A review of assembly line balancing and sequencing including line layouts

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ABSTRACT

This paper comprises a literature review focused on mixed-model assembly line balancing and sequencing problems, including different line layouts. The study was undertaken in collaboration with a company to assist in mapping current state of the art. Balancing problems affect businesses long-term strategic decisions and are complex problems with regard to installation and rebalancing of assembly lines. Sequencing concerns decisions of short-term problem. Sequencing approaches include: level scheduling, mixed-model sequencing and car sequencing. Level scheduling constructs a sequence of variants to create efficient deliveries supported by the just-in-time concept, whereas both car- and mixed-model sequencing aim to minimise violations of a work station's capacity through constructing a sequence, which alternates variants with high and low work intensity. Five layouts were considered: single-, mixed-model-, multi-model-, two-sided- and u-shaped assembly lines. These layouts were evaluated on the basis of the manufactured product(s), size and space at the production plant, economic resources, number of required operators and machinery. Following a thorough investigation of the literature, a substantial gap between academic discussions and real world practical applications was identified. The aim of forthcoming work is therefore to put this theory into practice.
Key words: Heijunka, balancing, leveling, sequencing assembly line, line layout

1. INTRODUCTION

Customisation demands variants with unique characteristics. Producing a range of variants often means that the time to complete a task at a work station differs between variants, resulting in difficulty keeping a high and constant utilisation. Different cycle times means that certain stations requires more time then is available, *"peaks"*, and it leads to operators having to work faster on oncoming models to compensate for this. Therefore, one should avoid sequencing "peak-models" after one another. Work load distribution is referred to as line balancing or the Japanese term heijunka (Liker, 2004). Balancing and sequencing activities attempt to evenly divide time over stations to achieve high utilisation and using available cycle time as efficiently as possible.

The aim was to investigate the literature on heijunka, line balancing and sequencing approaches for mixed-model assembly line, including line layouts.

2. METHODOLOGY

A comprehensive literature review was completed and current theories studied to gain an in-depth understanding. Searches were executed in the Swedish library search engine Libris. The keywords: heijunka, assembly line balancing and sequencing, mixed-model assembly line, line layouts, were used in combinations. Databases used were Emerald, Academic search elite, Science Direct and Google Scholar. Advantages, disadvantages, differences in approaches were analysed. Furthermore, the researchers participated in meetings, concerning line balancing and improvements, with the collaborating company. Participants were team-, and production mangers, technicians, safety officer and maintenance staff. Attending these meetings helped understanding issues regarding line balancing and facilitated the literature research.

3. THEORY
3.1. Heijunka

Atsushi Niimi, President and CEO of Toyota Motor Manufacturing North America Inc., explained the background of the term heijunka in a speech at the Manufacturing Week in Chicago, USA in February 2004. It originated in the 1950's when Toyota were making trucks for the U.S. for use in the Korean War. The production needed to be increased in order to meet demand. A shortage of parts meant nothing was obtained in correct quantity or on time. Two weeks of the month was spent gathering materials arriving in no particular order and assembly took place during the next two weeks, which would not work if production levels increased. Hence, like many other components of the Toyota Production System (TPS) heijunka was born out of necessity. *"The simple definition of heijunka is production leveling"* (Toyota imports forum, 2008). Heijunka is one of the cornerstones of Toyota's production, Figure 1. It is a vital part enabling Toyota to achieve highest quality, lowest cost and shortest lead time. It evens out workload over available production time both by product mix and volume. Production leveling is not only perfomed for the vehicle itself, it also concerns options e.g. engine type, sunroofs etc. A volume of orders over a period are leveled out. If the sequence was constructed from actual customer order flow an uneven workload would occur, as actual orders can differ greatly from day to day. Through leveling out the orders and sequencing, the same amount and mix are produced every day. Heijunka sequence production uniformly, involving both workload leveling and line balancing (Liker, 2004) and consequently carries dual intentions (Coleman and Vaghefi, 1994):

- Reduction in inventories due to very small batches, mixed production.
- The associated ability to equate work loads in each production process to each other and capacity.

Associated with heijunka are the three M's (Figure 2);

- Muda – non value added.
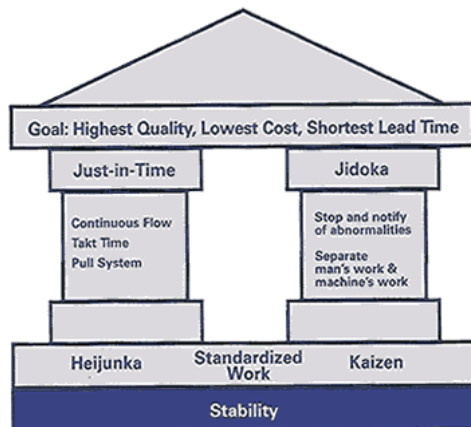- Muri – overburdening people or machines.
- Mura – unevenness.
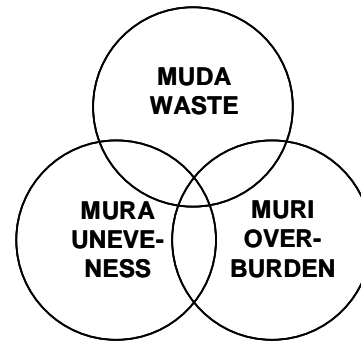
Figure 1: TPS (SWMAS, 2008).

Figure 2: The 3 M's; (Liker, 2004).

Muda the most familiar of the three, includes the eight wastes; overproduction, defects, transportation, waiting, inventory, unnecessary motions, inappropriate processing and unused employee creativity. Mura or unevenness is a result of irregular production schedule or uneven production volumes. Muri or overburdening people or machines causes breakdowns or defects. *"Achieving heijunka is fundamental to eliminating mura, which is fundamental to eliminating muri and muda"* (Liker, 2004). Toyota created the heijunka box to achieve levelling, a scheduling tool with a grid of boxes were each column represents a period of time, e.g. a shift, in form of a schedule. Kanban cards are placed in the box in order to visualise the sequence of variants. Effects of heijunka (Coleman and Vagehefi, 1994):

- Reduction in overall inventories.
- Reduction of required productive capacity.
- Reduction of lead times to the customer.
- Heijunka's line-balancing aspect implies that employees are not encouraged by dissimilar work loads to migrate toward easier tasks and away from those jobs which need most improvement.

Jones (2006) points out three advantages arising from applying heijunka:

- Employees – are no longer overburdened.
- Customers – gets better products on the date promised.
- Manufacturers – keep money saved when muda, mura and muri are reduced.

3.2. Line layouts

Different line design layouts are all associated with an assembly line balancing (ALB) problem. Balancing distributes tasks to work stations and work content per station and variant. Line balancing is divided in areas depending on layout of the assembly line. To minimise work overload sequencing is carried out (Boysen et al., 2008). The sequence determines spreading of material demand and labour utilisation at workstations. Two objectives are central (Boysen et al., 2007):

- Work overload: Work overload can be avoided if a sequence is found, where variants causing high station times alternate with less work-intensive ones.
- Just in time objectives: Different models are composed of different options and thus require different parts, so that the model sequence influences the progression of material demands over time.

The two objectives are split in three sequencing approaches; mixed-model sequencing, car sequencing and level scheduling (Boysen et al., 2007).

Single model-assembly lines

A single-model assembly line is limited to producing one variant, Figure 3, and is mainly used for mass production of one homogeneous product (Scholl, 1999).
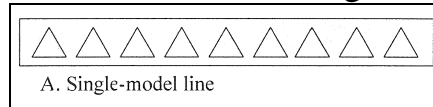

A. Single-model line

Figure 3: The principle of a single-model assembly line (Scholl, 1999).

The simple assembly line balancing problem, SALBP, occurs when stations are equally equipped with respect to workers and machines, alongside a paced line with fixed cycle time and deterministic operational times (Scholl, 1999).There are no assignment restrictions except fixed launching rate and precedence constraints. Precedence constraints are the required set of tasks connected by precedence relations (Scholl, 1999). This classical line possess a set of four well examined SALBPs; SALBP-F, SALBP-1, SALBP-2 and SALBP-E (Scholl, 1999). SALBP-F is a feasibility problem of deciding whether or not a line with m stations can be operated with a certain cycle time c and providing a line balance for the (m,c)-combination of stations and cycle time. SALBPs are defined according to NP (non-deterministic polynomial) class, meaning the number of computational steps increases exponentially with the number of inputs (Eriksson and Gavel, 2003). Different classes (e.g. NP-complete, NP-hard) depend on the level of difficulty. SALBP-F is NP-complete, whereas the other three SALBPs are NP-hard.

- SALBP-1: Minimize the number m of stations for a given cycle time c.
- SALBP-2: Minimize the cycle time c for a given number of stations m.
- SALBP-E: Maximize the line efficiency E or, equivalently, minimize m*c.

Algorithmic approaches have been suggested to solve SALBPs, among other are the algorithms Fable and Eureka, Salome-1 and Salome-2 (Scholl, 1999).

Mixed-model assembly line

A mixed-model assembly line produces several standardised products, Figure 4. Products may differ though all must contain certain percentage of identical basic parts so production is fairly similar. Depending on the order of optional parts extra tasks are either executed or left out (Scholl, 1999). Mixed-model assembly lines, often paced with a high proportion manual labour, are frequently used in final assembly of automobile production. Today car manufacturers offer a vast selection of models and variants. For example, BMW offers a catalogue of optional features which, theoretically, results in 10^{32} different variants (Stautner, 2001 see Meyr, 2004) and Mercedes delivers its C-Class in 2^{27} theoretically possible specifications (Röder and Tibeken, 2006). When offering an extensive amount of variants it is vital not to jeopardize efficient flow-production.
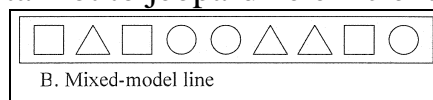

B. Mixed-model line

Figure 4: The principle of a mixed-model assembly line (Scholl, 1999).

Mixed-models provide; efficient continuous material flow, reduced inventory levels of final items and flexibility with respect to model changes (Scholl, 1999). However, setup needs reducing through flexible workers and machinery. Considerations when comparing mixed-model lines are; a paced line with multiple stations along a conveyor belt, workers performing pre-specified task in each production cycle. Additional assumptions are (Boysen et al., 2007):

- No buffers between stations.
- Workpieces have a fixed location on the transporting system, only their direction may change.
- Demand for models throughout the planning horizon is known and will not change, so no rush orders exsist.
- Multiple models contain different parts and require different tasks with individual processing times, such that demands for material and station utilisation may change from model to model.
- There are no disturbances, e.g. machine breakdowns or stock-outs, so that resequencing is not considered.

When handling mixed-model problems different planning horizons occur. Decisions have to be made in mid- or long-term aspect, e.g. concerning installation of the line and division of work between stations. Short-term problems regard sequencing. The objectives in sequencing are efficient utilisation of workstations and distribution of material demands.

Mixed-model line balancing – mid- or long-term

Mixed-model balancing problems, MALBP focus on avoiding inefficiencies and station times of variants have to be smoothed for each station, horizontal balancing (Becker and Scholl, 2006). Line balancing issues are more dependent on strategic decisions because they concern line installation rather then operational issues. When determining task times it is important not only to optimise the work for the product flow, considerations have to be taken for laws and trade union regulations: *"... in the German car industry task times are subjects to mutual agreements between the employer and the respective trade union, which usually results in very detailed regulations based on standardized time measurements methods concerning the exact amount of time a worker is granted for performing any given type of task"* (Boysen et al., 2008). To solve MALBP there are two approaches (Becker and Scholl, 2006):

1. Reduction to single-model problems: Some mixed-model data can be simplified and transformed to SALBP data trough calculations or relaxed assumptions and then easier be solved.
2. Horizontal balancing: In cases where the cycle times are measured on aggregated/averaged basis there often appears some inefficiency on the line. The imbalance can either impact the assembly line in work overload or idle time. To reduce the horizontal imbalance, heuristics and other mathematical procedures are proposed.

Scholl (1999) summarises four general MALBPs. MALBP-F concerns a feasibility problem and is NP-complete. Cycle time c and a number of K stations are assumed. A solution to MALBP-F is the Heuristic of Thomopoulos. MALBP-1 concerns the minimisation of work stations K for a cycle time c. MALBP-2 concerns minimisation of cycle time for a number K work stations. Suggested are to reduce and simplify MALBP into a single-model problem and use the algorithms Fable or Eureka. The Heuristic of Thomopoulos can be applied to MALBP-1 (Scholl, 1999). MALBP-E has the objective to maximise the line efficiency or, equivalently, to minimize $c*K$ (Scholl, 1999). This problem has not yet an accepted solution. However, *"in order to avoid installing inefficiencies into the system due to inadequate pre-specified parameters c or K, respectively, MALBP-E may be used to examine different parameter settings"* (Scholl, 1999).

Mixed-model sequencing – short-term

The mixed-model sequencing problem (MSP) aim to minimise work overload, finding sequences where models with longer and shorter processing times alternates (Boysen et al., 2007). The focus is on shop floor (Drexl et al., 2006). In order to develop an efficient sequence *"... models are scheduled at each station and cycle, by explicitly taking into account processing times, workers movements, station borders and further operational characteristics of the line"* (Boysen et al., 2007). MALBP and MSP arise in different planning horizons, but a strong connection exists. Mid-term balancing create solutions uses as input to short-term sequencing. The number of stations and cycles times decided in mid-term becomes input data for the model sequence (Scholl, 1999). *"The better this horizontal balancing works, the better solutions are possible in the connected short-term mixed-model sequencing"* (Becker and Scholl, 2006). Furthermore *"... the quality of sequencing decisions directly depends on the quality of the work load balancing. In the case where the line is almost perfectly balanced with respect to stations and models, the importance of the sequencing is minor, whereas it may not be possible to find acceptable sequences when the balancing solution leaves considerable imbalances"* (Scholl, 1999). Joint precedence graphs are used to determine mixed-model line balance (Scholl, 1999). From all cycle times an averaged cycle time is calculated to avoid excessive work capacity. If numerous models with high processing time follow one and other the operator cannot complete the work tasks before the workpiece has left the station boundaries and a new enters (Boysen et al., 2007). This results in work overload with either of those consequences (Boysen et al., 2007):

- The whole assembly line is stopped until all stations have finished work on their current workpiece.
- Utility workers support the operator(s) of the station to finish work just before the station's border is reached.
- Unfinished tasks and all successors are left out and executed off-line in finishing stations after the last station.

The opposite problem can occur when models with low processing time follow each other, so called idle time (Scholl, 1999). Work overload and idle time should be reduced as both bring down efficiency.

A mixed-model line has to consider three basic elements (Boysen et al., 2007):

1. Operational characteristics of the stations [α]: Characteristics depend on station boundaries, reaction on imminent work overload, processing time, alternatives on concurrent work, setups and parallel stations.
2. Characteristics of the assembly line [β]: Characteristics of the line depend on number of stations, homogeneity of stations, launching discipline, return velocity and line layout.
3. Objectives [γ]: Evaluating solutions objective(s) to minimise are e.g.: work overload, line length, throughput time, idle time, duration of line stoppages or minimise maximum displacement of workers.

α, β and γ are used in a classification scheme, which determines combinations of assembly line problems (Boysen et al., 2008). The review of MSPs revealed contribution in form of comparison of procedures, mathematical models, heuristic, metaheuristics and exact solution procedures (Boysen et al., 2007).

Car Sequencing – short-term

"Each option is installed by a different station, designed to handle at most a certain percentage of the cars passing along the assembly line, and the cars requiring this option must be spaced such that the capacity of every station is never exceeded" (Solnon et al., 2007). Through transformation of certain product options to particular sequencing rules, prevention of work overload can be made by only allowing a special ratio. *"The car sequencing problem then seeks to find a sequence of models which meets the required demands for each model without violating the given sequencing rules"* (Boysen et al., 2007). The rules are on the form $H_0:N_0$. Out of N_0 following models only H_0 may have the product option 0, otherwise work overload will

arise. An example of $H_0:N_0$ is: *"Assume that 60 % of the cars manufactured on the line need the option 'sun roof'. Moreover, assume that five cars (copies) pass the station where the sun roofs are installed during the time for the installation of a single copy. Then, three operators (installation teams) are necessary for the installation of sun roofs. Hence, the capacity constraint of the final assembly for the option 'sun roof' is three out of five in a sequence, or 3:5 for short"* (Drexl and Kimms, 2001). A widespread solution for optimisation problems is the *"sliding windows"* technique, with a penalty cost assigned to any violation of a restriction. Though, this approach tends to double-count violations and weights violations depending on their occurrence in the sequence. An alternative is suggested only accounting for options actually leading to a violation (Boysen et al., 2007). *"The decision problem consists in deciding whether it is possible to find a sequence that satisfies all capacity constrains, whereas the optimisation problem involves finding a minimum cost sequence, where the cost function evaluates constraint violation"* Solnon et al. (2007). Elements in car sequencing (Boysen et al., 2007):

1. Objectives [γ]: Merely distinguishes whether the feasibility or the optimisation problem is considered.
2. Operational characteristics [α]: Characteristics of the assembly line impacting car sequencing are; number of options, hard or soft sequencing rules, what sequencing rules that exists and assignment restrictions.

In the ROADEF challenge French industries submit operational research problems to be solved in a world wide research competition. In 2005 the subject of the challenge was the car sequencing problem submitted by Renault. Twenty-seven teams competed. The problem suggested was more complex then usual (Solnon et al., 2007): *"Client orders are sent in real time to the vehicle plants. The daily task of each plant is (1) to assign a single-day manufacturing period to each ordered vehicle, taking assembly line capacity constraints and client due dates into account. The next task is (2) to sequence the vehicles inside each production day while satisfying at best the requirements of the production workshops: body, paint and assembly workshops. The resulting vehicle sequence is the baseline sequence sent to the workshops."* The paint shop objective was to minimise consumptions of solvent for cleaning paint equipment. Objective for final assembly was work load balancing of different units. Renault has since 1993 solved the car sequencing problem using an in-house software based on simulated annealing (Solnon et al., 2007). *"During the last years, this problem became critical since the company made the strategic decision of enforcing at the workshop level a strict respect of the baseline sequence which is computed 6 days before the actual production. Before this point, it was possible to sort the vehicles at the paint shop entrance to improve colour runs without considering the ratio constraints. The sequence was then rearranged at the assembly shop entrance to minimize the ratio constraint violations. Such local rearrangements are no more allowed and the optimisation of the baseline sequence is now a key issue"* (Solnon et al., 2007). The winning algorithm with great potential savings is since 2006 integrated in Renault operational software (Estellon et al., 2007). Other solutions to car sequencing are heuristics, metaheuristics, exact solution and constraint programming (Boysen et al., 2007).

Level scheduling – short-term
Mixed-model and car sequencing minimise violations of capacity constraints while level scheduling, aims at finding sequences in line with JIT, evening out material demands and consequently reduce safety stock, focusing on final assembly (Boysen et al., 2007). An ideal, target consumption rate is assigned to materials. The target, a mean of overall demand of material in the planning period, must be as constant as possible (Monden, 1998). The idea is to produce precisely the amount demanded (Drexl and Kimms, 2001). Models are

sequenced such that both deviation between actual and ideal rates and work in process must be minimised (Monden, 1998). JIT, a pull system, only initiates a supply process if another process requires the earlier process output (Drexl and Kimms, 2001). Level scheduling is divided in (Boysen et al., 2007):

1. Objectives [γ]: Objective one to decide which indicator shall be leveled according to JIT. Three types of indicators; parts supply, workload and production rate. Objective two is the weighting function, i.e. how to measure, decide and base penalisation of deviations. Objective three is an aggregation function consisting of either min. sum of all separate deviations or min. largest deviation between actual and target schedule.
2. Operational characteristics [α]: Relevant operational characteristics of assembly line which has an impact when discussing level scheduling are; no. of production levels and no. of workstations.

Studying level scheduling found mathematical models, heuristic, metaheuristics and constraint programming (Boysen et al., 2007). Toyota applied Goal chasing II algorithm (Monden, 1998). Level scheduling may not regard constraints of car sequencing, but an algorithm computing optimal schedules without relaxing car sequencing constraints is suggested (Drexl et al., 2006).

Table 1: Summery of approaches for solving problems on a mixed-model line.

Approach	Planning horizon	Level of decision making	Main concern and aim
Mixed-model balancing	Mid- or long term	High level, with consideration to the strategic goals of the company and the production over a few years	Installation of line, rebalancing line, dividing work between stations.
Mixed-model sequencing	Short term	Operational level, with consideration of shop floor and the daily production.	Finding a sequence of models through a detailed scheduling of work content in order to minimise; work overload or throughput time etc. High intensive models alternate with less intensive models.
Car sequencing	Short term	Operational level, with consideration of shop floor and the daily production.	Creating a sequence of models by transformation of product options to sequencing rules in order to minimise work overload.
Level scheduling	Short term	Operational level, with consideration of shop floor and the daily production.	Creating a sequence that supports the JIT philosophy. Leveling out material demand from the production line so that even and smooth deliveries can be achieved.

Multi-model assembly line

A multi-model assembly line produces different variants in batches, Figure 5. The advantage is to avoid/reduce setups (Boysen et al., 2008). A trade-off problem occurs when deciding batch sizes and sequences (Scholl, 1999).
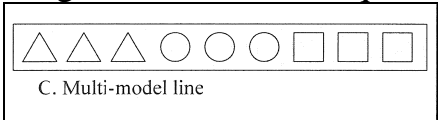

C. Multi-model line

Figure 5: The principle of a multi-model assembly line (Scholl, 1999).

For large batch sizes: *"The line balance can in principle be determined separately for each model, as the significance of setup times between batches is comparatively small"* (Boysen et al., 2008). If line balance determines separately some machines might need moving to other stations during setup, consequently increasing setup time. Work content may differ for variants, resulting in increased training and poor quality. Processing time will probably decrease over time due to learning effects (Boysen et al., 2008). In a multi-model line balancing can be conducted for all models simultaneously, and then targets and objectives needs considering as cycle times for each model can vary (Boysen et al., 2008).

Two-sided assembly line

Two-sided line has workstations opposite each other on left and right hand side of the conveyer belt, Figure 6. The operators, left and right, work simultaneously on particular tasks assigned to their station (Becker and Scholl, 2006).
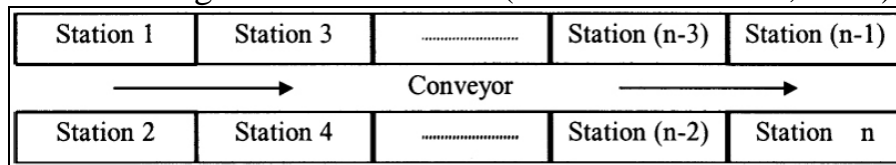
Station 1	Station 3	....	Station (n-3)	Station (n-1)
→		Conveyor	→	
Station 2	Station 4	....	Station (n-2)	Station n

Figure 6: The principle of a two-sided assembly line (Lee et al., 2001).

Stations without an operator can exist. A two-sided line does not demand more stations than a single line. A well planned two-sided line could have fewer stations depending on precedence constraints. In comparison with a one-sided assembly line there are several advantages including (Lee et al., 2001):

1. The conveyer belt becomes much shorter meaning fewer operators are needed.
2. Decreases necessary throughput time meaning products are produced faster.
3. Tools and fixtures have the opportunity to be shared at certain stations.
4. Material handling, movement of operator and setup time could be reduced.

When sequencing two-sided assembly lines, variations and number of stations are large and precedence constraints have to be carefully considered (Lee et al., 2001). In Figure 7, L represents task on left side, R tasks on right side, whereas E is for tasks which could be performed on either side. Circles are actual tasks with a number and the arrows connecting them symbolise their relation. Every task is connected with time and direction, the direction is either L, R or E. Consideration needs taken for both task sequences and demanded task time.
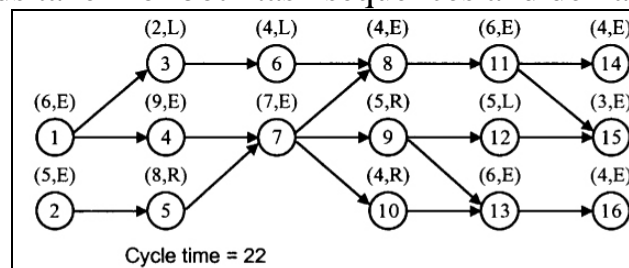

Figure 7: The principle of precedence constraints (Lee et al., 2001).

The direction depends on if groups have R or L task. A group with only E tasks could go to either side and there are two rules determining the direction:

1. Set the operation direction to the side where tasks can be started earlier.
2. When start time at both sides is same, set direction to the side expected to carry out least amount of tasks.

A genetic algorithm is suggested solution for a two-sided line (Kim et al., 2007)

U-shaped assembly line

Stations handled across two have combination cost synergies, Figure 8. *"The effectiveness of the u-line is greater than or equal to the effectiveness of the straight line when buffering inventories are located at all contact points (between stations)"* (Miltenburg, 2000). In the statement consideration has not been taken for extra cost of buffers and it is only valid if buffers are allowed, else a straight line would be better regarding breakdowns. A feature of the u-shaped assembly line is that the entrance station has the same location as the exit (Kara et al., 2008). Advantages of the u-shape are; improved

productivity, less work in process, faster throughput, easier material planning, less complicated planning of production and control and increased quality. Toyota has taken advantage of the u-line and its advantages of combining tasks, increase and decrease workers to meet demand of market fluctuations (Monden, 1998). The latter can be achieved by more or fewer staff in the inner area of the u-shaped line. However, it is not mentioned where Toyota has implemented the u-line, e.g. body, paint and assembly workshop or in which production site.
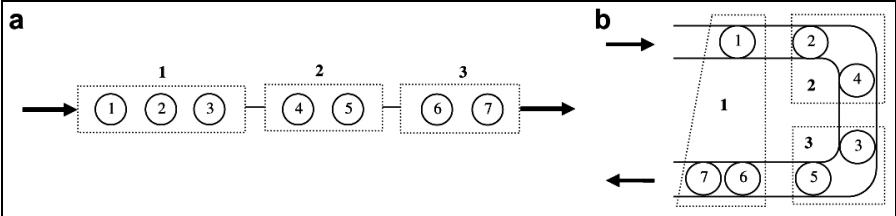

Figure 8: Straight (a) and u-shaped (b) assembly line (Kara et al., 2008).

Parallel stations and tasks

When problem arise that some tasks demand more time than others parallel workstations can be applied. Issues considered when installing parallel stations are; changes in processing time, buffer size, buffer position and length and balancing of the line (Leung and Lai, 2005). Strategies for implementing parallel stations are; on-line-, off-line- and tunnel-gated (Leung and Lai, 2005). Figure 9 shows the on-line station, when a workpiece leaves S1 it moves to S3 if available. If not, S2 takes it on and after completion sends it to station four.
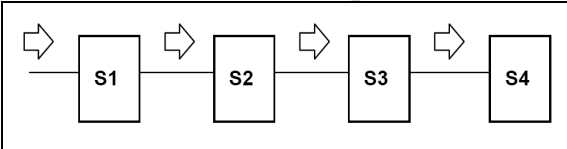

Figure 9: On-line stations. S2 and S3 are parallel (Leung and Lai, 2005).

Figure 10 shows the off-line station, S2 and S3 are placed on the side of the line, requiring extra equipment and transport. However, not affected by breakdowns of the main line. Figure 11 shows the tunnel-gated station, when work leaves S1 it moves to S2, an elevated tunnel-gated station. Meanwhile the workpiece is being processed at S2, other moves underneath directly to station three and four.
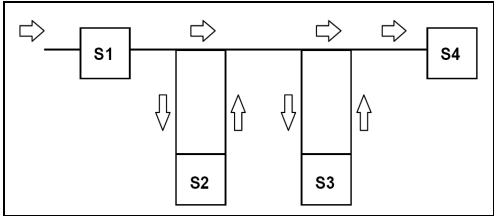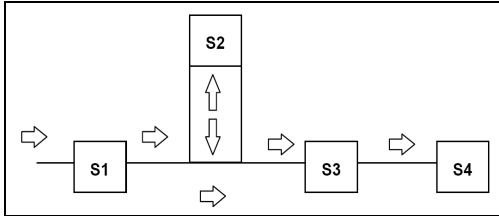

Figure 10: Off-line stations.

Figure 11: Tunnel-gated stations.

Table 2: Summary of on-line-, tunnel-gated- and off-line (Leung and Lei 2005).

	On-line stations	Tunnel-gated stations	Off-line stations
Extra space required	No	Low	High
Installation cost	Low	High	Medium
Capacity	Low	Medium	High

4.   ANALYSIS AND DISCUSSION

Balancing and sequencing have different planning horizons. Thus, concerns different problems. Strategic visions are focused when discussing line balancing, i.e. mid- or long-term horizon. Sequencing is performed on short-term horizon and concerns optimisation with respect to operational issues. Line design formulates inputs when seeking an optimal sequence. Mixed-model sequencing, car sequencing and level scheduling, have different objectives. The main idea of achieving a smooth and efficient sequence of models on the line is the same for the three approaches. However, method and objective differ. Mixed-model and car sequencing focus on reducing work overload whilst level scheduling aims at efficient JIT deliveries. The differences between the two work overload approaches are that in car sequencing product options are transferred to sequencing rules creating a sequence not violating any rules. The objectives in car sequencing are whether a special sequence is feasible or it is an optimisation problem aiming at minimising violation of sequencing rules. When applying mixed-model sequencing, operational and assembly line characteristics are accounted for. Advantages of mixed-model are many, though highlights of other layouts exist. These layouts could be used in combination with the mixed-model or on their own. In the era of mass production single-model line was common, today it suits markets with a constant and high demand without many variants. The multi-model is similar to the mixed-model. However, a feature of the multi-model is batching. Perhaps the multi-model could be applied such as a company would produce one model during the early shift and then in the afternoon change model on the second shift. Tasks would be repetitive for the operators although the efficiency could be enhanced and the idle time may be reduced. The advantage of u-shaped line is that stations can be combined and therefore copes well with *"peaks"*. Also, parallel stations can handle *"peaks"*. The layouts used today to achieve high utilisation are two-sided lines. A two-sided assembly line forces a design where tasks are combined. Hence, advantages are greater than with a one-sided, though planning is more complex.

5.   CONCLUSION

Car manufacturers today are faced with fierce competition and demands for customisation. Hence, line balancing and sequencing are important aspects. The literature review found few papers dealing explicitly with line balancing and sequencing problems. It was expected to find more literature concerning Toyota's approach to balancing and sequencing issues because of its openness and success with lean production. Information was found about heijunka, a method for leveling production. Through leveling and sequencing the same amount and mix are manufactured each day and results in a smooth and even utilisation. It is worth noting that hardly any Japanese authors were identified. This could be due to lack of translation. Another reason could be reluctance to

share knowledge. The literature focused on various theoretical solutions. Few articles dealt with real problems. No solutions were identified dealing explicitly with *"peaks"* and idle times, instead suggested solutions concerned sequencing. Single- and mixed-model resulted in plenty of literature, probably due to single-model existing since early 20th century and mixed-model common in car industry today. The research revealed little about multi-model and u-shaped lines. Nevertheless, literature found was positive with few disadvantages, which could be lack of research. All three sequencing approaches are possible techniques when handling *"peaks"*. Mixed-model sequencing was the only approach clearly stating the objective to minimise idle time. Mixed-model- and car sequencing aim at reducing peaks by either alternate work intense models or through sequencing rules where work intensive models are only allowed in a specific calculated ratio.

6.   CURRENT AND FUTURE WORK

The gap between academic research and practical applications needs attention. Theoretical solutions should be adapted to real problems. A study of approaches that can be put into practice is being undertaken with collaborating companies.

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