How to improve profitability and reduce the turn-around time by implement Lean Management in a large environmental PCDD/F and PCB laboratory

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Introduction

Taiichi Ohno published his book "*Toyota seisan hoshiki. Datzu kibo no keiei o mezashite*" in 1978 in Tokio, Japan.[1] The English version "*Toyota Production System. Beyond Large-Scale Production*" was published in 1988 in Cambridge, Massachusetts, USA.[2] Taiichi Ohno thus laid the foundation for a new way of thinking as an alternative to the classical Taylorism. In the years since publication, Lean has been successfully introduced in many manufacturing companies as well as in in medical laboratories. For contract laboratories on the other hand, the introduction of Lean is still at the very beginning. Similarly contract laboratories have the need to increase their profitability and quality as well as to reduce their costs and delivery time. While in the Taylorism all the different goals excluding themselves at once, Lean has its strength at this point to combine everything. According to the poster publication "*Lean management and "One-Piece-Flow" for PCDD/F and PCB analyses to reduce the turn-around time in smaller laboratories compared to classical batch operation*." of Dioxin2018 in which the writers looked at a small dioxin lab[3], this time the focus was to show how to increase the profitability in a large dioxin environmental laboratory without heavy investment setup. One important point was, that the increase of profitability was just a by-product of Lean management. It is necessary to understand, that Lean does not mean use the Common Sense or to use a few methods. Lean means "The Talent and Courage to rethink what we call Common Sense" or the way to break away from the squeezing habits of thinking. The focus is on avoiding waste and increasing quality.[2]

Materials and methods

The following instruments have been used for the single steps:
Water dividing: one Fritsch™ Rotary Cone Sample Divider LABORETTE 27™
Drying of Soil, Water- and Emission filter: three Thermo Scientific™ Heratherm™ Drying Cabinet
Soil moisture content 105°C: One Thermo Scientific™ Heratherm™ Drying Cabinet
Soil homogenization: three Fritsch™ Planetary Mono Mill PULVERISETTE 6™ classic line
Extraction of Water and Soil: six Velp Scientifica™ SER 158/3™ Series Automatic Solvent Extractor
Extraction of Emission: classical Soxhlet Extraction
Evaporation of Emission five Büchi™ rotary evaporator R3™ with Vakuubrand™ VARIO® chemistry pumping unit PC 3001 VARIO select™
Evaporation of Water liquid/liquid fraction: three Büchi™ rotary evaporator R3™ with Vakuubrand™ VARIO® chemistry pumping unit PC 3001 VARIO select™
Clean up: fourteen LCTech™ DEXTech Pure™
Evaporate of clean extracts: 1-3 Biotage® TurboVap® LV
Measurement: four Thermo Scientific™ Dual GC DFS™ Magnetic Sector GC-HRMS with Dual Data XL™

The following methods have been used for the introduction of Lean:
The standard Toyota Production System "House" (for explaining: Heijunka means production smoothing and Kaizen means conditional improvement)

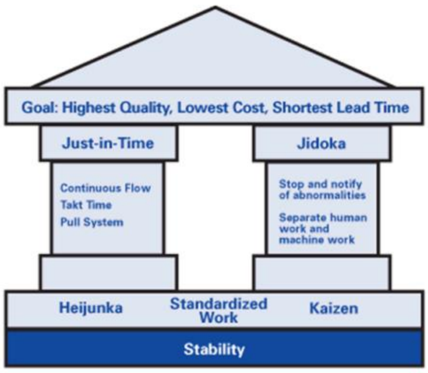

Figure 1: Toyota Production System (TPS)[4]

Results and discussion:

The first step was the implementation of Heijunka. The most laboratories are confronted with a fluctuating sample receipt. Heijunka was used to do a production smoothing, which means, create a production planning and fill in all samples. In the example the promised due Date for Emission was 7 working days, the analysis needed to be started at latest 3 working days in front of the due Date so that there was enough time for analyze and if necessary, a small number of re-analyses. Therefor and for high priority samples a "chef slot" was installed, to create some flexibility this kind of samples.
On every day 10 samples were analyzed. If there were free capacity, samples of the following day had moved up.

Table 1: Heijunka exemplary for Emission samples

Sample reception	**02.01**	**03.01.**	**04.01**	**05.01**	**06.01**	**09.01**	**10.01.**	**11.01.**	**12.01.**
No of Samples come in	10 (A)	14 (B)	5 (C)	11 (D)	12 (E)	8 (F)	…	…	…
Due date	10.01.	11.01.	12.01	13.01	15.01.	16.01.	17.01	18.01	19.01
Chef slot for repeating or high priority samples						E12			
Slot 9	…	…	…	A9	B9	E11	D9	E9	
Slot 8	…	…	…	A8	B8	E10	D8	E8	F8
Slot 7	…	…	…	A7	B7	D11	D7	E7	F7
Slot 6	…	…	B14	A6	B6	D10	D6	E6	F6
Slot 5	…	…	B13	A4	B5	C5	D5	E5	F5
Slot 4	…	…	B12	A4	B4	C4	D4	E4	F4
Slot 3	…	…	B11	A3	B3	C3	D3	E3	F3
Slot 2	…	…	B10	A2	B2	C2	D2	E2	F2
Slot 1	…	…	A10	A1	B1	C1	D1	E1	F1

Heijunka also was used to start standardized work with a classical value-stream mapping of all three matrices. In a Lean environment a permanent flow needs to be implemented. With classical departments for registration, extraction, clean up, measurement and reporting this goal cannot be reached. Overall it is more efficient if the lab technicians are responsible for the whole process, like it is usually done in smaller laboratories. Table 2 to Table 4 documented the necessary analytical steps for all three process lines.

Table 2: Overview of the necessary steps for Water (20 samples per day; Takt-Time 39 min/sample)

	registration	**dividing**	**filtration**	**liquid/ liquid**	**solid/liquid**	**evaporate**	**Clean up**	**evaporate**	**measurement**	**Data evaluation**	**report**	**total**
EBT	5 min	5 min	5 min	10 min	5 min	5 min	3 min	15 min	2 min	15 min	5 min	75 min
TBT	0 min	0 min	0 min	5 min	120 min	10 min	55 min	0 min	45min	0 min	0 min	235 min
Total BT	5 min	5 min	5 min	10 min	125 min	15 min	58 min	15 min	47 min	15 min	5 min	310 min

Table 3: Overview of the necessary steps for Soil (30 samples per day; Takt-Time 26 min/sample; 15 samples with 24h drying time)

	registration	**homogenization**	**solid/liquid**	**Clean up**	**evaporate**	**measurement**	**Data evaluation**	**report**	**total**
EBT	5 min	5 min	5 min	3 min	15 min	2 min	15 min	5 min	55 min
TBT	0 min	15 min	120 min	55 min	0 min	45 min	0 min	0 min	235 min
Total BT	5 min	20 min	125 min	58 min	15 min	47 min	15 min	5 min	290 min

Table 4: Overview of the necessary steps for Emission (10 samples per day; Takt-Time 78 min/sample)

	registration	**filtration**	**liquid/liquid**	**solid/liquid**	**evaporate**	**Clean up**	**evaporate**	**measurement**	**Data evaluation**	**report**	**total**
EBT	5 min	5 min	10 min	10 min	5 min	3 min	15 min	2 min	15 min	5 min	75 min
TBT	0 min	0 min	5 min	1200 min	30 min	55 min	0 min	45 min	0 min	0 min	1335 min
Total BT	5 min	5 min	10 min	1210 min	35 min	58 min	15 min	47 min	15 min	5 min	1410 min

(EBT → employee binding time; TBT → technical binding time; BT → binding time)

In all areas the technical binding time was higher than the Takt-Time, so machine capacity was needed to be raised up. The employee binding time in all steps was lower than the Takt-Time. The formula for the calculation of the needed staff was:

$$\frac{Process\ EBT * Number\ of\ samples * (1 + fluctuation)}{working\ time\ per\ employee} = needed\ staff$$

The result had to be rounded up in every case, as full employees are needed for the process steps. A total number of 11 lab technicians were needed, the results are shown in Table 5. Thereof four were needed in the Water-Lab-Team, five in the Soil-Lab-Team and two in the Emission-Lab-Team.

Table 5: Necessary staff

Matrix	Process EBT	No of samples	fluctuation	working time	theor. staff	round up
Water	75 min	20	20%	480 min	3.75 FTE	4 FTE
Soil	55 min	30	20%	480 min	4.12 FTE	5 FTE
Emission	75 min	10	20%	480 min	1,9 FTE	2 FTE

The second step was to implement standardized work in consideration of the Just in Time and Jidoka pillar. Standardized work doesn't mean the classical "standard operation procedure" (SOP), as in addition to the classical method description also a detailed handling step order need to be implemented. It is necessary to also document where the operation Line start, how exactly the lab technicians must handle the samples, or in which step the sample must handed over to the next employee.
As the standardized work implementation was planned, it was also necessary to analyze how it could be possible to implement continuous sample flow. One-Piece-Flow is the supreme discipline but if the regulation required a blanc or quality sample for every clean up, if the work flow is interrupted by a delay due to e.g. waiting time for a proper phase separation or if a technical step can only procedure a bigger amount of samples at ones it made no sense to implement One-Piece-Flow.
All attempts were made to get the lowest possible batch size in every analyzing line. Therefore, it was important to understand what step decide the batch size. In this case the mechanical extraction system for water and soil, as it was only possible to start all three samples at ones. For Emission it was the phase separation of the liquid/liquid extraction. The decision was, to use batches of 3 samples for Water and Soil and batches of 5 samples for Emission. But the batch operation was only used into the steps where it was necessary all other steps like registration, homogenization or measurement One-Piece-Flow was implemented, that gave the possibility for continuous improvement. Table 6 to Table 8 document the workload in all analytical lines.[5-7]

Table 6: Workload Table for Water ***(process-time up to 25h; ① = 2nd day)***

Prozess | Time	8am	9am	10am	11am	12am	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm
Registration	BW ①-②	③-⑤	⑥-⑧	⑨-⑪		⑫-⑭	⑮-⑰	⑱-⑳					
Dividing	BW ①-②	③-⑤	⑥-⑧		⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳					
Filtration	BW ①-②	③-⑤		⑥-⑧	⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳					
Liquid/Liquid		BW ①-②	③-⑤	⑥-⑧	⑨-⑪		⑫-⑭	⑮-⑰	⑱-⑳				
Solid/Liquid				BW ①-②	③-⑤	⑥-⑧		⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳		
Evaporate lq/lq		BW ①-②	③-⑤	⑥-⑧		⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳				
Clean up					BW ①-②	③-⑤	⑥-⑧		⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳	
evaporate					BW ①-②		③-⑤	⑥-⑧	⑨-⑪	⑫-⑭	⑮-⑰	⑱-⑳	
Measurement	⑩-⑳ Tunning	Cal check	Tuloene			BW	①	②	③④	⑤	⑥	⑦⑧	⑨
Data evaluation	⑩-⑫	⑬-⑮	⑯-⑱	⑲-⑳			BW,①	②	③	④-⑤	⑥	⑦	⑧-⑨
Report	⑩-⑫	⑬-⑮	⑯-⑱	⑲-⑳			BW,①	②	③	④-⑤	⑥	⑦	⑧-⑨

Table 7: Workload Table for Soil ***(process-time up to 40h; ① = 2nd day)***

Prozess | Time	8am	9am	10am	11am	12am	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm
Registration	BW,QS ①-⑤	⑥-⑨	⑩-⑭	⑮-⑲	⑳-㉒	㉓-㉗	㉘- 30						
Homogenization	①-④	⑤-⑧	⑨-⑬	⑭-⑱	⑲-㉒	㉓-㉖	㉗- 30						
Extraction				BW,QS ①-③	④-⑥	⑦-⑫	⑬-⑮	⑯-⑱	⑲-㉑	㉒-㉗	㉘- 30		
Clean up					BW,QS	①-⑥	⑦-⑨	⑩-⑫	⑬-⑱	⑲-㉑	㉒-㉗		㉘- 30
evaporate					BW,QS	①-③	④-⑨	⑩-⑫	⑬-⑮	⑯-㉑	㉒-㉔	㉕-㉗	㉘- 30
Measurement	⑩- 30 Tunning	Cal check	Tuloene				BW,QS			①-③		④-⑥	⑦-⑨
Data evaluation	⑦-⑨	⑩-⑫	⑬-⑮	⑯-⑱	⑲-㉑	㉒-㉔	㉕-㉗	㉘- 30		BW,QS	①-③		④-⑥
Report	⑦-⑨	⑩-⑫	⑬-⑮	⑯-⑱	⑲-㉑	㉒-㉔	㉕-㉗	㉘- 30			①-③		④-⑥

Table 8: Workload Table for Emission ***(process-time up to 32h; ① = 2nd day)***

Prozess | Time	8am	9am	10am	11am	12am	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm
Registration	①-⑤		⑥-⑩										
Filtration	①-⑤		⑥-⑩										
Liquid/Liquid		①-⑤		⑥-⑩									
Solid/Liquid	①-⑩												
Evaporate	①-⑤	⑥-⑩											
Clean up			①-⑤	⑥-⑩									
evaporate			①-⑤		⑥-⑩								
Measurement	Tunning	Cal check	Tuloene	①	②-③	④	⑤	⑥-⑦	⑧	⑨	⑩		
Data evaluation							①-②	③-⑤	⑥-⑧	⑨-⑩			
Report													

Conclusions

The classical contract laboratory with a high sample amount and matrix diversity sometimes needed several weeks to analyze all samples, depending on the fluctuation of sample amount and employees.
The here shown Lean implementation was able to give big labs (> 10,000 samples for PCDD/F and PCB per year) a higher cash flow and profitability. Without production planning and a fluctuating sample amount, also the cash flow decreases because the samples need a longer time until invoicing. With the everyday production planning the same number of samples will be reported and with the report also invoiced in a continual flow. The profitability increased because of the optimized amount of staff and instruments. The staff will be less stressed and stayed longer into the company. Shorter reaction times are possible, if the behavior of the customers change (matrix mix or number of samples).

Summarized Lean implementation means:

$$Highest\ Quality + Shortest\ Delivery\ Time = Lowest\ Costs$$

Lowest costs and a high profitability are the results not the goal of Lean and this results in continuous flow, continuous improvement and reduction of waste.

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