

“HUMANIZING” TAKT TIME AND PRODUCTIVITY IN THE LABOR-INTENSIVE MANUFACTURING SYSTEMS

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Abstract:

The concept of takt time is well known in the typical manufacturing branches like automobile and machine industry from which it originates. In these industries the rule is that once the takt time is calculated for some period, for example for a week, the takt time is then fixed and is not changed during this period. This is certainly right approach because it ensures the stability of the production system. However, it suits well to the manufacturing systems where process automatization is increasingly applied.

But for the manufacturing systems that still depends vastly on a labor work, where process automatization is not intensively utilized, the concept of takt time should be differently applied. In these processes, the takt time cannot be held fixed all the time for the period for which it was calculated, but it must be changed even during the same shift. In other words, the takt time as well as the productivity must be “humanized”. So we need to apply the hands-on knowledge when implementing the well-known concept from typical environment to the specific conditions. How to “humanize” the takt time and productivity in the labor-intensive manufacturing systems is the focus of this paper. The procedure will be explained on the case study from real manufacturing company with labor-intensive work.

Key words: “humanizing” productivity, labor-intensive manufacturing, concept of takt time, lean management,

1. INTRODUCTION

One of the tenets of lean management concept is to produce the goods according to actual consumption or customer demand. In the manufacturing systems, this is accomplished through a well-know concept of takt time. Usually the takt time calculation is made for some period, for example, for one month, two weeks, one week, or just one day, and is then fixed during this period. The fixed takt time works well in those manufacturing systems where either an automatization is vastly used or where it requires maintaining rigorous, steady material flow. This is typical for the automobile, machine, or electrotechnical industries. In other words, the fixed takt time is important for keeping a steady pace of work.

However, in the manufacturing systems where automatization did not penetrate intensively, where these systems depend largely on the labor work, having fixed takt time for some period would cause problems because humans have difficulties to keep a steady pace of work during longer period and thus getting the required productivity. So where the manufacturing systems depend largely on the people activity, like sewing industry, we have to change the pace of work according to situation and hands-on knowledge even during the same shift in order to maintain production plans and productivity. The focus of this paper is to explain how the pace of work, or takt time, can be changed even during one production shift, so that the company with labor-intensive manufacturing system can still maintain production plans, and thus being efficient and productive. The concept of changed takt time will be explained on the case study example of the manufacturing company that produces shoes in the Slovak republic.

2. THE CONCEPT OF TAKT TIME IN LEAN MANUFACTURING

Production systems and the related manufacturing operations have to be organized as a function of the demanded products, in terms of production quantity, product variety and quality requirements, to satisfy market demand and customer requirements. To achieve a customer driven value stream it is important to design the production or manufacturing system to be consistent with the pace at which the customer is demanding a part or product (Simons and Zokaei, 2005). This pace is often referred to as the “takt time”, which is originally a German word for cadence or pace.

Many companies nowadays are interested in implementing some lean control principles, such as takt time control, in order to make their resources productive. Takt time lean control principles have mainly been applied in high-volume flow environments in which jobs move through the production system in one direction along a limited number of identifiable routings (Bokhorst & Slomp, 2010).

There are many literature sources that describe the concept of takt time applied in the lean manufacturing systems. For example, Narusawa and Shook (2009) define the takt time is how often you should produce one part or product to meet customer requirements based on the rate of sales. Another description provides Duggan (2002). According to him, takt time is the customer demand rate. It is used to synchronize the pace of production with the pace of sales. It tells us how quickly we should produce one part.

The usual takt time calculation is as follows:

$$\text{Takt time} = \frac{\text{Available production time per day}}{\text{Customer demand per day}} = \frac{7.5 \text{ hours/day}}{15 \text{ units/day}} = 0.5 \text{ hours/unit}$$

The usual period for calculating takt time is one day or one shift. The core concept of lean manufacturing is to arrange all processes in the production sequence in a smooth flow based on the rate of sales, i.e. the takt time. Mathematically, as the customer demand is changing, also the takt time is changing.

Once the takt time is calculated for a determined period, it is fixed for that period. The working pace in that period is also fixed, that is, all parts during this period are produced in the same speed, for example every 30 minutes. This is typical and usual for final processes like assembly lines. Maintaining the same working pace is not a problem for processes driven with high technology. However, this represents a problem, when the processes require a large portion of human work. Humans are not able to keep the same working speed during the longer period as the machines can.

Supervisors need to constantly monitor the working speed of the operators even during the determined period like one day or one shift. How to organize the work on the shopfloor so that the supervisors manage to accommodate the operators' working speed even during one shift to eventually meet production plan at the end of the shift is the subject of this article.

3. RESEARCH METHODOLOGY

As the main research methodology a case study approach was chosen according to the works of Yin (2003), Perry (1998), and Voss, et al. (2002) to conduct research that allows the application of both qualitative and quantitative sources of information. The case study was conducted in the middle-sized manufacturing company, located in the Slovak republic, producing the shoes of different kinds. The main feature of manufacturing system in this company is that it is vastly a labor-intensive, job-shop system. The productivity is dependent mostly on the skillfulness and training of employees than on the state-of-the-art technology.

In order to disclose full information on how to increase the productivity and work speed in that company we decided on the request of the managers to hide the real company's name. We had only two options: either for the purpose of our research we use all provided (and sensitive) information and preserve company anonymity of the provider, or we can use the name of the company, but in this case we have to maintain proper secrecy. Since unveiling the identity of the company in which we conducted empirical research was not considered so important as the actual accumulated knowledge, we decided to exercise the first option.

The practical example presented in this case study will show the readers that generally accepted lean initiative, in this regard, the concept of takt time, must be translated into specific company conditions with careful attention.

The main sources of information were study of the company documents, talks with respective managers, and on-site visits of shopfloors or processes where the work was done. The research was conducted in the period from January 2011 until May 2011. The case study starts with the introduction of several necessary terms and their calculations as they are understood and worked with in that company for further understanding of how the concept of takt time and also productivity can be "humanized" by the operators. The outcomes of the research are mostly applicable to the companies or to the processes with the labor-intensive, job-shop manufacturing systems.

4. CASE STUDY

4.1. Necessary calculations for determining productivity and performance

As the first step, we need to understand and calculate some important production parameters in order to find out later what is the real productivity.

Process time is the time determined by the process engineer as a sum of all operations done on a machine. Process engineer sets up the process time based on his or her experience over many years and usually it contains also a time reserve, which can be for example 15%.

When an operator on a machine sews together parts in four steps or operations, the total time to sew these parts is a process time on this machine for a given shoes type. However, the process time can be different (but not necessarily) for each shoes type on the same machine.

Tempo is a speed that we compare with the process time. When we have as an example the process time 2.5 minutes per one piece and we are able to finish the operations on that machine by 2 minutes, then the tempo is $2.5 \div 2 = 1.25$. Thus, our tempo or speed is 125%.

Production time is the time that we have available for making the production volume according to a production plan. When we have one 8 hour shift with a 30-minute break for the lunch, then our production plan is 450 minutes. If we have seven operators in a workplace, we have $7 \times 450 = 3,150$ minutes of production time available.

Productivity is the ratio of production expected time and production real time to produce the required volume of products based on the production plan within specified time period. For example, 7

operators produce 100 pieces of products, which takes 7.5 hours together. The expected time to produce one piece is 30 minutes based on the sum of all process times on all machines. The total expected time is then $100 \times 30 = 3,000$ minutes. However, when we are able to produce 100 pieces in 3,150 minutes, then our team productivity is $3,000 \div 3,150 = 0.952$ or 95.2%.

Production is the volume of pieces of products (pcs) produced. When we produced 100 pieces, then our production is 100 pcs. *Production plan* is the expected volume of products that we need to make in a specified period based on the customer orders or forecasts. The customer has ordered for tomorrow 110 pieces, thus our production plan for tomorrow is 110 pcs.

Fulfillment of production plan is the ratio of the actual production versus production plan. In our example, the fulfillment is $100 \div 110 = 0.91$ or 91%.

Performance is how many products we produced for some period (pcs/shift, pcs/operator). When we produced 100 pcs in one shift and we had 7 operators for this production, then our performance was $100 \text{ pcs} \div 7.5 \text{ hours} = 13,333 \text{ pcs per hour}$, or $100 \text{ pcs} \div 7 \text{ operators} = 14,3 \text{ pcs per one operator per one shift}$, or $100 \text{ pcs} \div 7 \text{ operators} \div 7.5 \text{ hours} = 1.9 \text{ pieces made by one operator per one hour}$.

All these calculations need to be applied in a bottleneck process. The bottleneck is a process that has the longest process time. Let's have the example as is shown in Table 1 below.

Table 1: Set of machines with a bottleneck process

Machine	1	2	3	4	5	6	7	8	9	10
Process time/pcs	1.4	1.8	2.3	3.2	1.5	3.5	2.8	2.2	1.5	2.5

In this case the bottleneck is the machine (or operation) number 6. The bottleneck can stop or stifle the work on all other machines or operations in a cell. When we work with two shifts per day, which is 900 minutes, then daily capacity of this whole layout is $900 \div 3.5 = 257.14$ pcs.

But, is this capacity a fixed number? When a team leader assigns a slow operator to the bottleneck, this slow operator can slow down everybody's work in the cell even more. When a team leader assigns a quick operator, the material flow can increase and another machine or operation (in the Table 2 it is machine number 4) can become a new bottleneck.

Table 2: Set of machines with a changed bottleneck process

Machine	1	2	3	4	5	6	7	8	9	10
Process time/pcs	1.4	1.8	2.3	3.2	1.5	3.0	2.8	2.2	1.5	2.5

The calculations above are quite simple. This is because we need to be aware that we cannot approach the ordinary operators with complex calculations that would they hardly understand. When we want to persuade the operators about our ideas or we need to explain them the productivity issue, we need to approach the operators with simple, but persuasive calculations and information.

The calculations above are important for finding out what is our productivity, our performance, what we have to do when things does not go as desired, and to know the conditions for 100% productivity. Based on the calculations we can decide what and when to change something in these conditions.

4.2. Necessary productivity conditions

The necessary conditions for 100% productivity are:

1. Operators are at their working positions and they know *what* (expressed in financial and non-financial formulations), *when* (or by *what time* or period), *where*, and *how many* pieces of products they need to produce.
2. Operators know *how* (including quality) to perform an operation(s).
3. Operators maintain required *tempo* (speed), they know *how quickly* they need to work.
4. Operators do not violate the *order of working procedure* (operations) and *qualitative parameters* – they are *disciplined*.
5. Operators must *want to*.

Omitting any of these five conditions means complete loss of productivity and incomplete fulfillment of these conditions means decreased productivity. The consequences can be for example these:

1. 4.5 minutes of looking for information each shift means 1% loss of the production time, but not necessarily productivity. However, it can cause productivity decrease, if the loss is not caught up later with the increased speed.
2. If the operators do not have full information, they lose 100% of the production time.
3. Each 4.5 minutes thrown out production time is 1% loss of operator's productivity. Also each 4.5 minutes spent on repair is the 1% loss.
4. 100% speed will not catch up with the lost production time. This loss can be caught up only with the higher speed than 100%.

To avoid these losses, it is important that the operators know:

1. Where to find out the necessary information.
2. Who and how is training them and can help when they need this help.
3. Who, how, and when controls them.
4. Where they can search for the information about how quickly to work and how the supervisor knows how quick they are.

All operators and their supervisors need to speak with the same language and about the same things, supervisors need to secure the necessary conditions for the operators, and, finally, supervisors need to prevent time losses by:

- a) making work distribution quicker
- b) minimizing thrown-out minutes and scrap
- c) continuously checking on the operators and their speed
- d) effectively manage or influence production time or the work within a short time.

The information system, the company uses, provides the operators and their supervisors with the information about the assignments from 1 to 3 points (how much, where, by what time, for what – future time) and also provides them with the reports from the history about the results of individual operators and groups. These results can be matched with the causes of successes and failures. Based on the results from the past and the requirements for production volume, the number and location of operators can be optimized in a way that the smooth material flow through cells is maximalized.

The sewing work is monotonous and it can cause the illness from profession. This coincides with finding out how long an employee works behind the same machine without rotation. The information system monitors when an operator needs to be rotated in a preselected time interval. Based on the volume of work done on the machine (number of sewed shoes during time period) it can also be judged the rate of exposition to the workload and assessed the severance of a correlation among the workload and health complications and based on that better working conditions can be created.

The general goal in the company is not only maximal productivity and maximal machine utilization to the imaginary 100%. They put into the sewing process management the so called "operator's biofactor". While observing the operators' work, they have recognized that every operator has its own predispositions – what is 100% workload for one operator, this can be for more experienced and stronger operator only 85% workload. When the management took this into account and stationed the operators according to this finding (they call it internally as the "machine biologization"), they could increase the cell throughput, and thus improve continuous flow and productivity increasement. However, it would be short-sighted to "biologize" only a machine where an operator can be overloaded. Therefore, the management balances the machine biologization with the so-called "operator humanization", which means establishing the rules for the operators' rotation, changing the work pace (run or walk) and optimalization of the work breaks.

4.3. "Humanizing" takt time and productivity

It can be said that in every manufacturing system some kind of work-in-process exists. Work-in-process is started, but not finished production yet. It can be none, minimal, optimal, and large. The best is to have an optimal, because none and minimal work-in-process causes idle time. When we have idle times, even though we have a skillful, quick operator, he or she cannot catch up. The reason

can be that even though there are unoccupied machines, there is no or only a little material, and when an operator starts to work, the material drops to zero and idle time and waiting is again created.

On the other hand, large work-in-process causes waste, for example, in packaging and controlling area. When the parts start to be moved on a large volume at the end of the shift on the conveyor, the packaging and controlling staff is overloaded and this can decrease quality of their work.

The work-in-process is optimal when it fulfills several conditions:

1. The operator (or machine) in the bottleneck is sufficiently replenished with the material, and thus, never waits or stops working during the shift.
2. All other operators (or machines) with similar process time as the operator (or machine) in the bottleneck process are sufficiently replenished.
3. All other operators (or machines) have sufficient stock of material that ensures that it is possible to start working without any delay.

Table 3 shows the accumulation of work-in-process during the morning shift. The shift starts at 6.00 and finishes at 14.00 which represents 450 minutes of available process time during this shift. At the start of the shift with operators 1 to 4 we had 2.42 minutes and 1.86 minutes of work-in-process respectively. At the end of the shift, the work-in-process had increased with every operator. In the last column % of individual loss at each operator is calculated and from that average team loss is calculated. For example with operator 1, % of individual loss is $(8.77 \div 450) \times 100 = 1.95\%$. Totally, at the start of the shift we had only 4.28 minutes of work-in-process, but at the end of the shift the number had increased to 29.79.

Table 3: Accumulation of work-in-process

Operator	Start of shift: 6.00	End of shift: 14.00	Total minutes	% of individual loss
1	2.42	6.35	8.77	1.95
2	0	8.55	8.55	1.9
3	0	10.37	10.37	2.3
4	1.86	4.52	6.38	1.4
Total	4.28	29.79	34.37	Team loss 1.88 %

Now we can approach the idea of “humanizing” the takt time and productivity. *Takt time* is the repeated time that defines in what time each piece is supposed to be finished in order to meet a production plan. If the production plan for one shift is 100 pieces, then the planned takt time is $450 \div 100 = 4.5$ minutes. But we always need to be aware of the real takt time during the shift. Let’s say that by 9.30 we have produced 35 pieces. From 6.00 to 9.30 we have spent 210 minutes, thus, the real takt time is $210 \div 35 = 6$ minutes per one piece. The result from this calculation is that we need to increase the speed of work. But is that really true? Remember that we are behind only with the finished products.

When we compare only these both calculations, it can be the truth. The statement is true when the work-in-process is low or nonexistent and takt time is high. In that case, we can catch up with only when there is enough time till the end of the shift. If we disclose this problem in the last shift’s hour, there is no way to catch up with. The statement is also true when the work-in-process is high and pieces are just waiting for the processing at their last operation with low duration time of performing, for example, 1 minute. Table 4 below shows, if we need to increase the work speed, or focus on finishing pieces, or both.

Table 4: Rules for changing work speed

Prod. hour	Plan (in pcs)	Reality (in pcs)	+ / -	
06.00 – 07.00	10	7	-3	Increase the speed, if the work-in-process is low or nonexistent
07.00 – 08.00	10	10	0	
08.00 – 09.00	12	10	-2	Finish the pieces, if the work-in-process is high
09.00 – 10.00	13			
10.00 – 11.00	10			
11.00 – 12.00	15			
12.00 – 13.00	15			Both is needed, if we are

13.00 – 14.00	15			behind the plan in the last quarter of the shift and the work-in-process is low
Total	100	27	-5	

From the Table 1 we know that the bottleneck process is the machine No. 6 with the processing time 3.5 minutes. When the production plan is to produce 100 pieces, the capacity time requirement for this machine is: $100 \times 3.5 = 350$ minutes. But the available process time during one shift is 450 minutes, therefore, the machine utilization is $350 \div 450 = 0.77$ or only 77%. But is this number constant during the whole shift? Which row of numbers does not change during the whole shift? Calculations are shown in the Tables 5 and 6.

The calculations are done for machines 2 and 5 in both tables with processing time taken from Table 1. In the variant 1, we produce 12 pieces, in the variant 2, 13 pieces. There is a 30-minute break during the lunch time, therefore, we produce a half of these numbers, which is 6 pieces. Notice, that the only row, where the numbers are stable, is the processing time row. In all other rows the numbers are changing during the shift.

Table 5: Machine utilization – Variant 1

Machine No. 2	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining time / shift	450	390	330	270	210	150	120	60	0
Processing time / pc	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Pieces produced	0	12	12	12	12	12	6	12	12
Plan pcs	100	88	76	64	52	40	34	22	10
Time needed	180	158.4	136.8	115.2	93.6	72	61.2	39.6	18
Machine utilization	40.00	40.61	41.45	42.66	44.57	48.00	51.00	66.00	∞
Machine No. 5	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining time / shift	450	390	330	270	210	150	120	60	0
Processing time / pc	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pieces produced	0	12	12	12	12	12	6	12	12
Plan pcs	100	88	76	64	52	40	34	22	10
Time needed	150	132	114	96	78	60	51	33	15
Machine utilization	33.33	33.85	34.55	35.55	37.14	40.00	42.50	55.00	∞
Operator	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining time / shift	450	390	330	270	210	150	120	60	0
Time needed	330	290.4	250.8	211.2	171.6	132	112.2	72.6	33
Operator utilization	73.33	74.46	76.00	78.22	81.71	88.00	93.5	121.00	∞

Number of operators can be planned (or calculated) based on the various conditions (aims or priorities) in these three basic ways:

1. To produce according to the planned production volume (number of pieces regardless of productivity).
2. To produce according to the productivity efficiency (regardless of the planned production volume).
3. To produce according to both – the planned production volume and the productivity efficiency.

Of course, the best is the third way, but in reality, when there are sudden changes in production volume and there is a risk of not meeting the production plan, the possibility to solve this problem is to “borrow” people from other places, so the priority of productivity efficiency goes down. When and by what percentage the productivity efficiency drops or raises when you borrow people for a help?

Let’s explain it on this example. The goal is to make 100% production volume and to reach 100% of productivity efficiency. The production plan is 100 shoes and processing time for completing 1 pair of shoes is 25 minutes. How many operators do we need for this production?

The calculation based on the production time is as follows:

$100 \times 25 = 2,500$ minutes is the necessary processing time for making 100 shoes.
 1 operator per one shift has 450 minutes available for producing shoes.

Therefore, $2,500 \div 450 = 5.56$ operators are needed for producing 100 shoes during one shift. In this way we reach 100% productivity.

The same results can be obtained from the calculation based on takt time:
 $450 \div 100 = 4.5$ minutes is the takt time for producing one pair of shoes.
 $25 \div 4.5 = 5.56$ operators. So, how many operators do we need then, 5 or 6?

When we have 5 operators, we will reach 100% productivity efficiency, but we will not make 100% production volume, only 90%. With 5 operators we can only make 90 pairs of shoes ($5 \times 450 = 2,250$ minutes, $2,250 \div 25 = 90$ pairs of shoes).

When we put 6 operators and produce 100 pairs of shoes, we will not reach 100% of productivity efficiency, but only 92.6% ($6 \times 450 = 2,700$ minutes, $2,500 \div 2,700 = 0.926$).

When we have 5.56 operators for producing 100 pairs of shoes, it means that 1 operator will be utilized for 56% and we have to move this operator in the right moment to other place in order to keep the team productivity.

Table 6: Machine utilization – Variant 2

Machine No. 2	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining time / shift	450	390	330	270	210	150	120	60	0
Processing time / pc	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Pieces produced	0	13	13	13	13	13	6	13	13
Plan pcs	100	87	74	61	48	35	29	16	3
Time needed	180	156.6	133.2	109.8	86.4	63	52.2	28.8	5.4
Machine utilization	40.00	40.15	40.36	40.66	41.14	42.00	43.5	48.00	∞
Machine No. 5	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining time / shift	450	390	330	270	210	150	120	60	0
Processing time / pc	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pieces produced	0	13	13	13	13	13	6	13	13
Plan pcs	100	87	74	61	48	35	29	16	3
Time needed	150	130.5	111	91.5	72	52.5	43.5	24	4.5
Machine utilization	33.33	33.46	33.64	33.88	34.28	35.00	36.25	40.00	∞
Operator	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00
Remaining	450	390	330	270	210	150	120	60	0

time / shift									
Time needed	330	287.1	244.2	201.3	158.4	115.5	95.7	52.8	9.9
Operator utilization	73.33	73.62	74.00	74.55	75.43	77.00	79.75	87.83	∞

So what options exist from this situation?

1. To have 6 operators, but in order to have 100% productivity efficiency, it is necessary to produce more pairs of shoes than 100 (production volume), and that will be 108 pairs of shoes ($2,700 \div 25 = 108$). Also, we have to recalculate the output per hour.
2. To have 5 operators, but their productivity efficiency must be 111.11% in order to keep the production volume of 100 pairs of shoes ($5 \times 450 = 2,250$ minutes, $2,500 \div 2,250 = 1.1111$). But we need to have such skillful operators. Also here we need to recalculate the output per hour.
3. Effective option is to take one operator from training with a calculated 50% productivity and add to 5 operators. But team leader must ask this operator for the 56% productivity.

In all these cases it is necessary that every operator knows at all times during the shift:

- What machines they operate – *where*.
- What to do on the machines – *what*.
- How to work on the machines – *how*.
- How many pieces to complete – *production plan*.
- How many pieces were completed – *production plan fulfillment*.

In order to make this happen, the supervisor should know:

- How to use and exploit the existing management tools for the organization of production.
- How to optimize and place the operators with different skills and working speed.
- How to calculate and plan number of operators based on production plan.
- How to receive warning signals that address the issue in the beginning.
- How to decide and undertake corrective actions on time.

5. CONCLUSION

The example in the case study shows how it is important to smartly accommodate the established procedures and approaches into the conditions specific for the company. The well-known theory and praxis about takt time and productivity from the industries and manufacturing systems vastly equipped with automation cannot be blindly applied in the manufacturing systems and processes with mostly manual labor work. So we need to effectively combine the contemporary theory with the hands-on knowledge from the actual workplace and apply it effectively into our specific conditions.

This is why lean management concept prefers to focus on gathering experience, learning from it, and applying it to our own and real environment. Lean management prefers learning through our own expertise gained through experience on the real workplaces.

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