Simulation in Production
and Logistics 2015
Markus Rabe & Uwe Clausen (eds.)
Fraunhofer IRB Verlag, Stuttgart 2015

Influence of Customer Information Uncertainties on Production Order Variance Comparing two Different Kinds of Customer Order Behaviours

Einfluss von Kundeninformationsunsicherheit auf die Varianz der Fertigungsaufträge zweier unterschiedlicher Arten von Kundenbestellverhalten

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Abstract: In this paper, two different order behaviours, differentiating how customers provide information about their required demand are discussed. On the one hand this is customer-required lead time order behaviour where customers order a stochastic order amount with a customer required lead time. On the other hand this is forecast evolution order behaviour where the customers provide a forecast quantity for a specific due date for a long horizon in advance and update their forecast quantities periodically. The performance is evaluated by measuring variance of customer demand, gross requirements and production orders and the information quality progress by varying order behaviour parameters as well as forecast error levels. Analysing this performance measures this study investigates how much master production schedule and material requirement planning mitigate customer information uncertainty.

1 Introduction

Two different kinds of how customers provide information about the required demand to their suppliers can be observed and are as well discussed in literature. Firstly, this is customer required lead time (CRL) order behaviour where customers state certain orders with specific CRL and stochastic order amounts. In this case, the manufacturing company generates an aggregated forecast for a long time in advance. The second customer behaviour is forecast evolution (FEV) order behaviour where customers provide a forecast quantity for a specific due date for a long horizon in advance and update their forecast quantities periodically. In both order behaviours, manufacturing companies are facing the problem of information dynamics and uncertainty, i.e. stochastic behaviour of arrivals, due dates and order amounts over time. In this study the stochastic nature of both customer order behaviours FEV and

CRL are compared by analysing the output of the intermediate planning level. Additionally, different levels of forecast errors, which is the deviation of the planned monthly demand to its realisation, are analysed. For the CRL order behaviour we investigate different expected values and variances of customer required lead time. The second source of randomness for CRL is the variance of the order amount. For the FEV order behaviour, the length of frozen zone, meaning the time window where a customer does not change its order anymore is investigated. Another interesting parameter studied for FEV is the change frequency of forecast and the variance of the order amount per change, indicating how volatile the forecast is. To evaluate the negative influence of these different kinds of uncertainty on the production system behaviour, this paper does not measure costs, but the input into the medium term planning, being the mean and standard deviation of gross requirements and its output, consisting of the mean and standard deviation of production order lot sizes. Another indicator for the negative influence of customer demand uncertainty is the variance of capacity needed. We monitor this indicator, to investigate how much the hierarchical planning structure already mitigates these uncertainty effects. As the interaction of the different planning levels cannot be treated analytically a simulation study is conducted for this investigation.

2 Literature Review

The Manufacturing resource planning concept (MRPII), is a structured approach which is widely used. MRPII consists of three planning levels: Long-term planning, intermediate planning and short term control. The long-term planning involves the functions forecasting and aggregate production planning (APP). The main functions of mid-term planning are master production scheduling (MPS), which compares the production plan with the actual customer orders, and material requirements planning (MRP), which identifies a list of production orders (see Orlicky 1975). The short-term planning conducts scheduling and dispatching tasks (see Panwalkar and Iskander 1977) for the released production orders and available resources.

Based on the decision hierarchy in manufacturing and the information uncertainties, there is still a research gap concerning the influence of information dynamics and uncertainties on the decisions taken on the upper hierarchical level. Ignoring this information uncertainty influence leads to a lack of coordination and integration also reported in surveys by Fleischmann and Meyr (2003), Kok and Fransoo (2003) and Missbauer and Uzsoy (2011).

Fildes and Kingsman (2010) develop a framework for examining the effect of demand uncertainty and forecast error on unit costs and customer service levels in supply chain planning, including MRP type manufacturing systems.

3 Problem Description

The hierarchical production planning approach is modelled in a simulation model. For a detailed description see Huebl et al. (2011) and for a further application see Felberbauer et al. (2012) or Felberbauer and Altendorfer (2014). The simulation model is running a rolling horizon planning on the long and intermediate range planning level. On the long range planning level, the functionality of APP is conducted. In this study we do not calculate an optimal production program but use the forecast

as production program. The intermediate-range planning uses the information of the production program. In the MPS, the production program is disaggregated and actual customer orders are used for the calculation of the gross requirements. The gross requirements are calculated taking the maximum of disaggregated production program and customer demand. MRP runs daily and planned order releases are calculated with the main MRP-functions netting, lot sizing, backward scheduling and bill of material (BOM) explosion (see also Hopp and Spearman (2008) for details on the MRP run). Planned orders from the MRP run are released to real production orders if all required sub materials are available. Production orders are produced on the shop floor according to the routing information and the dispatching rule.

3.1 Forecast Error

For both order behaviours the forecast error includes the difference between the monthly constant demand forecast $F_{p,t}$ and the stochastic realized monthly demand $D_{p,t}$ of sales product p in time period t. The forecast error $\varepsilon_{p,t}$ is an identically independent truncated-normal-distributed random variable with an expected value $E[\varepsilon_{p,t}] = 0$ and variance $Var[\varepsilon_{p,t}] = (\alpha F_{p,t})^2$. The forecast error parameter α defines the quality of the forecast and is independent of time period t and item p. The random monthly demand per sales product p and time period t is defined as $D_{p,t} = F_{p,t} + \varepsilon_{p,t}$.

3.2 CRL Order Behaviour

The order amount O_p for item p is log-normally distributed and $Var[O_p]$ is calculated based on the coefficient of variation $CV[O_p]$. The order arrival rate is $\lambda_{p,t} = \frac{D_{p,t}}{E[O_p]} = \frac{F_{p,t}+\varepsilon_{p,t}}{E[O_p]}$. Note that in the simulation study, the order rate $\lambda_{p,t}$ is adjusted to account for forecast error. Each customer order requests a stochastic customer required lead time L based on the coefficient of variation $CV[L]$.

3.3 FEV Order Behaviour

For the evolution of forecasts in FEV behaviour we are using an extension of the Martingale Model for Forecast Evolution (MMFE), presented in Heath and Jackson (1994). This way of modelling forecasts is originally based on the model of Hausman (1969). In this FEV order behaviour, the customer provides a planned order amount per due date in advance of the real customer order for a certain forecast horizon. This amount stays unchanged until the forecast evolution horizon is reached. Between the forecast evolution horizon and the due date, the customer changes the order amount periodically. For each change, the identically independent truncated-normal-distributed evolution error $\omega_{p,t}$ is added to the actual order amount. To account for the forecast error $\varepsilon_{p,t}$, the evolution error is defined by $E[\omega_{p,t}] = \frac{\varepsilon_{p,t}}{n_{p,t}\lceil (h-fz)/cf \rceil}$ and $Var[\omega_{p,t}] = (\delta \bar{d}_p)^2$. Where $n_{p,t}$ is the number of orders per time period t and sales product p, h the forecast evolution horizon, fz the frozen zone and cf the change frequency. $(h - fz)/cf$ is the number of changes per customer order and therefore $n_{p,t}\lceil (h - fz)/cf \rceil$ is the total number of changes of all customer orders per time period t and sales product p. The parameter δ defines

the variance of the evolution error $\omega_{p,t}$ and is independent of time period t and sales product p. $\bar{d}_p$ is the constant demand forecast of sales product p and due date τ. Assuming that the error terms are independent of each other leads to the following Equation for the customer order of item p in subperiod τ. Note that Equation 1 defines the realized order amount.

$$O_{p,\tau} = \bar{d}_p + \sum_{k=1}^{\lceil (h-fz)/cf \rceil} \omega_{p,t,k} \tag{1}$$

3.4 Performance Indicators

In this study we analyse the effects of information uncertainty and forecast error of both customer order behaviours on customer demand, gross requirements and production orders. Therefore, the smoothing effects of the MPS and the MRP algorithm are investigated. Figure 1 shows the evaluated performance measures.

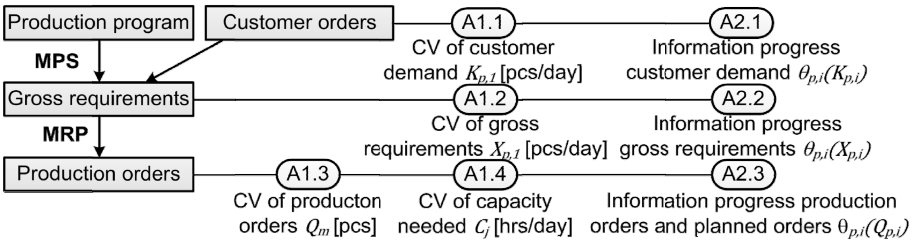

Figure 1: *Performance indicators*

Analyses A1.1 measures the coefficient of realized customer demand $CV[K_{p,1}]$ (note that index 1 again refers to the realized demand) for sales product p which identifies the information uncertainty from the customer order process without any planning interaction. Analysis A1.2 measures coefficient of variation of realized gross requirements $CV[X_{p,1}]$ for sales product p which is already smoothed by the MPS function. With A1.3, being the coefficient of variation of production order amounts $CV[Q_m]$ for material m, and A1.4, being the coefficient of variation of capacity requirements $E[C_j]$ per resource j, the influence of MRP is identified. A2.1, A2.2 and A2.3 show the evolution of the respective values. Equation (2) shows the calculation of the customer demand evolution quality measure. It evaluates the deviation between the value known i periods in advance in comparison to the value realized (i=1) in percent. Note that the equations for $\theta_{p,i}(X_{p,i})$ (i.e. A2.2) and $\theta_{p,i}(Q_{p,i})$ (i.e. A2.3) are similar to $\theta_{p,i}(K_{p,i})$ and therefore omitted.

$$\theta_{p,i}\left(K_{p,i}\right) = \sqrt{E\left[\left(K_{p,1} - K_{p,i}\right)^2\right]} \Big/ E\left[K_{p,1}\right] \tag{2}$$

To discuss the smoothing effect of the MPS and MRP on the gross requirements and production orders, respectively, in comparison to $\theta_{p,i}(K_{p,i})$, two normalized values are introduced in Equation (3).

$$P1_{p,i} = \theta_{p,i}\left(X_{p,i}\right)/\theta_{p,i}\left(K_{p,i}\right);\ P2_{p,i} = \theta_{p,i}\left(Q_{p,i}\right)/\theta_{p,i}\left(K_{p,i}\right) \tag{3}$$

4 Numerical Study Design

4.1 Production System

The modelled production system follows a flow shop structure and consists of 6 resources. The production system is inspired by different production facilities operating in the automotive sector. However, it is a streamlined version of such systems which clearly restricts the findings in this study. The arcs and numbers in Figure 2 represent the BOM structure with LLC being the low level code for the MRP run. The materials in LLC 3 are purchased parts which are always available and not further considered. Information about lot sizing policy, safety stock, planned lead time, and the monthly deterministic forecast are presented next to the sales products/materials m. In figure 2 the routing information is included showing at which resource j the sales product or material is manufactured.

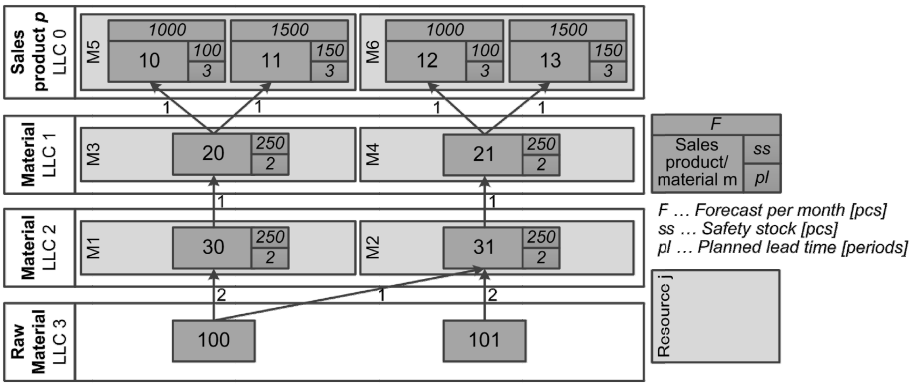

Figure 2: *Bill of material and routing information*

The applied lot sizing policy for all materials is lot-for-lot and no setup times are modelled. Each processing step requires a deterministic processing time of approximately 10 minutes and the internal capacity per resource is 480 hours per month. In the simulation study, five years are simulated with one year is the warm up time and 20 replications.

4.2 Parameter Settings

The forecast error parameter α is varied between 0 and 0.5 with a step size of 0.1. The parameters investigated for the CRL order behaviour are order amount: $E[O_p] = 30\ \forall\ p \in \{10,12\}$, $E[O_p] = 50\ \forall\ p \in \{11,13\}$, and $CV[O] \in \{0,0.15,0.5\}$; and customer required lead time: $E[L] \in \{3,6,12\}$ and $CV[L] \in \{0,0.5,1\}$. A basic scenario for detailed analysis is defined with $CV[O_p] = 0.15$, $E[L] = 6$ and $CV[L] = 0.5$. The parameters investigated for the FEV order behaviour are forecast

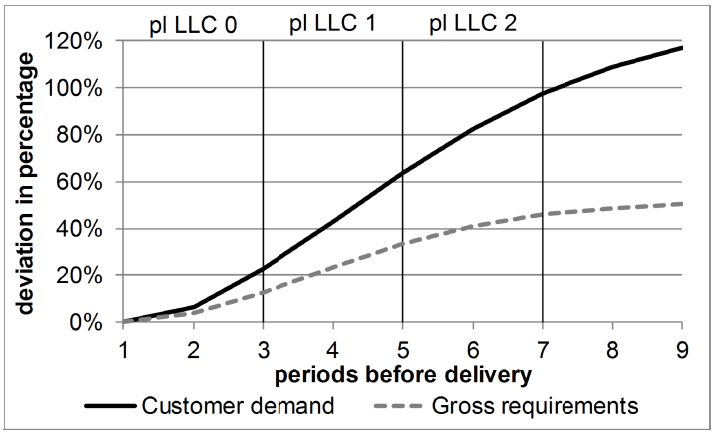

Figure 3: *Information progress CRL order behaviour with MPS functionality*

evolution horizon $h = 8$, frozen zone $fz \in \{0,2,4\}$, change frequency $cf \in \{1,2,4\}$, and variance of evolution error $\delta \in \{0.1,0.3,0.6\}$. Here the basic scenario is defined with $fz = 2$, $cf = 1$, and $\delta = 0.3$.

All results are shown for sales product 10, nevertheless, all other sales products and resources show a similar behaviour. The capacity requirements are shown for all resources (i.e. M5, M3 and M1 respectively) where sales product 10 is manufactured. Due to clarity the index of sales product 10 is not shown in the results.

5 Results

5.1 MPS Smoothing Effect for CRL Behaviour

The influence of the MPS functionality to smooth the demand uncertainty is studied here in detail for the CRL order behaviour without forecast error for the basic scenario. This order behaviour for the pure MTO system shows the following results:

$CV[K_1] = 0.91$, $CV[X_1] = 0.91$, $CV[C_{M5}] = 0.69$, $CV[C_{M3}] = 0.76$ and $CV[C_{M1}] = 0.74$.

Applying the MPS functionality this leads to:

$CV[K_1] = 0.91$, $CV[X_1] = 0.45$, $CV[C_{M5}] = 0.51$, $CV[C_{M3}] = 0.42$ and $CV[C_{M1}] = 0.38$.

Note that without MPS functionality $CV[X_1]$ is equal to $CV[K_1]$.

A first observation from this setting is that the MPS functionality within the hierarchical planning structure mitigates the negative effect of demand uncertainty which is given by variance in order amount and CRL. The results show a lower CV of capacity requirements for the scenario with the MPS. The CV of capacity requirements decreases in the upstream manufacturing levels with MPS functionality. Such behaviour is not identified for the pure MTO system.

Figure 3 shows the information progress of customer demand and gross requirements orders by applying the presented information evolution quality measures $\theta_{p,i}(K_{p,i})$ and $\theta_{p,i}(X_{p,i})$ (see 3.4) for the CRL order behaviour with MPS functionality.

An observation from this setting is that the information quality of the customer demand continuously improves until the final delivery date. The information quality of the gross requirements is lower than the information quality of customer demand showing that the MPS functionality has a smoothing effect on the gross requirements.

5.2 Effect of Frozen Zone for FEV Behaviour

The FEV order behaviour is discussed for the basic scenario with a frozen zone of two days and without a frozen zone. Without a frozen zone the following results can be observed:

$CV[K_1] = 0.70$, $CV[X_1] = 0.34$, $CV[C_{M5}] = 0.40$, $CV[C_{M3}] = 0.40$ and $CV[C_{M1}] = 0.38$.

With frozen zone the results are:

$CV[K_1] = 0.67$, $CV[X_1] = 0.33$, $CV[C_{M5}] = 0.38$, $CV[C_{M3}] = 0.37$ and $CV[C_{M1}] = 0.35$.

An intuitive observation for the FEV order behaviour is that within the hierarchical production planning a frozen zone leads to a lower CV in customer demand and gross requirements as well as lower CV in capacity requirements.

5.3 Effect of Forecast Error

Figure 4 shows the performance measures P1 (gross requirments, abbr. *gr*) and P2 (production orders, abbr. *po*) for different levels of the forecast error values α for both order behaviours. Note that P1 can be interpreted as gross requirements uncertainty in comparison to customer demand uncertainty and P2 can be interpreted as production order uncertainty in comparison to customer demand uncertainty.

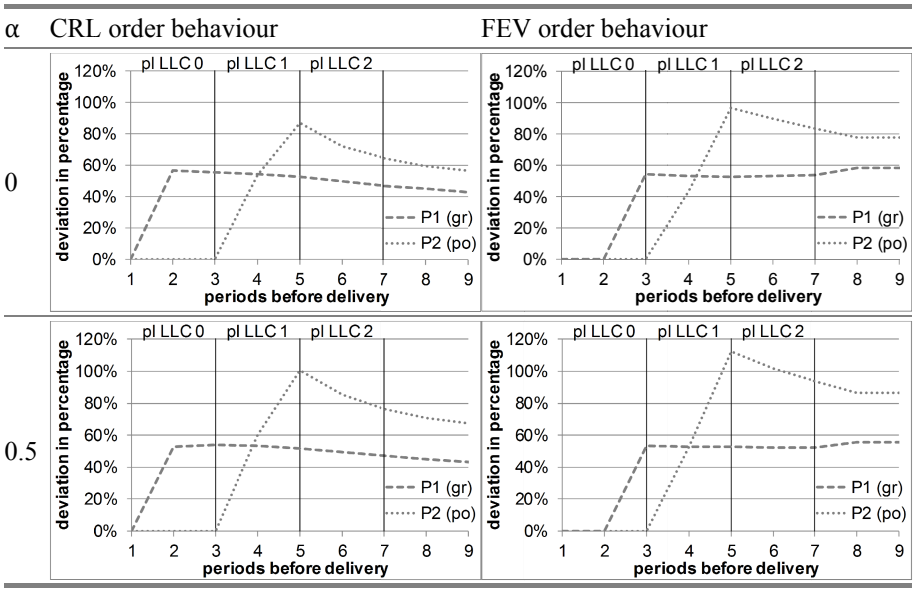

Figure 4: *Information progress with forecast error for both order behaviours*

One unexpected observation from this setting is that the forecast error, which increases uncertainty of the customer order amounts and also leads to higher gross requirements variance (see fig. 5 and fig. 6), decreases the MPS improvement percentage only slightly.

		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
$CV[O_p]$	0	0.33	0.43	0.33	0.45	0.34	0.50	0.35	0.55	0.36	0.60	0.37	0.68	***0.35***	**0.54**
	0.15	0.33	0.45	0.33	0.46	0.34	0.51	0.35	0.55	0.37	0.60	0.37	0.68	***0.35***	**0.54**
	0.5	0.38	0.54	0.38	0.55	0.39	0.58	0.40	0.62	0.41	0.66	0.41	0.73	***0.40***	**0.61**
	Ø	**0.35**	**0.47**	**0.35**	**0.49**	**0.36**	**0.53**	**0.37**	**0.57**	**0.38**	**0.62**	**0.38**	**0.70**	**0.36**	**0.56**
		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
$E[L]$	3	0.43	0.44	0.43	0.45	0.45	0.50	0.47	0.56	0.48	0.62	0.49	0.70	***0.46***	**0.55**
	6	0.41	0.52	0.42	0.53	0.43	0.58	0.44	0.62	0.46	0.67	0.46	0.75	***0.44***	**0.61**
	12	0.19	0.46	0.19	0.47	0.19	0.50	0.19	0.54	0.20	0.57	0.20	0.64	***0.19***	**0.53**
	Ø	**0.35**	**0.47**	**0.35**	**0.49**	**0.36**	**0.53**	**0.37**	**0.57**	**0.38**	**0.62**	**0.38**	**0.70**	**0.36**	**0.56**
		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
$CV[L]$	0	0.19	0.26	0.20	0.30	0.22	0.37	0.23	0.45	0.25	0.51	0.25	0.60	***0.22***	**0.41**
	0.5	0.40	0.58	0.40	0.59	0.41	0.61	0.41	0.64	0.42	0.68	0.43	0.75	***0.41***	**0.64**
	1	0.45	0.57	0.45	0.58	0.45	0.60	0.46	0.63	0.47	0.67	0.47	0.74	***0.46***	**0.63**
	Ø	**0.35**	**0.47**	**0.35**	**0.49**	**0.36**	**0.53**	**0.37**	**0.57**	**0.38**	**0.62**	**0.38**	**0.70**	**0.36**	**0.56**

Figure 5: *Parameter variation CRL order behaviour*

		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
f_z	0	0.25	0.39	0.25	0.40	0.26	0.43	0.27	0.47	0.28	0.51	0.29	0.54	***0.27***	**0.46**
	2	0.23	0.37	0.23	0.38	0.24	0.42	0.25	0.46	0.27	0.50	0.27	0.53	***0.25***	**0.44**
	4	0.14	0.31	0.14	0.33	0.15	0.36	0.15	0.40	0.16	0.44	0.17	0.47	***0.15***	**0.38**
	Ø	**0.20**	**0.36**	**0.21**	**0.37**	**0.22**	**0.40**	**0.23**	**0.44**	**0.24**	**0.48**	**0.24**	**0.51**	**0.22**	**0.43**
		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
c_f	1	0.30	0.46	0.30	0.48	0.31	0.50	0.32	0.54	0.34	0.57	0.35	0.61	***0.32***	**0.53**
	2	0.21	0.36	0.21	0.37	0.22	0.40	0.23	0.44	0.25	0.48	0.26	0.51	***0.23***	**0.43**
	4	0.11	0.25	0.11	0.27	0.11	0.30	0.12	0.34	0.13	0.38	0.13	0.42	***0.12***	**0.33**
	Ø	**0.20**	**0.36**	**0.21**	**0.37**	**0.22**	**0.40**	**0.23**	**0.44**	**0.24**	**0.48**	**0.24**	**0.51**	**0.22**	**0.43**
		a													
		0		0.1		0.2		0.3		0.4		0.5		Ø	
		gr	po	gr	po	gr	po	gr	po	gr	po	gr	po	gr	po
δ	0.1	0.09	0.14	0.09	0.17	0.11	0.22	0.14	0.29	0.16	0.36	0.17	0.41	***0.13***	**0.26**
	0.3	0.22	0.38	0.22	0.39	0.23	0.42	0.23	0.46	0.24	0.50	0.25	0.53	***0.23***	**0.45**
	0.6	0.31	0.55	0.31	0.56	0.31	0.56	0.31	0.57	0.31	0.58	0.31	0.60	***0.31***	**0.57**
	Ø	**0.20**	**0.36**	**0.21**	**0.37**	**0.22**	**0.40**	**0.23**	**0.44**	**0.24**	**0.48**	**0.24**	**0.51**	**0.22**	**0.43**

Figure 6: *Parameter variation FEV order behaviour*

Another counterintuitive effect is that the production order amount has over a long range a higher uncertainty than the gross requirements (only below 4 periods before delivery its uncertainty is lower) and the forecast error significantly decreases this performance.

5.4 CRL and FEV parameter variation

The influence of different parameters on the information evolution quality measure for gross requirements $\theta_{p,i}(X_{p,i})$ (abbr. gr) and production orders $\theta_{p,i}(Q_{p,i})$ (abbr. po) is studied for sales product 10, 7 periods (sum of planned lead times) before the delivery date for the CRL, in figure 5, and FEV, in figure 6, order behaviours. Different levels of forecast error parameter α are discussed. Each figure consists of three sub tables for the respective parameters of CRL and FEV. The study shows for both order behaviours that with increasing forecast error parameter α the information evolution quality measure gr and po increase for all parameter combinations, which means more information progress deviation.

An observation valid for both order behaviours is that the forecast error value α has a negative correlation with the information quality.

An observation from the CRL parameter variation in Figure 4 *is that the longer the customer required lead time and the lower its variance the better is the information quality of gross requirements.*

The positive effect of a frozen zone on information quality is discussed in 5.2.

An observation from the FEV parameter variation is that a higher number of changes per customer order and big changes are leading to a decrease of information quality.

6 Conclusions

In this paper the effect of two different order behaviours, which differ how customers provide information about the demand, namely CRL and FEV is investigated. To identify the influence of information uncertainty within the hierarchical production planning a measure for information quality and information evolution is developed. The results of the simulation study show that for the CRL order behaviour the MPS mitigates the information uncertainty. For the FEV order behaviour the information quality improves with the use of a frozen zone. If the production system is facing forecast errors the system has to deal with higher information uncertainties. In further research we would like to discuss what information quality is needed to justify investments in information sharing between supply chain members.

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