's inventory autonomously and the customer is providing an accurate demand forecast. Information sharing has been identified as a major aspect of VMI to counteract distorted information and therefore mitigate the bullwhip effect. It reduces costs and inventory for the supplier (Lee et al. 1996), and if combined with replenishment coordination, the benefits become significant for customers as well (Lee et al. 1996; Zhao et al. 2002). There are different types of information that can be shared, including Point Of Sale (POS), demand information, inventory level, production schedules, goods in transit and alert communications (Achabal et al. 2000; Dong and Xu 2001; DeToni and Zamolo 2005; Disney and Towill 2003; Franke 2010; Kamalapur et al. 2013; Ryu 2014; Sari 2008; Stadtler et al. 2014; Vigtil 2007; Völker and Neu 2008; Odette International 2004). Information sharing can trigger communication, trust, improved collaboration and thereduction of biased forecasts; the last one being responsible for the bullwhip effect.

VMI is generally assumed to be located at the customer's site (Claassen et al. 2008; Disney and Towill 2003; Mentzer et al. 2007; Stadtler et al. 2014; Völker and Neu 2008; Werner 2013; Zammori et al. 2009) and a VMI warehouse can either be a customer inbound warehouse or a warehouse close to the customer's site, owned by a third party logistics provider (Odette International 2004). Lastly, various authors do not broach the issue of ownership in the VMI definition specifically (Claassen et al. 2008; DeToni and Zamolo 2005; Disney and Towill 2003; Mentzer et al. 2007; Stadtler et al. 2014; Völker and Neu 2008; Werner 2013; Zammori et al. 2009). The term consignment on the other hand, which refers to supplier owned inventory at the customer, gives a clear statement about ownership. The two concepts

VMI and consignment inventory are used interchangeably in some cases (Dong and Xu 2002; Völker and Neu 2008; Zachariassen et al. 2014), according to Vigtil (2007), the combination of the two concepts is an indicator of an integrated supply chain. An overview of different concepts of VMI over time is illustrated in Figure 1. No literature about shared responsibility in the case of a poor VMI performance has been found.

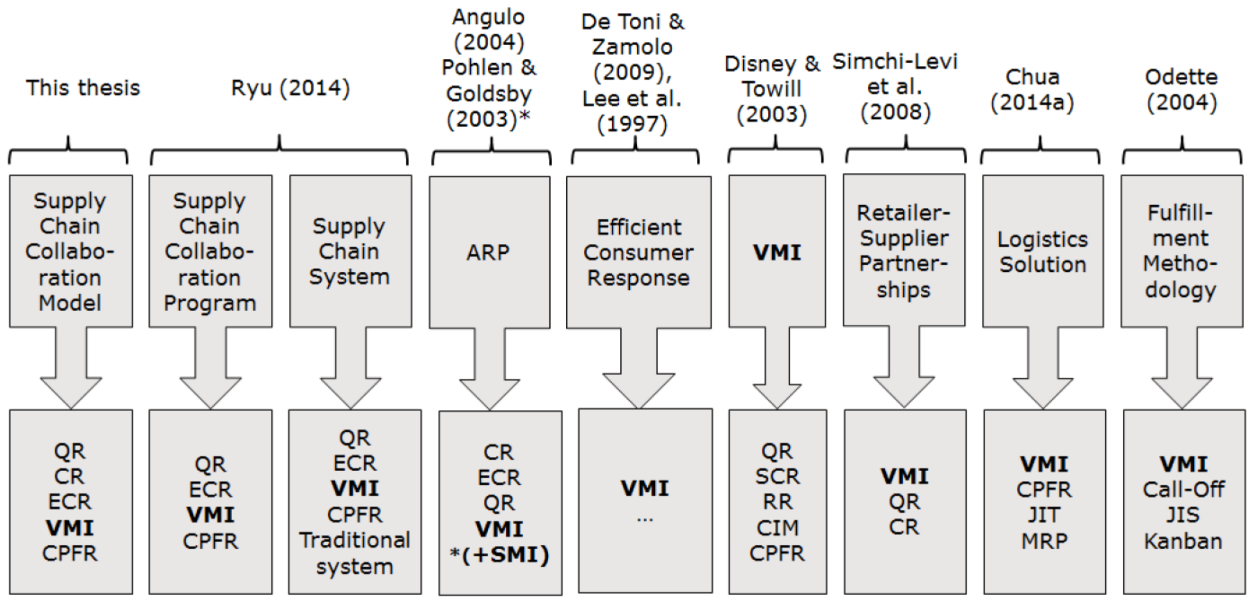

Figure 1: Different concepts of VMI embedded in the superior term.

3 DEVELOPMENT OF A GENERIC VMI MEASUREMENT APPROACH

3.1 Generic VMI Measurement Approach

A clear assignment of responsibilities is necessary when it comes to applying VMI. Thus, a metric will be described and further developed that helps to assign responsibilities easily in case of min/max border violations. Further to this, it is expected that the metric fosters collaboration, subsequently reducing the Bullwhip Effect.

The process of developing such a metric starts with the analysis of the basic VMI setting as visualized in Figure 2. The concept of collaboration on forecast creation consists of a forecast provided by the customer to the supplier. The supplier takes current stock information into account, plans and executes replenishments and carries out the deliveries. The customer may pull from stock anytime. With this system, the supplier does not receive further information about how the demand forecasts were generated and which factors were considered by the customer. In other words, the supplier uses the forecast without any further information.

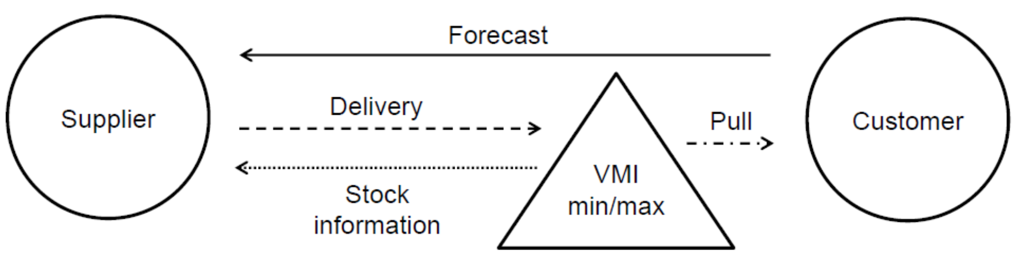

Figure 2: Basic VMI setting.

If the customer's demand suddenly rises (without being forecasted), the supplier might run out of stock. As a result of the current setup, the supplier will be made responsible since the delivery could not be carried out according to the customer's final demand due to stock out.

The generic VMI measurement approach which we use as a base for the assignment of responsibility starts with an evaluation and an explanation of the overall performance of the VMI system on a weekly basis. If the Weekly Performance (P_w), does not meet the Predefined Target $P_{wtarget}$, the responsibility for low performance of that specific week will be determined, as depicted in Figure 3.

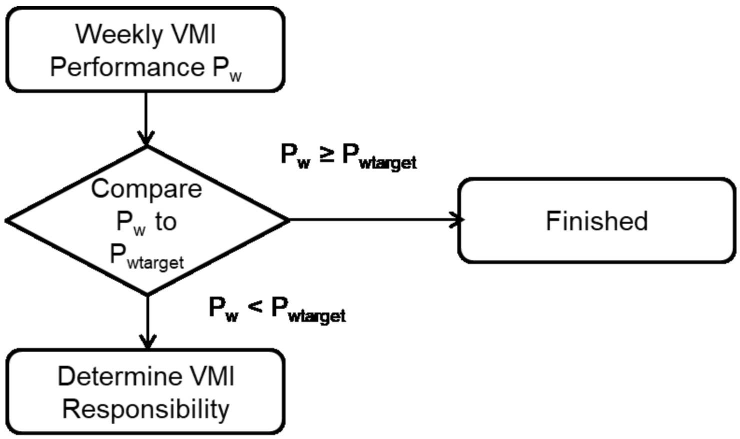

Figure 3: Aggregated VMI Measurement Process Logic.

3.1.1 Assessment of the weekly VMI Performance

It is assumed that VMI data is collected on a daily basis, which ensures a high level of measurement accuracy. However, daily evaluations to determine responsibility might be too detailed, as supplier customer collaboration alignments are commonly less frequent. Thus, this daily data set is being aggregated to a weekly value.

The weekly aggregated VMI performance measurement is based on the VMI Indicator by Odette (2004). For the use within the generic measurement approach it is parametrized to accurately determine a weekly VMI performance based on daily data. The stock level status gets assigned a grade and a weighting. The grades of overstock, understock and stock out which are used can be seen in Table 1. An overstock violation is for example less severe than an understock violation. A stock out situation is weighed heavily since it may interrupt the customers' follow-up processes. The weighting is of a flexible nature and depends on the agreement between the customer and supplier.

Table 1: Used stock level dependent weighting based on Odette International (2004).

stock level status (SLS)	grade g	weight w	recommended weight w	number of days in a week d
No violation	$g_{nv} = 100\%$	w_{nv}	$w_{nv} = 1$	d_{nv}
Overstock	$g_{os} = 0\%$	w_{os}	$w_{os} = 1$	d_{os}
Understock	$g_{us} = 0\%$	w_{us}	$w_{us} = 3$	d_{us}
Stock out	$g_{so} = 0\%$	w_{so}	$w_{so} = 7$	d_{so}

For the determination of the weekly performance, the relevant time period is set to 7 days. In case data is generated during working days only, the time period may be adjusted to 5 days. In order to determine the P_w of a VMI system, the following formula is used (Odette International 2004):

$$Pw = \frac{\sum_{SLS}(g*d*w)}{\sum_{SLS}(d*w)} \quad . \tag{1}$$

Written out, the formula will appear as follow:

$$Pw = \frac{(g_{nv}*d_{nv}*w_{nv})+(g_{os}*d_{ns}*w_{os})+(g_{us}*d_{us}*w_{us})+(g_{so}*d_{so}*w_{so})}{(d_{nv}*w_{nv})+(d_{ns}*w_{os})+(d_{us}*w_{us})+(d_{so}*w_{so})} \quad . \tag{2}$$
$$with \sum_{SLS} d = 7$$

This approach can be applied not only to VMI systems with minimum and maximum levels but it can also be adjusted for systems that use just either one of them. For example, the maximum level can be set to ∞ and thus, only minimum violations will be considered. Consequently, the minimum level can be set to 0 and only maximum violations will occur.

3.1.2 Determination of the Forecast Accuracy

The basic concept of determining responsibility is that both parties are liable for the performance of the VMI system. In case the customer's inaccurate forecast is less than agreed in the contract, the customer is responsible. To evaluate the customers committed forecast accuracy, Symmetric Mean Absolute Percentage Error (SMAPE) is being used (Habla 2008): $FcA = 1 - SMAPE(\%)$

$$FcA = 1 - \frac{|Forecast + Pull|}{|Forecast - Pull|}(\%) \quad . \tag{3}$$

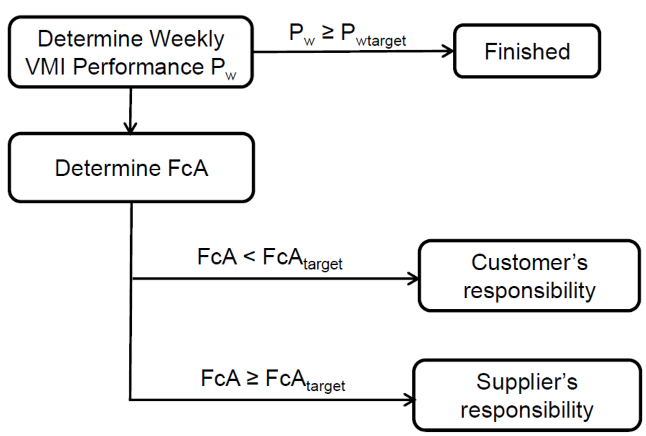

Figure 4: VMI Measurement Process extended by forecast accuracy and assigning responsibilities.

Customer forecasts in VMI in the semiconductor industry are rolling forecasts. For the generic VMI measurement approach, the default can be a simple or more sophisticated weight on all forecasts transmitted during the production period. The forecast accuracy is the absolute value of the forecast error in relation to the sum of forecast and demand, so the information about the direction of the forecast error is already summed up. Situations with low forecast accuracies due to strong customer forecast biases, pose a great challenge to the supplier. On the other hand, when low forecast accuracies are caused by great, but two-sided fluctuations, the replenishment task is more feasible. In fact, it is expected from the supplier to manage the inventory successfully in that case, due to the fact that VMI systems are set up for that purpose. The VMI measurement process including the FcA measure is illustrated in Figure 4.

3.1.3 Assignment of Responsibility

As forecasts are prone to bias which has a significant impact for the VMI, the measurement approach will include this aspect. A measure to calculate the Forecast Bias (FcB) has to be introduced. The following formula to determine the tracking signal (forecast bias) was identified (Trigg 1964):

$$FcB = \frac{\sum_{weeks} (Forecast - Pull)}{\sum_{weeks} \left| Forecase - Pull \right|} \quad . \tag{4}$$

Equation 4 indicates the bias of the forecast over a certain number of weeks by generating results between minus one and plus one. If all forecasts are lower than the demand, the counter becomes negative and the denominator has the same value, but positive; the result being minus one. If the forecasts are constantly higher than the demand, both counter and denominator have the same positive value and the FcB is consequently plus one. In case the forecasts fluctuate in both directions around the demand, the result of the formula is close to zero, since the values in the counter neutralize each other. This measure does not provide any information about the dimension of the forecast error. The result will be the same for a continuous 1% over-forecast (FcB=1) as well as for a 100% over-forecast (FcB=1).

To include the bias measurement into the customer forecast accuracy measurement, the 'Bias-Adjusted Forecast Accuracy' (FcA_B) is created. It is the actual forecast accuracy calculated via SMAPE added to the part of the Forecast Error which is unbiased:

$$\begin{aligned} FcA_B &= FcA + (1 - \left| FcB \right|) * SMAPE \\ FcA_B &= FcA + (1 - \left| FcB \right|) * (1 - FcA) \quad . \end{aligned} \tag{5}$$

The value of $(1 - \left| FcB \right|)$ provides information about how unbiased the forecast is, with zero being continuously biased and one not being biased at all, multiplied with the forecast error, a value between zero and one, in case of bias, and the forecast error, in case of no bias, will be the result. The generic VMI measurement will be applied with the inclusion of the bias and added to Equation 6. Further a so called Bias Factor (BF) was added, which allows a weighting in order to keep the approach generic.

$$FcA_B = FcA + BF * (1 - \left| FcB \right|) * (1 - FcA) \, , \tag{6}$$

$$\text{with } BF = \left[0;1 \right].$$

In addition, a parameter has to be predefined for the number of weeks the calculation of the bias is based on. Twelve weeks are recommended to get a reliable result on the forecast bias. It should also be a rolling bias calculation, which means each week should be recalculated based on the most recent data.

To sum it up, the calculation of the bias has the purpose to give the customer a bonus when his forecast accuracy is fluctuating around a mean value as shown in example 3. This sometimes also happens due to unaligned time stamps of pull signals and Forecast transmissions, such as when the transmission is via Electronic Data Interchange. Figure 5 illustrates an overview of the complete generic VMI measurement to determine the responsibility of supplier and customer in case of poor performance.

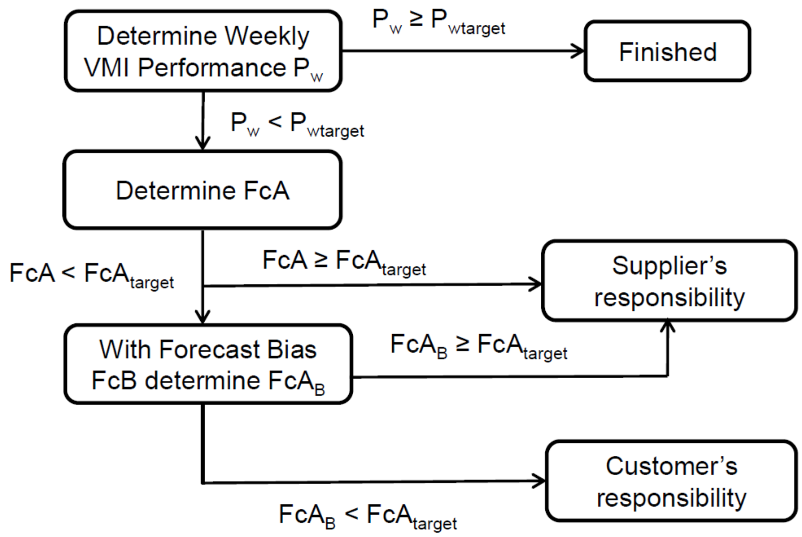

Figure 5: Final VMI Measurement Process Logic.

3.2 Simulation Tool for a Generic VMI Measurement

3.2.1 Validation of the VMI Measurement process

As shown in figure 5 above, the measurement process consists of two major parts, the VMI performance calculation and the assignment of responsibility in case of bad performance. In order to validate the approach an Excel tool is used, where different parameters are used to test the sensitivity of the developed approach. These parameters include daily information of forecast, and pull and delivery signals On this basis the tool calculates the desired inventory target levels, the stock level status and the weekly VMI performance. Following pur process, the calculated weekly performance then compared with the weekly target performance. Forecast accuracy and bias-adjusted forecast accuracy are also included in this step. In case the Pw target was not fulfilled, the FcA_B and the FcA_{target} are compared and depending on the result, the responsible party is assigned as responsible one, building the basis for improving the VMI performance.

3.2.2 Application on Exemplary Data

For our example we used typical values. For minimum level and maximum level calculation the average of the next 4 future forecasts was used. The minimum level is equal to that value and the maximum level is three times that average. The weights for the different stock level statuses we used were as recommended by Odette International (2004) as described in Table 1. The $P_{wtarget}$ was set to 50%, which allows small deviations such as one overstock or understock violation in one week. The bias factor was selected to be 50%, which means that 50% of unbiased forecast errors are credited to the customer. The forecast agreement was set to 90%, which is also common. Two short examples to illustrate the comparison of the actual weekly performance with the weekly performance target are shown in Figures 6 and 7 below. Figure 6 shows a week with a perfect VMI performance (P_w is 100 %.) with no stock level violation. Figure 7 shows a week with two overstock violations.

Delivery day		1	2	3	4	5	6	7
Aggregated Forecast		204	252	230	239	198	248	247
Pull		209	192	190	242	243	230	174
Delivery		247	194	200	232	217	230	192
Inventory	1506	1544	1545	1555	1545	1520	1519	1537
Min		1532	1532	1532	1532	1532	1532	1532
Max		4595	4595	4595	4595	4595	4595	4595
violation						us	us	
overstock								0
understock								7
stockout								0
performance								0%

Figure 6: Generic VMI Measurement - Example 1.

Delivery day		1	2	3	4	5	6	7
Aggregated Forecast		231	179	211	221	230	178	206
Pull		227	197	195	185	186	195	210
Delivery		225	171	178	212	198	214	177
Inventory	1506	1997	1972	1955	1982	1994	2013	1980
Min		2774	2774	2774	2774	2774	2774	2774
Max		4161	4161	4161	4161	4161	4161	4161
violation								
overstock								0
understock								7
stockout								0
performance								0%

Figure 7: Generic VMI Measurement - Example 2.

To show how the determining the responsibility works and to prove its effectiveness, Figures 8 and 10 show the development of Forecast, Pull and Delivery databases for the two examples 3 and 4.

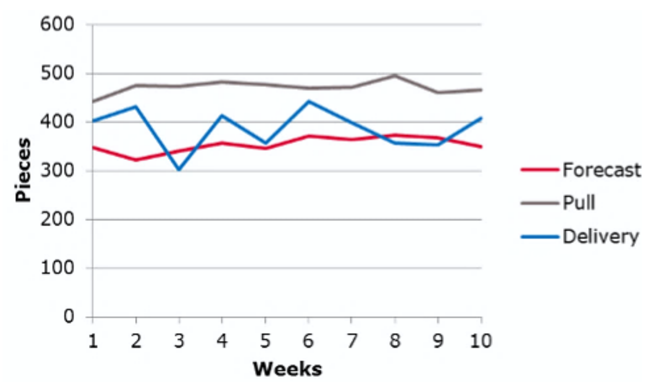

Figure 8: Development of forecast, pull and delivery of example 3.

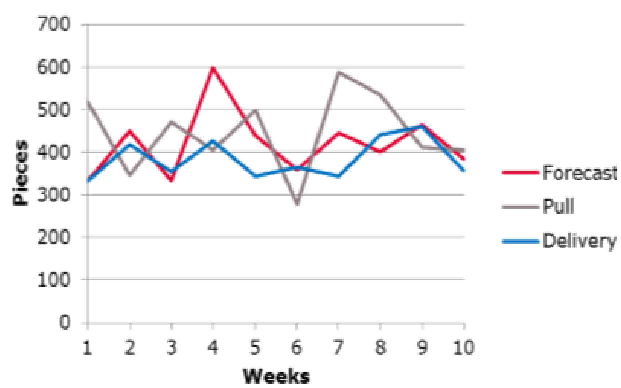

Figure 9: Development of forecast, pull and delivery of example 4.

Example 3 consists of Figure 8 and Figure 9 present that the customer is consistently under-forecasting. According to Figure 9, from weeks seven to ten, the performance target was not fulfilled and resulted in a value lower than 50%. The customer's forecast accuracy is lower than 90% in this time period as well as a strong bias with no additional credit is given to the customer. FcA_B is constantly below the agreed FcA of 90% and as a result, the customer is responsible for the low weekly performance.
Example 4 represents a situation in which the customer has a bad FcA due to unbiased fluctuations. The result is visualized in Figure 11. From week five onwards, the weekly performance has been identified to be below the weekly target performance $P_{wtarget}$. In weeks six and seven, the customer's FcA is below the target of 90%. In both weeks, the bias value shows rather low values and therefore, a bonus is added to the original FcA. Since the resulting FcA_B fulfils the requirement of 90%, the responsibility for the unsatisfactory VMI performance is assigned to the supplier in all six weeks.

Week		1	2	3	4	5	6	7	8	9	10
Forecast		347,52	323	340	357	346	371	364	372	367	350
Demand		441,54	474	472	482	476	469	472	495	460	466,3
Delivery		401,61	432	302	412	357	442	398	356	353	407,7
Ending inventory	900	860	818	647	577	458	431	357	218	111	53
Fulfillment of $P_{wtarget}$		YES	YES	YES	YES	YES	YES	NO	NO	NO	NO
FcA		88%	81%	84%	85%	84%	88%	87%	86%	89%	86%
Bias		-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
FcA_B		88%	81%	84%	85%	84%	88%	87%	86%	89%	86%
Agreed FcA		90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Responsibility								C	C	C	C

Figure 10: 'Generic VMI Measurement - Excel' Sheet for example 3.

Week		1	2	3	4	5	6	7	8	9	10
Forecast		332,28	450	333	599	440	358	447	401	465	383,4
Demand		517,35	346	470	406	499	277	588	534	412	405,3
Delivery		333	417	355	426	344	366	343	442	460	356
Ending inventory	700	516	587	472	492	337	426	181	89	137	88
Fulfillment of $P_{wtarget}$		YES	YES	YES	YES	NO	NO	NO	NO	NO	NO
FcA		78%	87%	83%	81%	94%	87%	86%	86%	94%	97%
Bias		-1	-0,28	-0,51	-0,04	-0,12	-0	-0,16	-0,27	-0,21	-0,222
FcA_B		78%	92%	87%	90%	96%	94%	92%	91%	96%	98%
Agreed FcA		90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Responsibility						S	S	S	S	S	S

Figure 11: 'Generic VMI Measurement' for example 4.

An overview of a more complex example is shown in Figure 12 and Figure 13 where responsibilities between customer and supplier is changing.

Delivery Week k	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Forecast	1770	1605	1600	1700	1575	1575	1770	1510	1660	1555
Min Stock Level	3222	3288	3252	3236	3228	3158	3010	2966	2862	2800
Max Stock Level	4833	4932	4878	4854	4842	4737	4515	4449	4293	4200
Pull	1590	1700	1590	1610	1785	315	2355	1485	1070	350
Delivery	1565	1250	1290	1265	1290	1585	1565	1610	1580	1565
Inventory	3975	3525	3225	2880	2385	3655	2865	2990	3500	4715
Weekly Performance	100%	100%	67%	0%	0%	20%	45%	5%	100%	42%
Performance Target	66%	66%	66%	66%	66%	66%	66%	66%	66%	66%
Fulfillment of Target	YES	YES	YES	NO	NO	NO	NO	NO	YES	NO
Forecast Accuracy FcA				97%	94%	33%	86%	99%		37%
Agreed FcATarget				90%	90%	90%	90%	90%		90%
Responsibility 1st Check				S	S	C	C	S		C
Bias						0,67	0.27			0.58
FcA+CG						44%	91%			50%
Responsibility2nd Check						C	S			C

Figure 12: Results of Simulating VMI Measurement with responsibility change of poor performance.

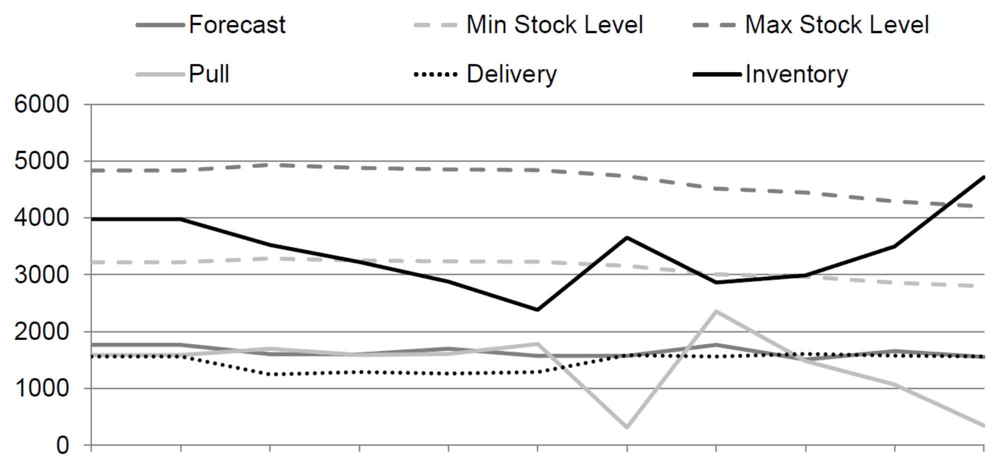

Figure 13: Results of Simulating VMI Measurement of forecast, pull and delivery with responsibility change of poor performance.

4 DISCUSSION OF RESULTS

The responsibility aspect of poor VMI performance is discussed in this paper. The process logic was described step by step and the generated results summarized. The entire process is designed to be flexible through introduction of different parameters and thus, adjustable to different industries and partnerships. In order to leverage this flexibility, the parameters have to be predefined when apllying the measurement as visualized in Figure 14.

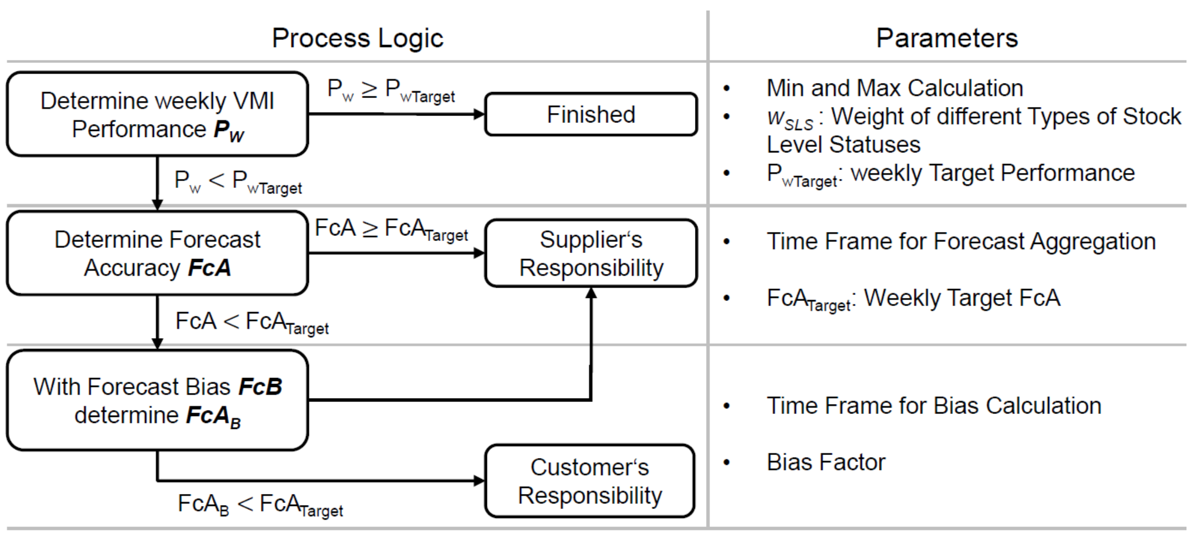

Figure 14: Parameters for VMI Measurement to identify responsibility for poor performance.

5 CONCLUSIONS AND OUTOOK

Literature research shows that the term VMI is commonly perceived as a concept with a shift in the replenishment decision to the supplier. A parametrized generic VMI measurement approach was extended to measure the responsibility for poor performance taking into account the agreed forecast accuracy for the demand. The approach was tested and validated on a set of sample data. The challenge ahead will be to convince customers of the benefit of a measurement including responsibilities. Especially as they are exposed to the risk of being assigned responsibility for poor VMI performance. As a further outlook, a change management process for existing and new VMI customers needs to be considered.

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AUTHOR BIOGRAPHIES

HANS EHM is Lead Principal Supply Chain heading the supply chain innovation department at Infineon Technologies AG. His email is Hans.Ehm@infineon.com.

VERONIKA FILSER Veronika Filser, is a Trainee at Corporate Supply Chain at Infineon Technologies AG. She holds a M.Sc. degree in environmental planning and engineering ecology from TU Munich. Her email address is Veronika.Filser@infineon.com.

FREDERIC JANKOWIAK is a Master student in Business Administration at University of Münster with major on Management and minor on Information Systems. His email address is Frederic.Jankowiak@infineon.com.

TIM LAUER is a PhD student at Infineon Technologies in cooperation with the Chair of Enterprise Logistics and the Technical University of Dortmund. His email address is Tim.Lauer@ infineon.com.

ANH NGUYEN is a Bachelor student in Logistics Management (Economics) at Hogeschool van Arnhem en Nijmegen, The Netherlands. She is also writing her Bachelor Thesis at Infineon Technologies AG in Munich, Germany. Her email address is Anh.Nguyen@infineon.com