TOWARDS TAKT TIME CONTROLLED PRODUCTION UNITS IN LOW VOLUME HIGH VARIETY ENVIRONMENTS

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ABSTRACT
Takt time control is a widely used lean principle within repetitive environments. Its transparency and simplicity support the realization of short and reliable throughput times. This paper examines the applicability of a takt time concept designed for a non-repetitive or low volume high variety environment. An industrial case describes the phased implementation of the concept and shows its applicability and benefits in practice. A simulation study indicates the impact of the amount of work in process and the extent of processing variability on the performance of the concept in each of the implementation phases. The results show that the restrictions added with each implementation phase generally lead to some performance losses. However, if the amount of WIP set is sufficient, this degradation of performance is minimal. As in the industrial case, the benefits of the takt time concept will then most likely outweigh these small performance losses.

Keywords: takt time, job shop, simulation

INTRODUCTION
Takt time control is an important and powerful design principle in Lean manufacturing (see e.g. Linck and Cochran, 1999; Miltenburg, 2001). Takt time can be defined as the time between units of production output in the case that output is geared to customer demand. It can thus be calculated by dividing the net available production time per period by the demand for that period. Takt time control requires a balanced division of work. Important advantages of takt time control are the realization of short and reliable throughput times. Takt time control may also have motivational benefits due to the immediate feedback on performance (Hopp and Spearman, 2001:374).

Takt time control is predominantly found in high volume assembly environments. Here, products are often produced in one-piece flow, meaning that single products move from operation to operation in a (relatively) fixed order. The operations are divided in stages which all have to produce according takt time. The product variety is usually limited with respect to the number of required routings. Variety in the mix of product types and in the required processing times may ask for advanced methods to determine the assembly stages and to distribute tasks and workers to these stages such that each stage is able to produce efficiently according takt time.

This paper concerns the implementation of a takt time concept in a low volume high variety part manufacturing environment. We will first describe the industrial case that triggered the development of the takt time concept. Then we will concisely describe the takt time concept and present the phases defined for implementing the concept in the firm. Next, we will present a simulation study to gain...
insights into the applicability of the concept and the implementation phases in a broader setting. The simulation study indicates how the degree of processing time variability, which can be seen as a main characteristic of a particular low volume high variety environment, plays a role in the concept and during the implementation phases. We will also show the moderating role of the amount of Work In Process (WIP). The last section is a concluding section.

TAKT TIME CONCEPT IN A LOW VOLUME HIGH VARIETY ENVIRONMENT

Industrial case description

‘Copper bars’ is one of the departments of a firm that develops, produces and sells products for switching, distributing, and protecting electrical energy on the low and medium voltage level. Copper bars supplies components and semi-finished products to other departments within the firm. At copper bars, copper strips undergo punching, trimming, bending, drilling, milling and bench working operations. The production process starts with punching. Orders that require the same thickness of copper bars are nested on the same (type) of copper bar and are punched as one order, in order to reduce copper waste and setup times. The operations performed after punching are grouped under the heading ‘strip manufacturing’. In strip manufacturing, the routing variety of products is large. An analysis of about 3500 orders showed that the number of processing steps lies between 1 and 5, with an average of 1.6. The average processing time per operation is about 32 minutes, with differences between machines and processing variability at each machine. The products leave copper bars either to go to the assembly department or to receive another operation outside copper bars and then possibly come back to copper bars again. Copper bars operates in two shifts. Three workers work only in daytime, due to physical reasons, and thus partly participate in both shifts. Depending on the time of the day, between 5-9 workers are available for production. Since there are more machines than workers available, copper bars can be characterized as a ‘dual resource constrained’ system. The internal customers of copper bars demand fast and on-time product deliveries, with high quality and at low costs. Reducing lead time (speed) and improving the service level (reliability) is of major importance for copper bars.

In the base situation, before June 2007, the amount of WIP was large, waiting times of jobs varied much, it was not clear for workers which job to work on, workers often remained at their preferred machine, and 20% of the orders were indicated as ‘rush orders’. This resulted in unreliable lead times. The goal of implementing a takt time concept at copper bars has been to create a stable production system in which predictable and short throughput times can be realized. This takt time concept has to be able to deal with variety encountered in the number of processing steps and the sequence of jobs, processing time variability, and fluctuating worker capacity.

Takt time concept

It was proposed that all the operations of copper bars after punching (i.e., strip manufacturing) should be regarded as one production unit (PU) controlled by means of takt time control. In the takt time concept, the amount of WIP in the PU is fixed and the sequence of jobs leaving the PU should be First in First Out (FIFO). The internal lead time of each job through the PU equals ‘WIP x Takt time’. Each job in the PU has its own WIP/Kanban card. A WIP/Kanban card can only be connected to another job after its job is finished and the internal lead time has passed.

The takt time concept, as presented here, is applied to the PU as a whole and not to each of the required operations individually. Whereas the output of the PU is takt driven, the internal production processes are not controlled by the takt times. Processing times at individual work stations may be larger than the takt time. The total work content of a job, however, needs to be less than WIP x Takt
time. The team of workers has to take care that jobs are able to leave copper bars in FIFO sequence and in takt. Within a traditional takt time controlled assembly line, the amount of WIP is fixed and equals the number of stations. Each station in the line contains one job that is transferred to the next station after each takt. In the proposed takt time concept, however, the fixed amount of WIP needs to be larger than the number of active resources (workers) in the PU. This is needed to deal with processing time and routing variability. If the PU is able to finish a job in FIFO sequence each takt with a reasonable amount of WIP, short and reliable throughput times are guaranteed. The reserved throughput times in the ERP system can then be brought down and reliable start dates of orders can be determined. The team of workers will have more working space, shorter searching times for jobs and a clear performance target. This will all positively influence the delivery performance.

PHASED IMPLEMENTATION OF THE TAKT TIME CONCEPT AND INITIAL RESULTS

Since the proposed takt time concept was quite different from the base situation, management opted for a phased implementation. We defined three phases for the implementation of the takt time concept which were chosen such that each phase would show certain performance advantages. The defined phases of implementation are:

- **CONWIP.** This phase forces a reduction of the Work in Process to a fixed number of production orders;
- **FIFO.** This phase requires the team of workers to focus on the oldest jobs in the system.
- **TAKT.** This phase asks from the team of workers that each takt, one order (a particular order in conformity with the FIFO rule) has to be ready to leave the system.

Before the implementation started, the current situation (base situation, phase 0) at copper bars was recorded with the help of two bachelor students Industrial Engineering. Also, we developed a game/animation to give insights into the basic workings of the concept and to convince those involved that the takt time concept works in the low volume high variety environment of the PU. The game/animation used real production data of jobs (routing and processing time information) and has had a very positive influence on the acceptance of the takt time concept.

Starting from the base situation, the first step we defined towards takt time control was to create a CONWIP (CONstant Work In Process) system with an acceptable level of WIP. CONWIP implies that only when a job is finished, a new job is allowed to enter the system. Starting from an initial situation of about 150 orders (i.e. jobs) on the workfloor, we gradually reduced this number to 60 orders. Each order got a unique number/card. After a job was finished, the card was free to be used for a new job. Workers were stimulated not to start with a new job, but to proceed with current jobs in the system. This much lower level of WIP has reduced the throughput time in the PU significantly from about 4.2 days to less than one day. Workers as well as supervisors enjoyed the new situation and noted several advantages, such as a better overview of the situation and less time spent for finding urgent jobs.

In the FIFO phase, jobs need to depart the PU in order of arrival. The reason to introduce this phase is that it gives a clear priority to jobs. Workers are stimulated to work on the right jobs. They cannot ignore boring or difficult jobs anymore, which was one of the causes of bad delivery performance in the base situation (and which could still be a cause in the CONWIP phase). Only when the oldest job in the PU is finished, a new job is allowed to enter. This restriction lowers the actual WIP level in the case that the job that needs to be finished is still in process while all operations of ‘younger’ jobs are finished and able to leave the PU. The constant amount of WIP determined in the first phase is the maximum amount of WIP in the PU starting from the FIFO phase. In order to support the FIFO phase,
we developed a so-called ‘takt time screen’ indicating the sequence in which the jobs need to leave the PU. The screen shows all numbers/cards linked to jobs and the time that the cards/orders are in the system. Workers and supervisors were very enthusiastic about the screen. It was helpful for them to prioritize jobs. The variability of throughput times reduced significantly at this stage.

In the TAKT phase, jobs need to leave the PU in order and in takt. The passing of the takt time before a new order can be released in the system is an additional restriction compared to the FIFO phase. As a consequence, the total time of the job in the PU would ideally be WIP x Takt. These fixed throughput times of jobs support the ability to reserve correct lead times in the production control system (MRP) of the firm. Furthermore, the fixed throughput time also provides a means to supervisors and workers to control the timely flow of jobs through the system. The ‘takt time screen’ was used to indicate late jobs (i.e. jobs longer than WIP x Takt in the system). These jobs were marked red. It needs to be noted that the takt time rule does not have a direct impact on balancing the workload in course of time. It is possible for workers to work ‘in advance’ to some extent. In that case, some jobs will be finished earlier than needed. These jobs, however, formally leave the system at their associated takt time. The ‘buffer’ of jobs finished too early is helpful in periods where jobs are relatively large, or where there are temporarily fewer workers.

At the moment, the ‘copper bars’ team is busy to improve their performance. Measures are taken to reduce the number of ‘red orders’. Some workers, for instance, receive training to operate machines which currently can only be operated by one worker. Also, the maintenance of some machines is intensified. Supervisors are asked to stimulate and teach workers to perform the correct jobs. Furthermore, a set of performance indicators are developed (quality, delivery performance, efficiency) to be used at the workflow level. Following the changes in the ‘copper bars’ team, also some required changes outside the team have been implemented. The takt time concept controls job release and priority dispatching for the strip manufacturing PU within copper bars and has led to short and controllable throughput times. Without any further changes in the production control system, this could lead to long waiting times of jobs before the PU. Therefore, we developed and implemented a controlled order entry mechanism in cooperation with the firm. In this mechanism, jobs are released to copper bars every day up to a level of 2.5 days work, including the jobs in the PU. Due dates of jobs entering at day $x$ were set at day $x+3$. In order to recognize the jobs which need to be finished at a particular day, the planner puts order information in files with a different color for each day. This system of order entry has been implemented in February 2008 and works satisfactory. The planner is responsible for the limited entry of jobs at least three days before the (MRP) due date. In case there are too many orders, the planner has to decide about subcontracting or extending manufacturing capacity (overwork, additional shift, more workers).

Management of the firm is enthusiastic about the concept. The short and reliable throughput times foster possibilities for Direct-to-Line delivery of components. Currently, the firm is busy implementing the takt time concept in other production units as well. They believe that the takt time concept is robust and can be used in departments with other manufacturing characteristics. In order to generalize the applicability of the takt time concept, we performed a simulation study.

SIMULATION STUDY
The proposed takt time concept will lead to short and controllable throughput times if the amount of WIP is low and workers are able to finish jobs in order and in takt. Additionally, performance may then be improved due to factors such as better overview of the situation on the workfloor and less time spent for finding jobs. The management of the firm clearly experienced these benefits in practice. However, reducing the amount of WIP and imposing additional restrictions on the release of new jobs, relating to the time (takt) and priority (FIFO) of jobs leaving the PU, may also result in performance losses. If the
amount of WIP is too low, or the processing time variability is too high, workers may not have enough work to continue working, or the desired sequence of jobs cannot be realized in takt. We therefore used simulation to indicate how the amount of WIP and the extent of processing time variability play a role in the different phases of implementation of the takt time concept. With the simulation results we are able to identify the possible downside of the concept in each of the implementation phases in various manufacturing situations. Combined with the many positive effects of the takt time concept as described before, this will indicate the generic applicability of the concept.

Whereas the animation/game showed the workings of the TAKT phase for the PU without extensive performance analyses, the simulation experiments were meant to thoroughly compare the performance of the PU during the different implementation phases in various manufacturing situations. The simulation model used is similar to that used in the game/animation, but uses statistical distributions for processing times and routing generation and is modeled for speed. The advantage of statistical distributions is that changes in the parameters can be easily made and data for multiple replications are easily obtained. Also, the use of a statistical distribution is an attempt to represent the population distribution rather than just a sample as given by empirical data (see e.g. Robinson, 2004). This leads to more generic results. The simulation study is described in more detail next.

Model description
We used discrete event simulation to gain insights in the impact of processing time variability and the amount of WIP on the feasibility of the takt time concept in the different phases of implementation. All simulation models are written in the object-oriented simulation software package Tecnomatix Plant Simulation 7.6 (Texas: UGS Corporation). The simulation models are stochastic, steady-state, and non-terminating. We use multiple replications (40) each with the same initial conditions to estimate the steady-state means of the output parameters (see e.g. Robinson, 2004). Different seeds are used for each replication to maximize sampling independence. We set the run length at 6640 hours, which is more or less equivalent to a two-year working period for a system working in two shifts.

The simulated production system consists of 7 machines and 5 workers. All workers are able to operate all machines with equal proficiency. A job shop routing of jobs is modeled by randomly assigning each job a sequence and a number of machines it needs to visit (ranging from 1-7). The average number of machines a job needs to visit is four. We assume that once a job visits a machine, it cannot visit the same machine again. Other assumptions are that there are no machine-failures, no absenteeism, and always sufficient jobs available to enter the system when required. The gamma distribution is used for the processing times with an average of 32 minutes per operation (which is equal to the average in the empirical data set of the PU). An average job thus has a work content of 4x32=128 minutes.

The where-rule, which assigns a worker eligible for transfer to the next machine, is FIFO. A worker is thus sent to an available machine with the oldest job in queue and that job is then processed. After a worker finishes a job, he/she is eligible for transfer again (this represents a so-called ‘central when-rule’). Compared with practice, this is an optimistic rule. In many practical situations, workers remain working at their machines until the queue of jobs before the machine is empty (this is a ‘decentral when rule’). It is conceivable that workers will apply the central when-rule in later phases of the implementation. The central when-rule leads to lower throughput times than the decentral when-rule. As a who-rule the ‘longest idle time’ rule is used. This rule assigns the worker who has been waiting the longest in the case that more than one worker is eligible for transfer.

In practice, the takt time is calculated by dividing the available production time per period by the number of jobs requested by the customer in that period. Once this desired takt time is known, the capacity of the production process usually is adjusted to meet the desired takt time as close as possible,
taking into account the average work content of a job. For our simulation, we started the other way around. We fixed the capacity of the production process (5 workers) and calculated the corresponding takt time by dividing the average work content of a job by the number of workers in the system (128/5 \approx 26 \text{ minutes}). The takt rules in all implementation phases are as follows. In takt one, job one needs to be finished, in takt 2, job two needs to be finished, etc. A new takt only starts if the takt time has passed AND the corresponding job is finished. Please note that the takt rules are equal in all implementation phases, but the release of new jobs differs per phase (see experimental factors).

Three performance measures are recorded: the throughput per worker per hour (TWH), the number of times that the takt time is exceeded per hour (ETAKT), and the time that the takt is exceeded per hour (ETIME). TWH is measured as the division of the total number of jobs that departed the system by the man-hours that were available during production. ETAKT equals the total number of times the takt time is exceeded divided by the simulated time in hours. ETIME is measured as the total amount of time the takt is exceeded divided by the simulated time in hours. Note that ETAKT and ETIME do not explicitly play a role in the worker assignment rules used in the simulation. In reality, workers will adapt their decisions to the performance indicators. The performance results in our simulation, therefore, are conservative and do not include positive effects of setting new performance indicators. The three performance indicators, as presented here, determine, to a certain extent, the acceptability of the takt time concept. It is the objective of the takt time concept to have the lowest amount of WIP, with an acceptable performance on the presented indicators. The amount of WIP determines the throughput times of jobs.

*Experimental factors and levels*

The experimental factors are the phase of implementation (Phase), the processing time variability (Variability), and the (maximum) amount of work-in-process (WIP). The variability of processing times was initially mentioned by the supervisors and planners as being a critical issue for the feasibility of the concept. There were, and still are, discussions about the issue in which cases WIP can be measured by the number of jobs in the system or when it is needed to control WIP by means of the work content in hours. We decided to measure and control WIP by means of the number of jobs. This simplifies the control mechanism (free cards can automatically be assigned to new jobs) and ensures equal lead times for each job through the production unit. In the simulation study, we explore to what extent processing time variability plays a role in this choice. The amount of WIP is likely to be an important moderating factor, since inventory is able to absorb fluctuations in the load. The amount of WIP, however, needs to be as low as possible. WIP is related directly to throughput times of jobs and to other advantages of the takt-time concept, such as the extent of overview on the workfloor and the time needed to find appropriate jobs.

As explained earlier, we distinguish the current situation and three phases of takt control implementation: (0) BASE, (1) CONWIP, (2) FIFO, and (3) TAKT. For each phase, the takt registration is equal but the job release is dealt with differently. In the BASE situation, all jobs that arrive at the system are released directly to the shop floor. This results in a large average amount of WIP. In the simulation, we modeled this BASE phase as a CONWIP system with a large amount of WIP (120 jobs). When a job is finished and leaves the system, a new job is released and thus the WIP remains constant. In the CONWIP phase, the amount of WIP is reduced drastically and the release mechanism equals that of the BASE phase. In the FIFO phase, a new job is released only when the ‘oldest’ job in the system is finished. Finally, in the TAKT phase, a new job is released only if the takt time has passed AND the ‘oldest’ job is finished.

We distinguished four levels of processing time variability (leaving the mean at 32 minutes) by altering the parameters of the gamma distribution. The first level represents the lowest variability
(Low), with a squared coefficient of variation (SCV) of 0.125. The second level represents low to medium variability (LM), with a SCV of 0.25, the third level represents medium to high variability (MH), with a SCV of 0.5. Finally, the fourth level represents high variability (High), with a SCV of 1.

The amount of WIP in the system is 120 for the BASE phase and is not varied within this phase. For the other phases, the amount of WIP is 10, 15, 20, or 25. For the CONWIP phase these levels are constant, for the FIFO and TAKT phases they represent the maximum amount of WIP in the system.

RESULTS

Table 1 shows the performance results in all phases under all levels of WIP and Variability. In the BASE phase, the processing time variability does not impact the performance measures. With the amount of WIP fixed at 120, the TWH in the BASE phase is 0.468. This equals the maximum throughput, which is the inverse of the average work content of a job expressed in hours (1/2.133). This means that all workers are constantly working: there are no blocking or starving effects. It is easy to understand that if there are 120 jobs in a system of 7 machines and 5 workers with a job shop routing, all machines and certainly all workers have enough work to process. This high utilization of workers combined with a maximum throughput time allowed for each job of (120 x takt time) results in a good takt time performance, but also in long average lead times. The takt time is exceeded on average only once each 1000 hours, with an average of 0.001 hours per hour worked. Note that dividing ETIME by ETAKT gives the average time a takt is exceeded in hours, here 1 hour. The BASE situation performs well with respect to the three indicators. The WIP level, however, is large which indicates a low controllability on lead time performance. The takt time concept is developed to improve this controllability and to ensure small throughput times.

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<th>Low ETAKT</th>
<th>Low ETIME</th>
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<th>LM ETAKT</th>
<th>LM ETIME</th>
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The results of the CONWIP phase, the FIFO phase and the TAKT phase have been analyzed by means of Analysis of Variance (ANOVA) with Phase, Variability, and WIP as independent variables and TWH, ETAKT and ETIME as dependent variables. Table 2 shows the ANOVA results for TWH, ETAKT and ETIME. For all these measures, the homogeneity of variance assumption does not hold (Levene test, p < 0.05). The F statistic, however, is robust against heterogeneous variances, as long as
the group sizes are equal (Glass et al., 1972) or approximately equal (Stevens, 1996: 249). Because these between-subjects ANOVAs are conducted with equal cell sizes, we continue the analyses. Table 2 shows that the main effects and the interaction effects are significant (p < 0.05) for all performance measures. In our further analysis, we will mainly focus on the largest effects (the main effects and the interaction effect of Phase and WIP). The main effects of all performance measures are further analyzed by Tukey post-hoc tests to compare the means of all levels of a factor. For all three performance measures, the differences between all levels of all main effects appeared to be significant (p < 0.05).

<table>
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<td>Variability</td>
<td>33053.08</td>
<td>p &lt; 0.001</td>
<td>6130.32</td>
</tr>
<tr>
<td>WIP</td>
<td>121614.47</td>
<td>p &lt; 0.001</td>
<td>134270.93</td>
</tr>
<tr>
<td>Phase x Variability</td>
<td>1807.57</td>
<td>p &lt; 0.001</td>
<td>326.23</td>
</tr>
<tr>
<td>Phase x WIP</td>
<td>6696.49</td>
<td>p &lt; 0.001</td>
<td>9379.80</td>
</tr>
<tr>
<td>Variability x WIP</td>
<td>1186.44</td>
<td>p &lt; 0.001</td>
<td>329.02</td>
</tr>
<tr>
<td>Phase x Variability x WIP</td>
<td>71.31</td>
<td>p &lt; 0.001</td>
<td>387.71</td>
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</table>

We will first discuss the TWH results. The main effect of Phase reveals that TWH is the highest in the CONWIP phase (0.454), then in the FIFO phase (0.425) and lowest in the TAKT phase (0.400). This was expected, since each phase adds another restriction to the previous phase. The main effect of Variability shows that a higher processing time variability leads to less throughput per worker per hour (TWH equals 0.442, 0.436, 0.425, and 0.402 for Low, LM, MH, and High variability, respectively). Finally, the main effect of WIP reveals that a low amount of WIP leads to less throughput than a high amount of WIP (TWH equals 0.380, 0.423, 0.445, and 0.456 for WIP amounts of 10, 15, 20 and 25, respectively). The interaction effect of Phase and WIP shows that the effect of Phase is stronger under lower amounts of WIP. Also, the effect of WIP is weakest in the CONWIP phase and strongest in the TAKT phase. Figure 1 shows the TWH results for all phases at all WIP amounts under low variability (left side) and high variability (right side). The BASE phase results (which are for a WIP amount of 120) are added to show the maximum achievable TWH performance.

These results show that a phased implementation of the takt time concept does not need to degrade the throughput performance much as long as the amount of WIP is sufficient. The negative effect of more processing time variability can be partly covered by the amount of WIP one allows in the system.

![Figure 1 – TWH results under low and high variability. Note that the BASE phase results are for a WIP of 120.](image-url)
For ETAKT, the main effect of Phase shows that the takt time is exceeded least in the CONWIP phase (0.0242), then in the FIFO phase (0.0823) and most in the TAKT phase (0.1318). The main effect of Variability shows that a higher variability causes the takt time to be exceeded more often than a lower variability (ETAKT equals 0.0651, 0.0711, 0.0825, and 0.0990 for Low, LM, MH, and High variability, respectively). The main effect of WIP reveals that with a low amount of WIP, the takt time is exceeded more often than with a high amount of WIP (ETAKT equals 0.1762, 0.0828, 0.0389, and 0.0197 for WIP amounts of 10, 15, 20 and 25, respectively). The interaction effect of Phase and WIP shows again that the effect of Phase is stronger under lower amounts of WIP and the effect of WIP is weakest in the CONWIP phase and strongest in the TAKT phase. Figure 2 shows the ETAKT results for all phases at all WIP amounts under low variability (left side) and high variability (right side). The BASE phase results (which are for a WIP amount of 120) are added to show the minimum.

These results show that with a sufficient amount of WIP, the number of times that the takt time is exceeded is negligible for the CONWIP and FIFO phases in the case of low variability, and for the CONWIP phase in the case of high variability. In the TAKT phase (and in the FIFO phase under high variability) an amount of WIP of 25, which is 5 times the number of workers in the system, will still result in some exceeded takt times.

For ETIME, the main effect of Phase shows that the time the takt is exceeded is lowest in the CONWIP phase (0.0246), then in the FIFO phase (0.0807) and highest in the TAKT phase (0.1331). The main effect of Variability shows that a higher variability causes the takt time to be exceeded for a longer period of time (ETIME equals 0.0474, 0.0585, 0.0825, and 0.1294 for Low, LM, MH, and High variability, respectively). Finally, the main effect of WIP reveals that a low amount of WIP leads to more excess time than a high amount of WIP (ETIME=0.1770, 0.0818, 0.0390, and 0.0201 for WIP amounts of 10, 15, 20 and 25, respectively). The interaction effect of Phase and WIP for ETIME is similar to that described for TWH and ETAKT. Figure 3 shows the ETIME results.

These results show that a phased implementation of the takt time concept does not need to degrade the throughput performance much as long as the amount of WIP is sufficient. The negative effect of more processing time variability can only be partly covered by the amount of WIP one allows in the system in the FIFO and TAKT phases. In comparing figure 2 and 3, the larger main effect of Variability for ETIME than for ETAKT can be clearly seen: the negative effect of increased Variability is stronger for the time that the takt is exceeded than for the number of times the takt is exceeded.
CONCLUSION

We developed a takt time concept for a low volume high variety environment and defined several phases to gradually implement it. We showed the benefits of the concept in an industrial case. An important success factor of the concept was the increased controllability of the production unit. The fixed throughput times of jobs in the takt phase provide a means to supervisors and workers to control the timely flow of jobs through the system and support the ability to reserve correct lead times in the production control system of the firm. Additionally, the lower amount of WIP on the workfloor resulted in performance improvements due to the fact that workers had a better overview and spent less time searching for jobs. The simulation study showed that with each implementation phase, generally, the throughput per worker per hour decreases and the number of times and the time that the takt time is exceeded per hour increase. However, the amount of WIP has a strong influence. If the amount of WIP set is sufficient, the degradation of these performance measures is minimal, certainly in the case of low processing time variability. This implies that managers should carefully determine the fixed amount of WIP taking into account the processing time variability their system encounters. Setting the amount of WIP too low will frustrate the performance of the takt concept, while setting it too high will unnecessarily increase the production throughput time.

REFERENCES


