NTNU
Norwegian University of Science and Technology

Lean Construction
(Chapter 8)

Professor Bjørn Sørskot Andersen

Learning Objectives

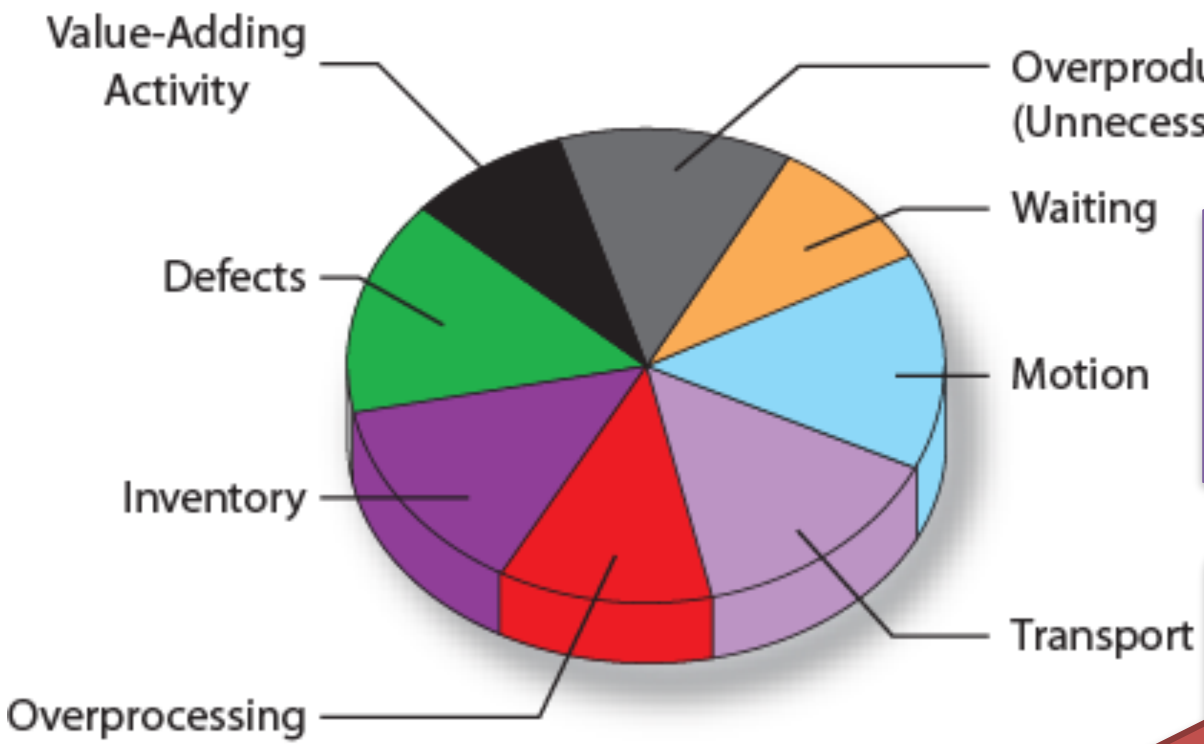
- Know of the basics of lean
- Know the history of lean construction
- Understand production planning in lean construction

- Perform exercise - Parade of Trade Games

Brief History of Lean

- Approach to manufacturing (and all kinds of business processes) aimed at the elimination of waste ("muda")
- Roots back to Just in Time (JIT) concept, inspired by American supermarkets and the car production line established by Henry Ford in 1913
- Toyota Production System (TPS) was launched in 1960, which in practice covered much of what we today think of as lean
- The success of Toyota/other Japanese manufacturers 1970s/ 1980s lead many from the west to study the practices of these companies
- Most influential book was "The Machine That Changed the World" by Roos et al. (2000)
- The core principles of lean have later been developed further and adapted to different industries, including construction

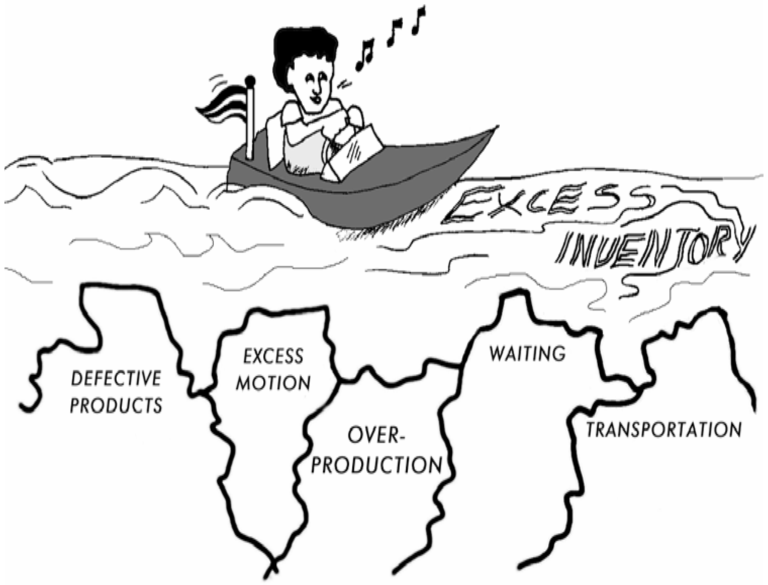
The Seven Deadly Wastes



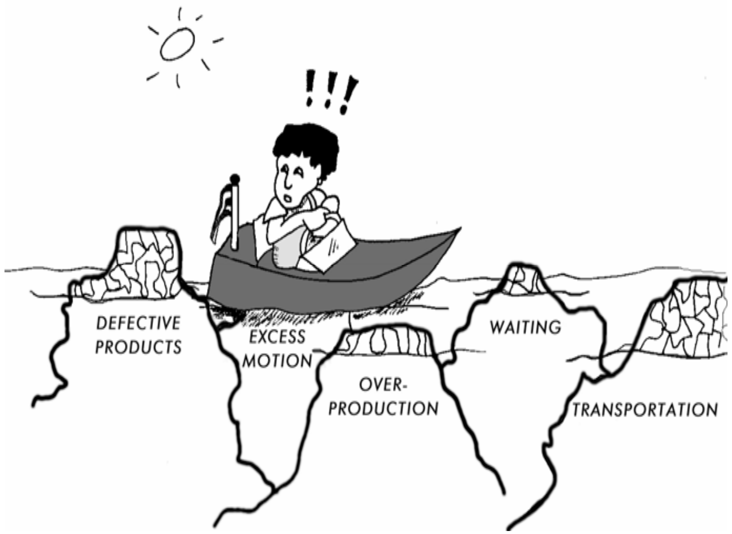
Recently an eighth waste has been identified—underutilization of people

Waste, anything that adds cost or time without adding value

Excess Inventory – The Corporate Body Guard of Bad Processes



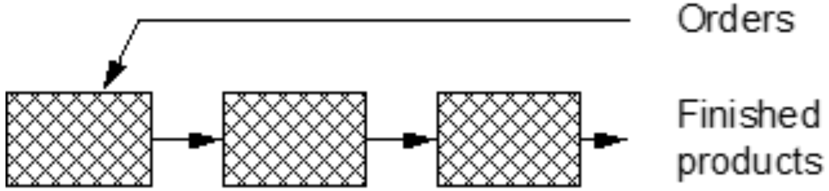
A $ea of RM & WIP



Reduce the inventory and see the wa$te!

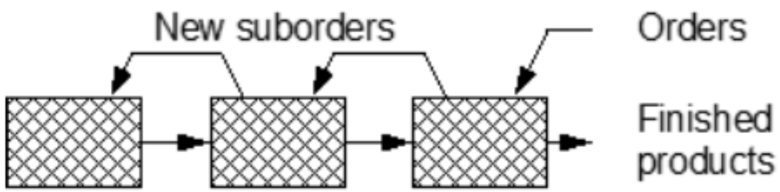
Push Principle

- Push = the orders are pushed through the production system:
  - Starting of new orders is initiated by a calculated production plan
  - Lead time usually extremely long, equivalent to the throughput time
  - A deviation of only one sub-component can make a critical delay for the entire order
  - A common solution is to forecast the future demand and base the production on this prediction
  - Forecasts based on long-term forecasts involve great uncertainty
  - To neutralize the uncertainty of the demand forecast, the use of stocks to smooth the demand is a common approach
  - This goes against the lean principle



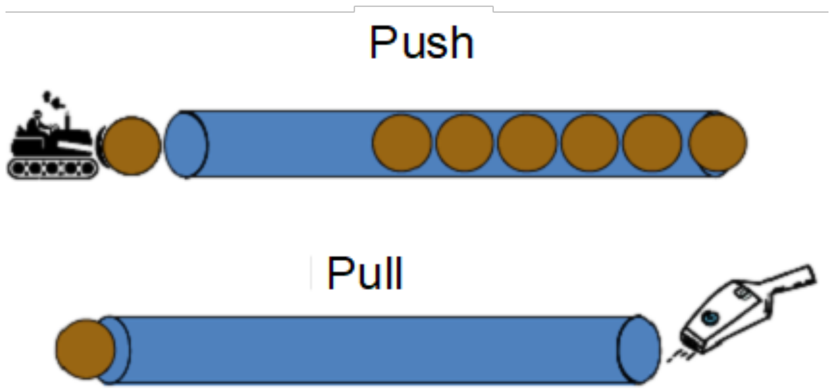
Pull Principle

- Pull = every link in the production chain orders the requisite factor inputs themselves:
  - Products are ordered from the last link
  - Then each station has to make an order to the previous one for the needed components
  - No parts are being produced before a need from the next link is indicated, and the products are pulled through the value chain



Push vs. Pull

- It has been proven beyond doubt that in most cases*, the pull system leads to a more efficient system with less waste
- * Subject to some pre-requisites, such as sufficiently short change-over times, not too extensive demand fluctuations, etc.
- The question is, can this approach be used in project-based production?

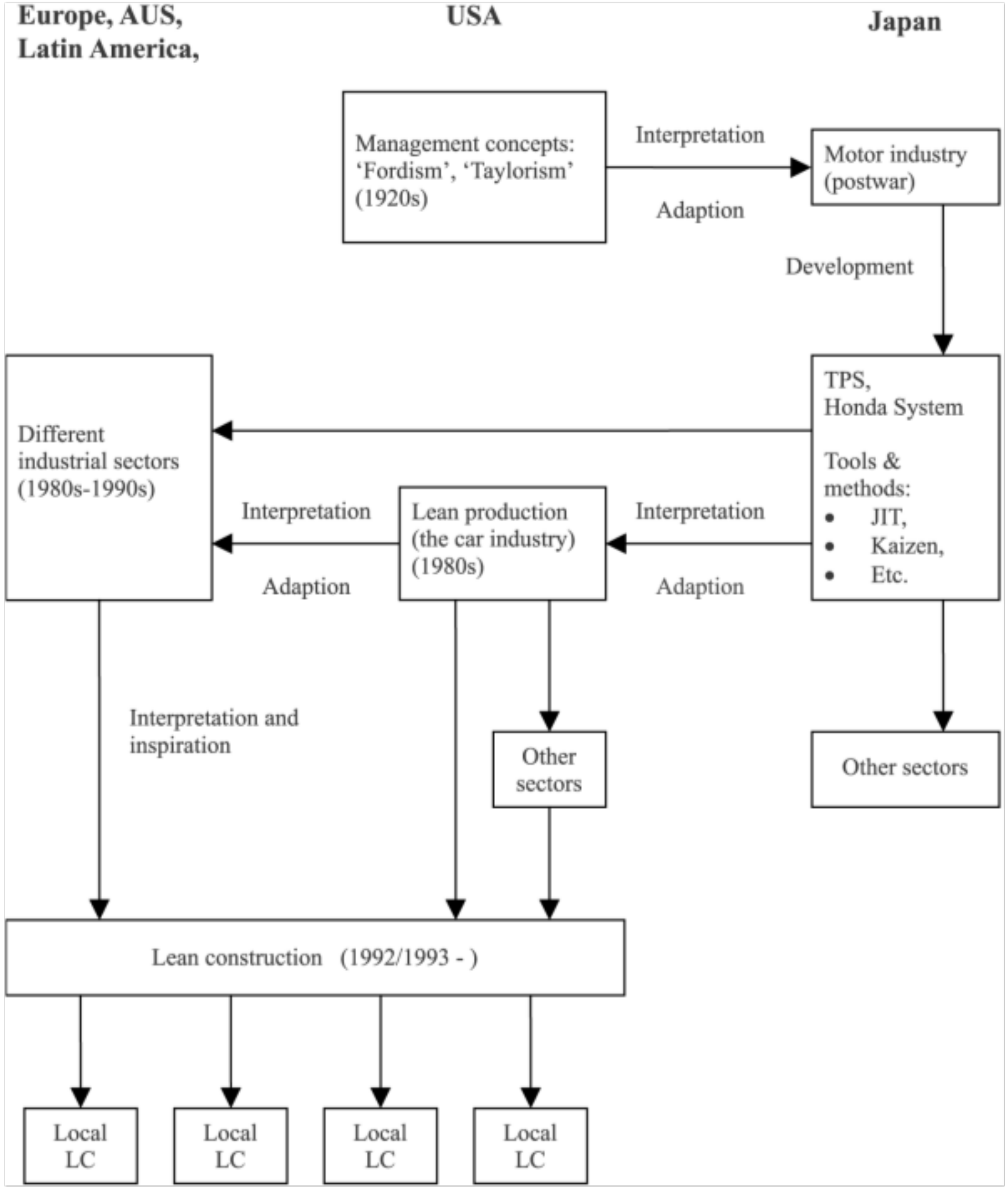


Key Lean Techniques
(Especially for Manufacturing)

- Value Stream Mapping, Flow
- Single Minute Exchange of Dies (SMED)
- Kanban
- 5S
- Cellular Manufacturing

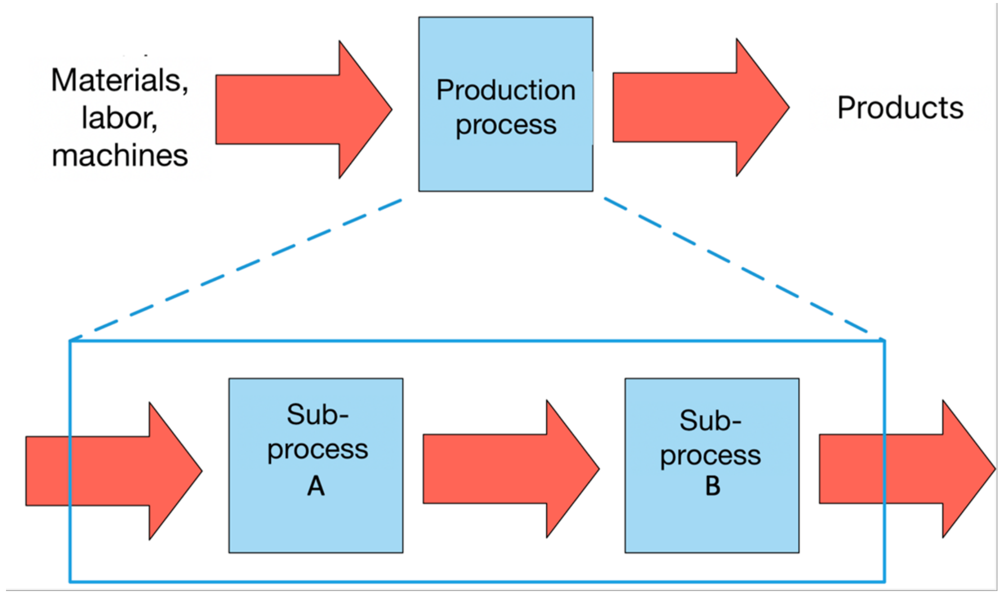
Lean construction

- Lean was developed to work in production systems where the products are mobile and with the people or machines stationary.
- When the “products” become very large, this is no longer feasible, such as buildings, ships, planes, etc.
- Here, the “product” is stationery and people and machines move around to where they are needed
- Pioneered by Koskela (1992) and Ballard (2011), lean construction was developed

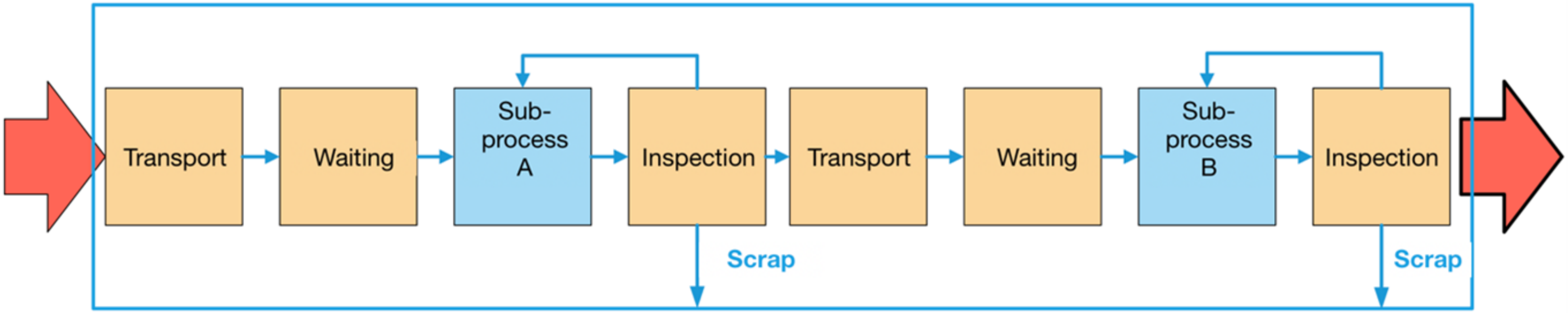


The TFV Model (Transformation, Flow, Value)

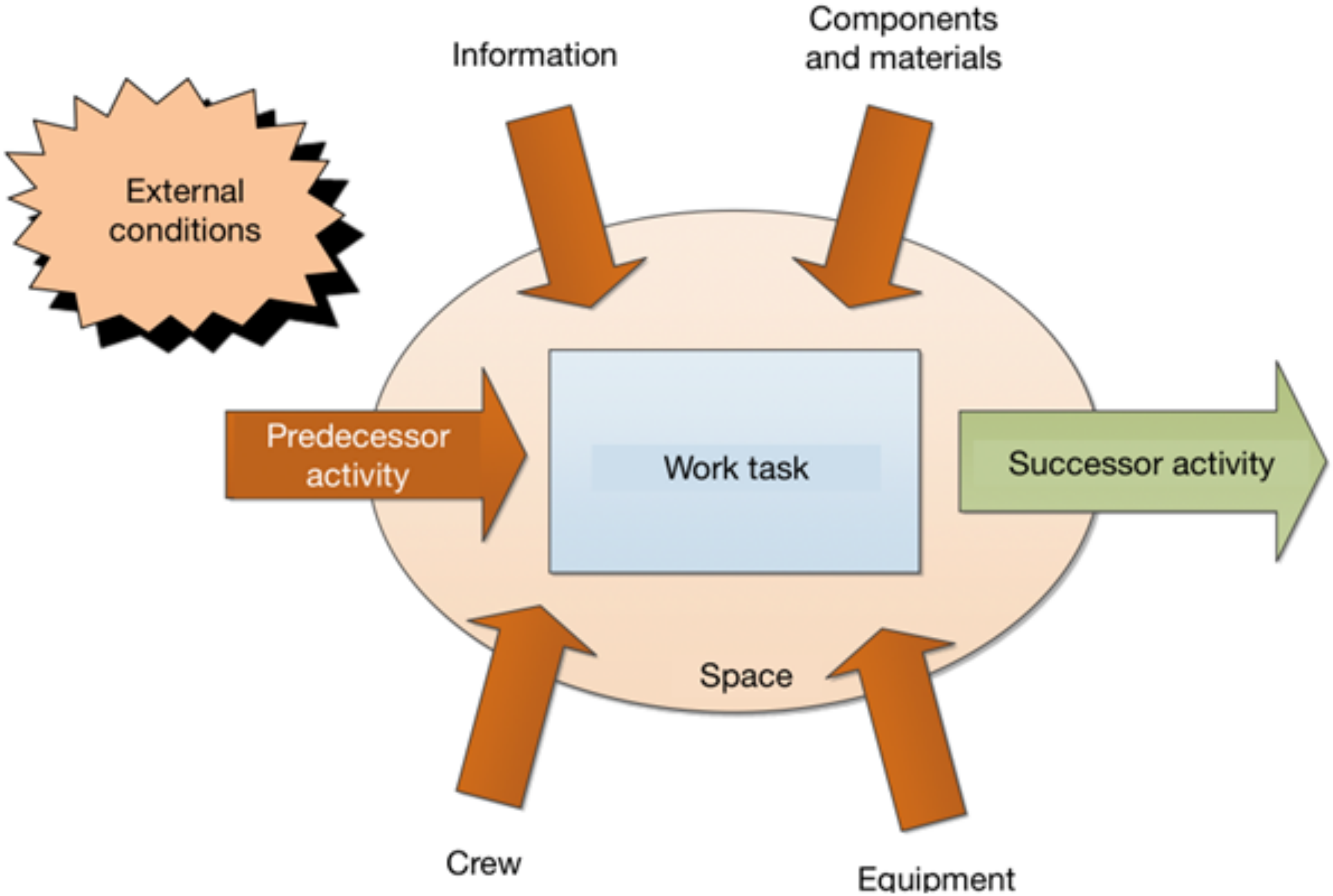
- The lean construction production system contains the same assets/concepts as product manufacturing:
  - Customers, which is defined as any downstream actor affected by the product under construction, including partnering contractors
  - Work stations, resources that perform production tasks, these resources can be people, machines, computers, etc.
  - Batches and batch sizes, the amount of units produced in one go, which can be apartments, rooms, square meters of wall, etc.
- These interact in is often called the TFV model, where resources are used to transform materials, through production processes, into products, that provide value to customers



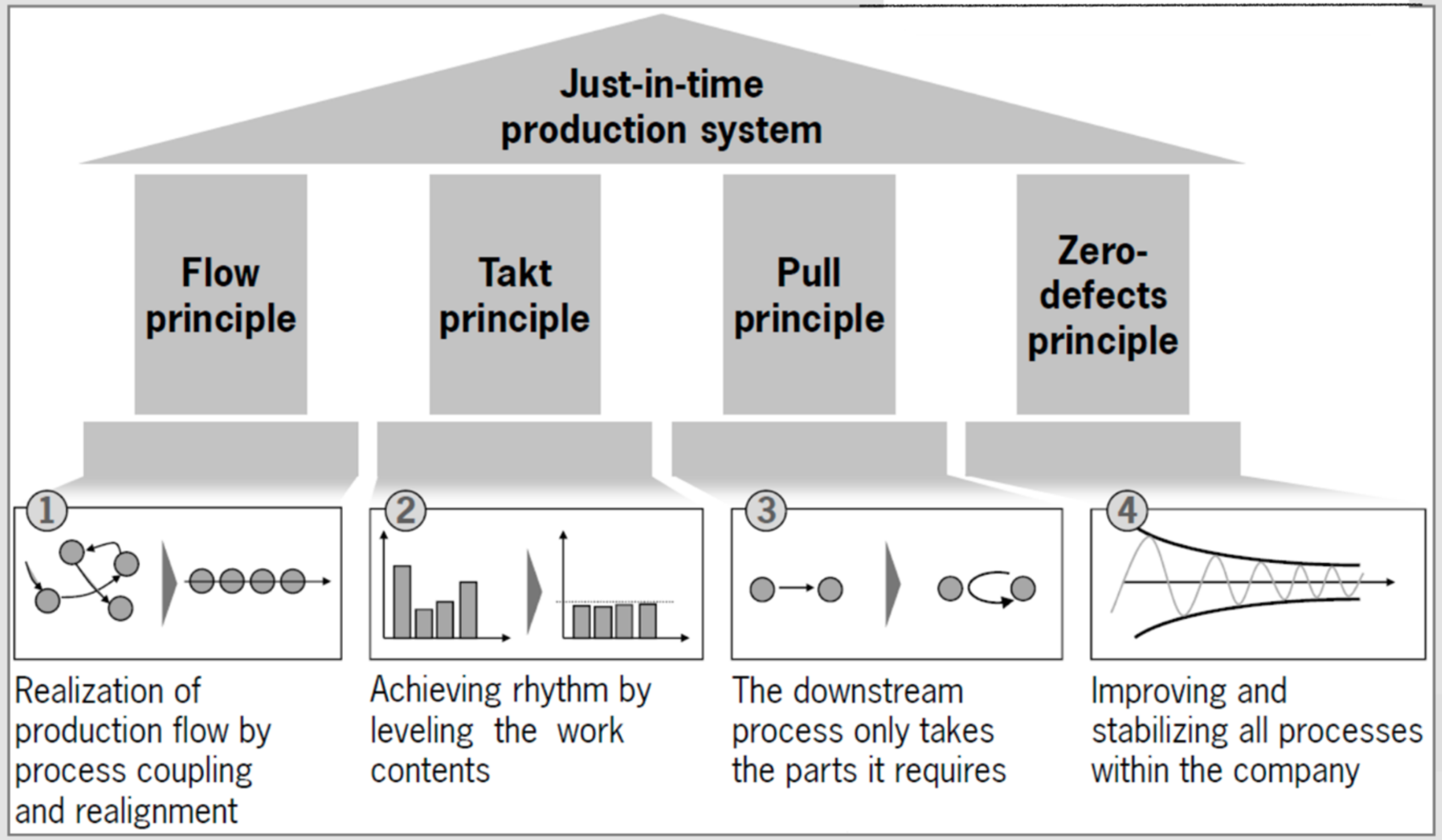
Processes in Construction



Prerequisites for Process Execution



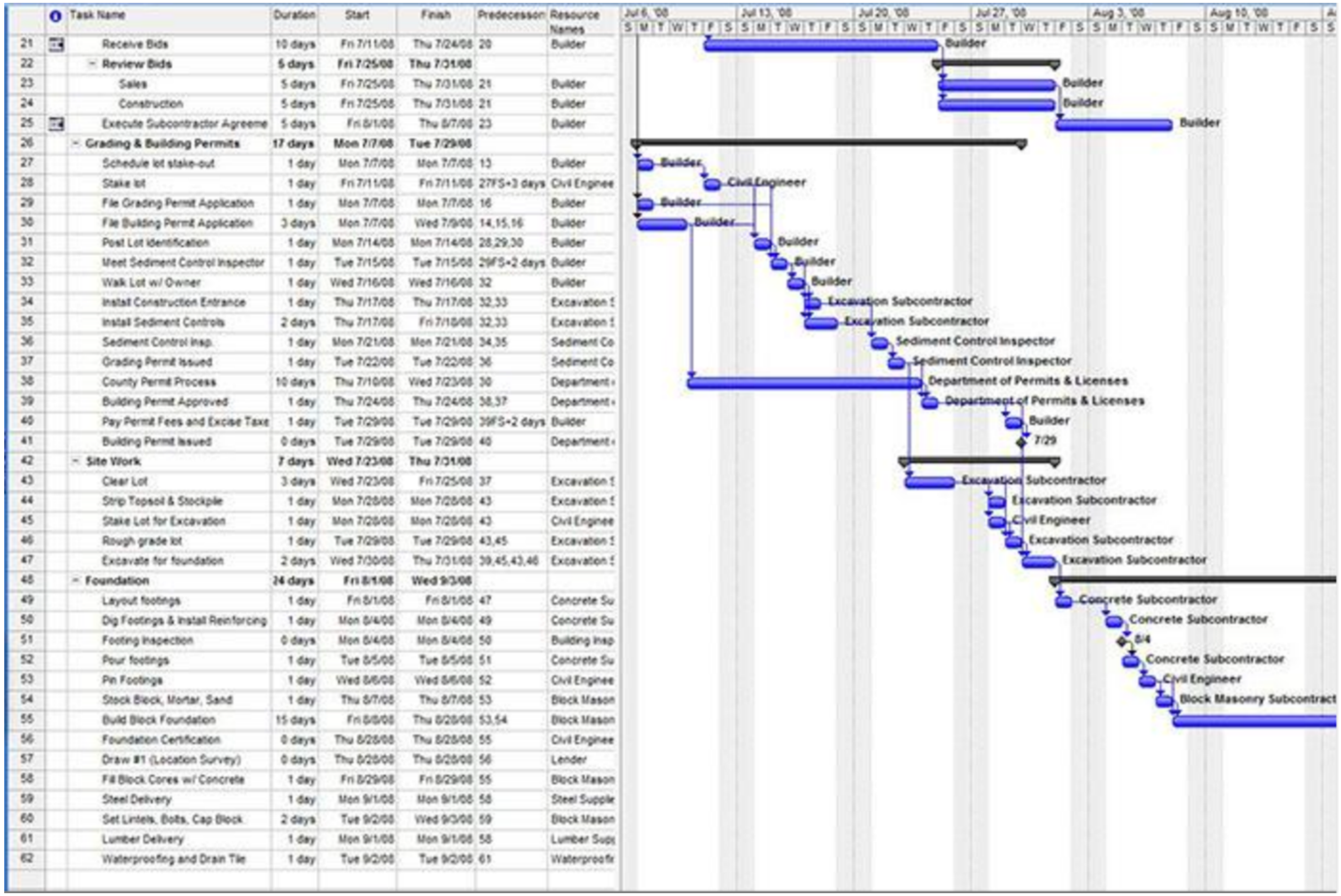
The Porsche Lean Framework



Combines pull, flow, waste, and the takt principle

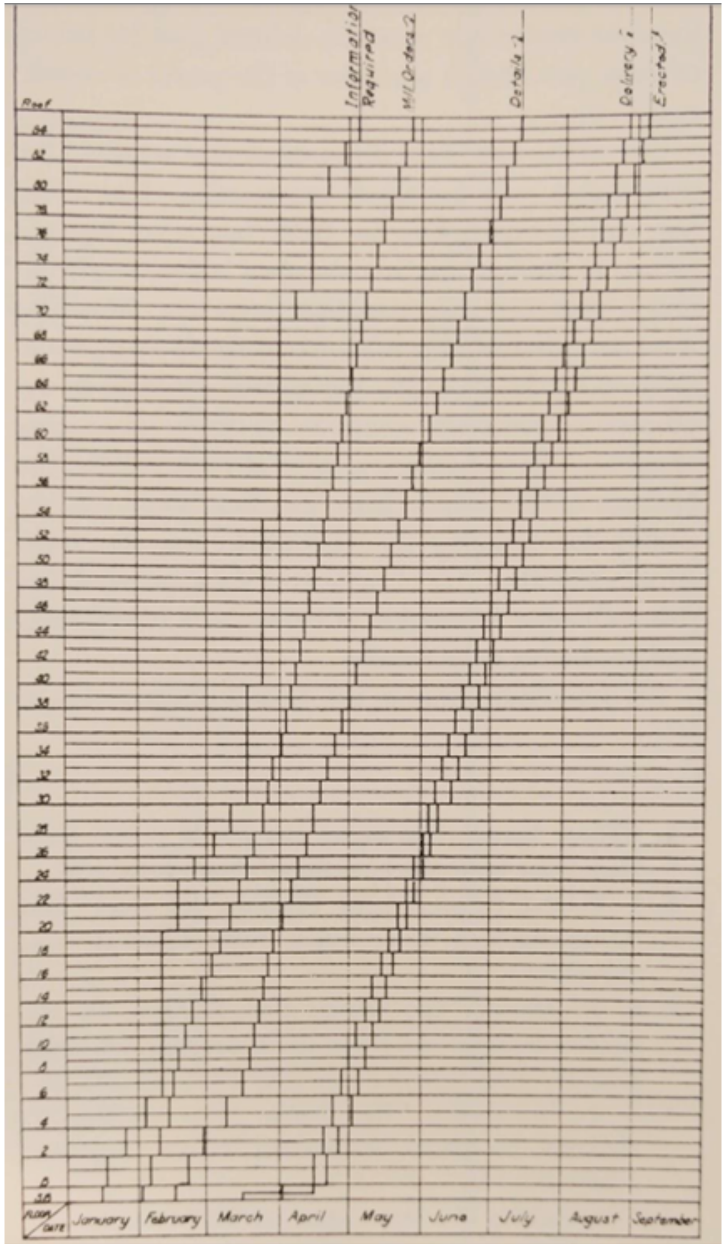
Classical Project Planning

- Uses the traditional Gantt chart
- This is an activity-based approach
- It quickly gets extremely complicated, since construction projects can contain thousands of activities
- It is time-consuming to use, complicated to follow, and vulnerable to changes due to
- disruptions



Location-Based Planning

- Less used throughout history, but not a recent invention
- A famous example is the Empire State Building in New York
- It was completed in just over one year in 1931
- Preserved hand-drawn location-based plan, with each floor representing a line in the chart
- Clearly much less complex



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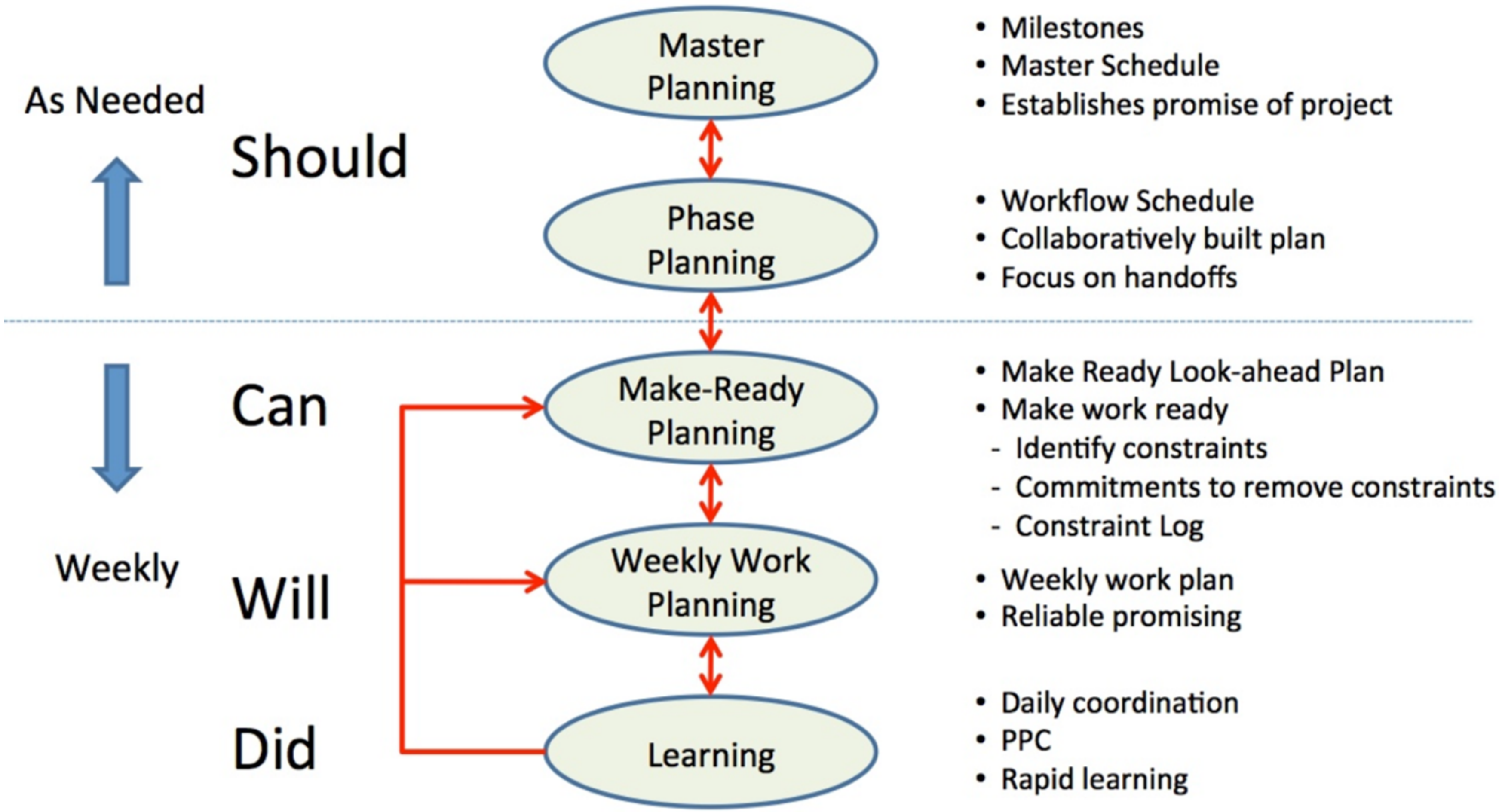
Last Planner System

- An activity-based approach (thus more familiar to companies that have been using the traditional project planning methods)
- But integrates the principles of pull, waste, zero defects, etc.
- The core is that the detailed planning of the construction activities on site should be handled by the “last planner”
- This is typically the foreman supervising a crew of crafts people

Last Planner System Has Five Major Parts



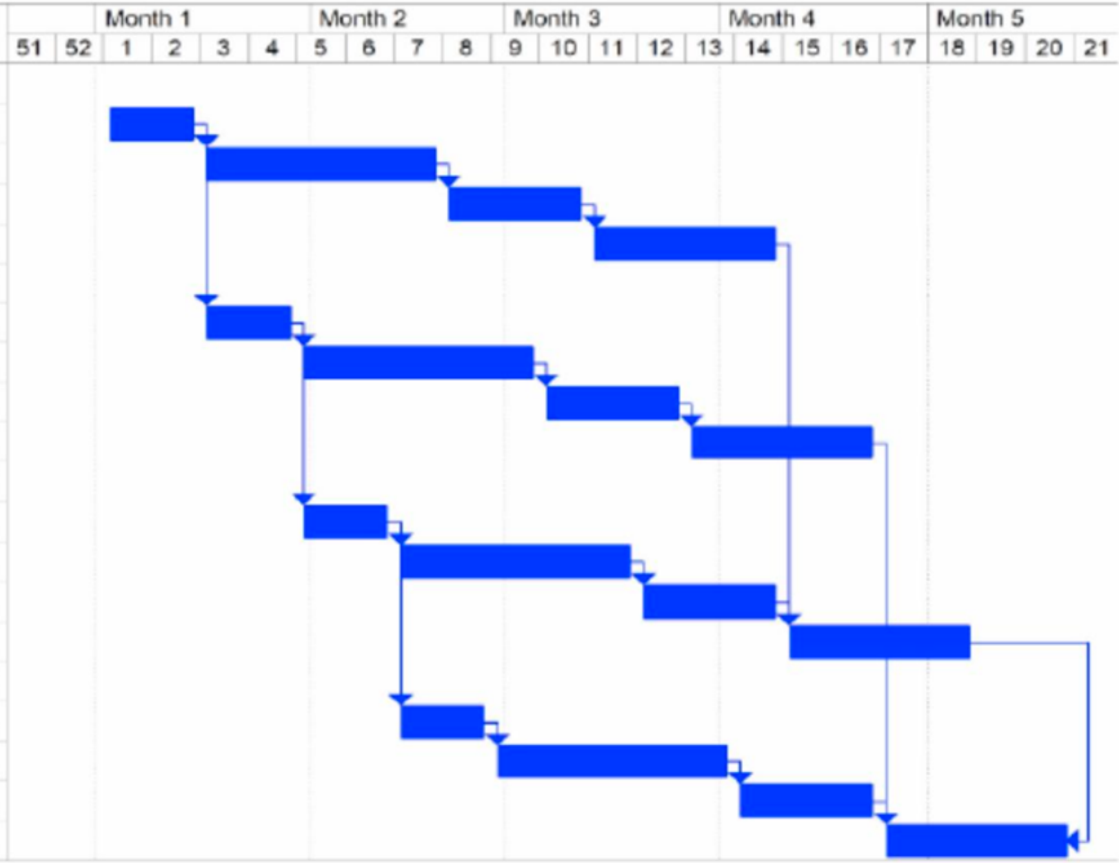
The Five Elements

- The first two parts focus on identifying the work that should be done to complete a successful lean project:
    1. Master Planning, focused on identifying major milestones that will set the pace of the project
    2. Phase planning, two to three months before the beginning of each phase, develops an agreement between last planners on how all the work between those two milestones will be completed and is done through backward planning (pull)
- The three last parts are done throughout execution of the work:
    3. Make ready planning, look ahead to evaluate whether there are constraints to upcoming tasks (usually considering six weeks ahead)
    4. Clarify what each last planner will do to fulfill the promises made, using a Weekly Work Plan, identifying the tasks the teams will complete each day of the following week
    5. Learning, based on measurements of progress and adherence to the plans, where a key performance measurement is PPC (percentage plan complete)

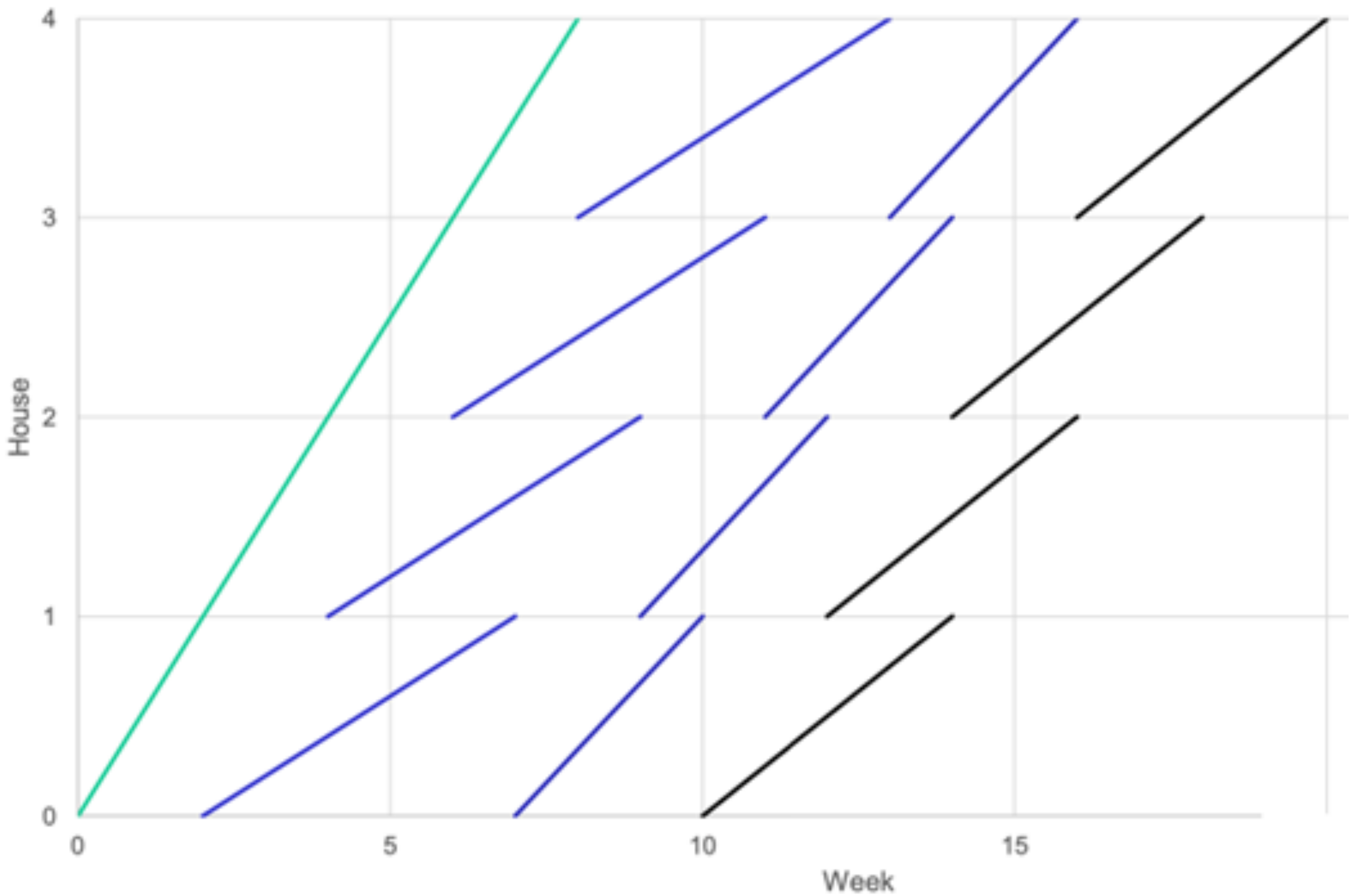
Activity-Based Plan

- How efficient is this production plan?

ID	Task Name	Duration
1	**House 1**	**70 days**
2	Foundations	10 days
3	Brickwork	25 days
4	Roof Construction	15 days
5	Internal Works	20 days
6	**House 2**	**70 days**
7	Foundations	10 days
8	Brickwork	25 days
9	Roof Construction	15 days
10	Internal Works	20 days
11	**House 3**	**70 days**
12	Foundations	10 days
13	Brickwork	25 days
14	Roof Construction	15 days
15	Internal Works	20 days
16	**House 4**	**70 days**
17	Foundations	10 days
18	Brickwork	25 days
19	Roof Construction	15 days
20	Internal Works	20 days

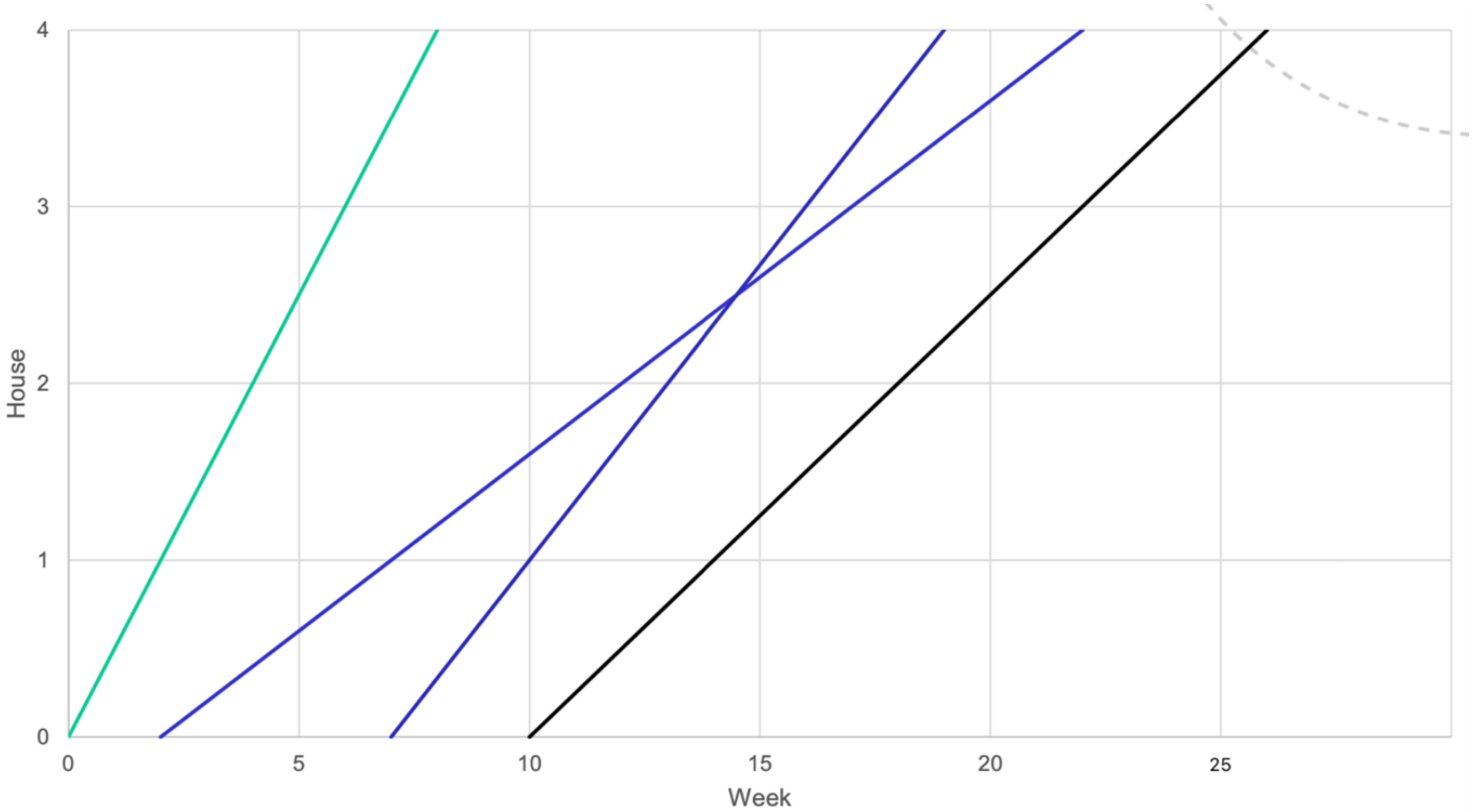


Converting to Location-Based, Step 1



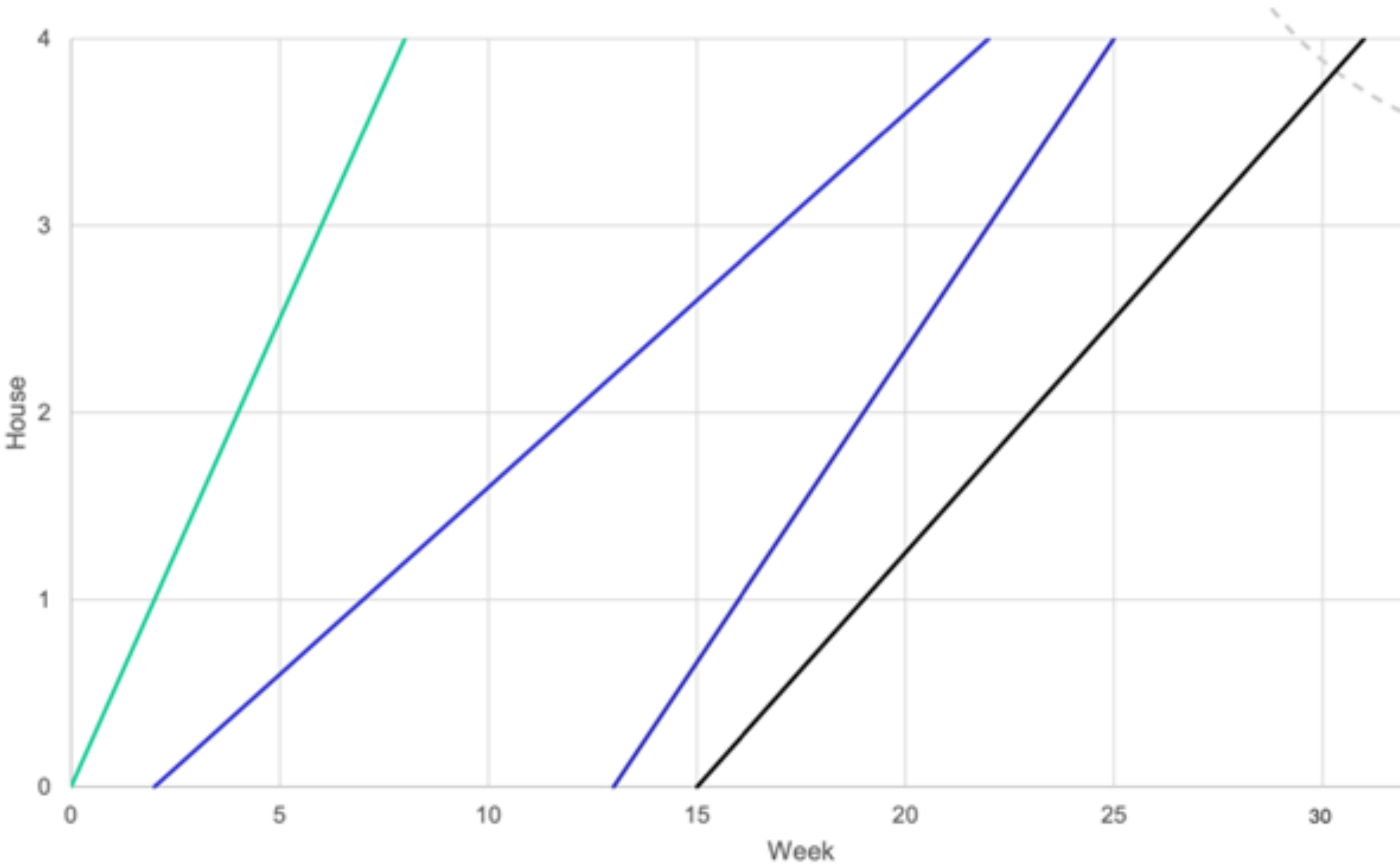
Does not make too much sense, because the Gantt chart plan was not good

Sequencing the Activities, Step 2



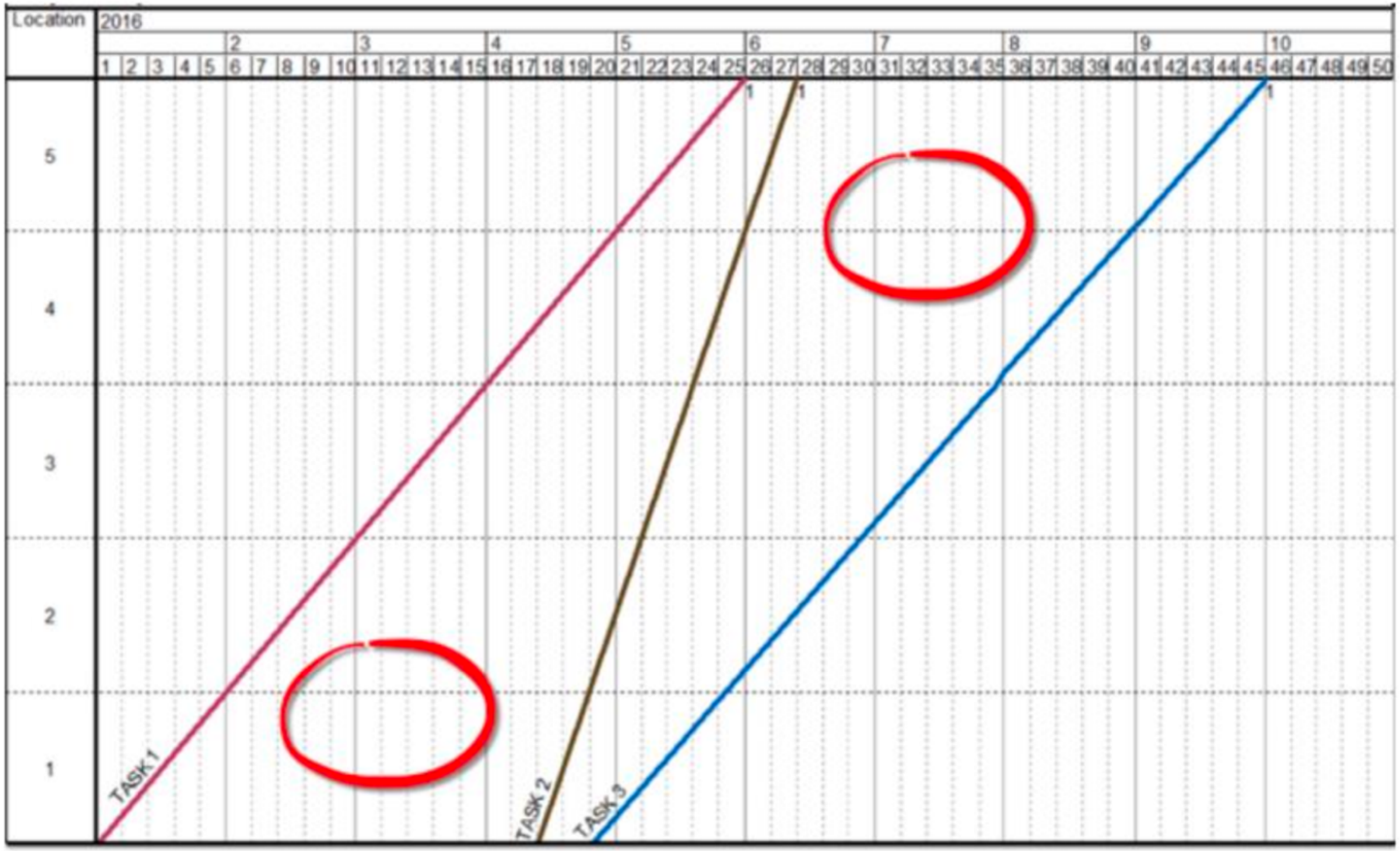
Two of the activities "cross" one another, meaning they will conflict

Adjusting the Sequencing, Step 3



Now no conflicts

“Empty spaces” that represent a potential for optimization



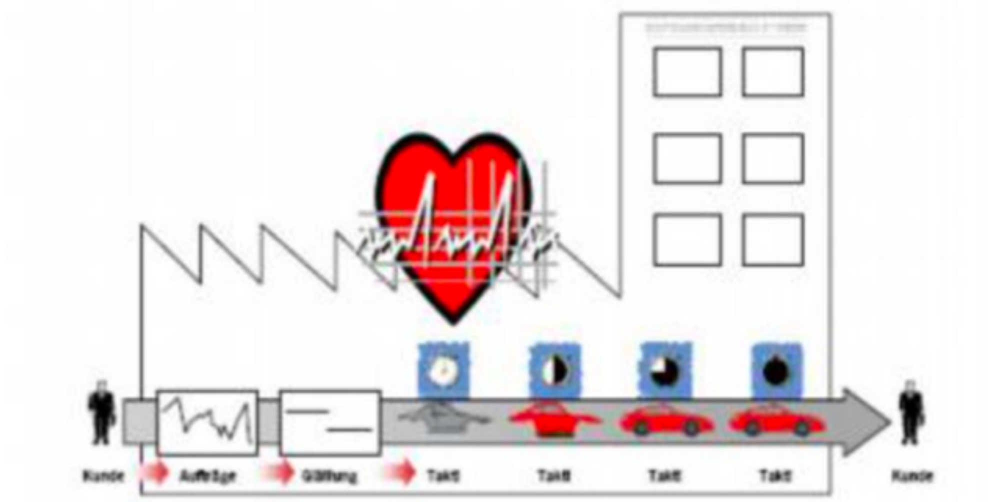
Optimizing the Plan, Step 4

The original plan = more than 25 weeks to complete

Optimized plan = 35 days

Takt Planning

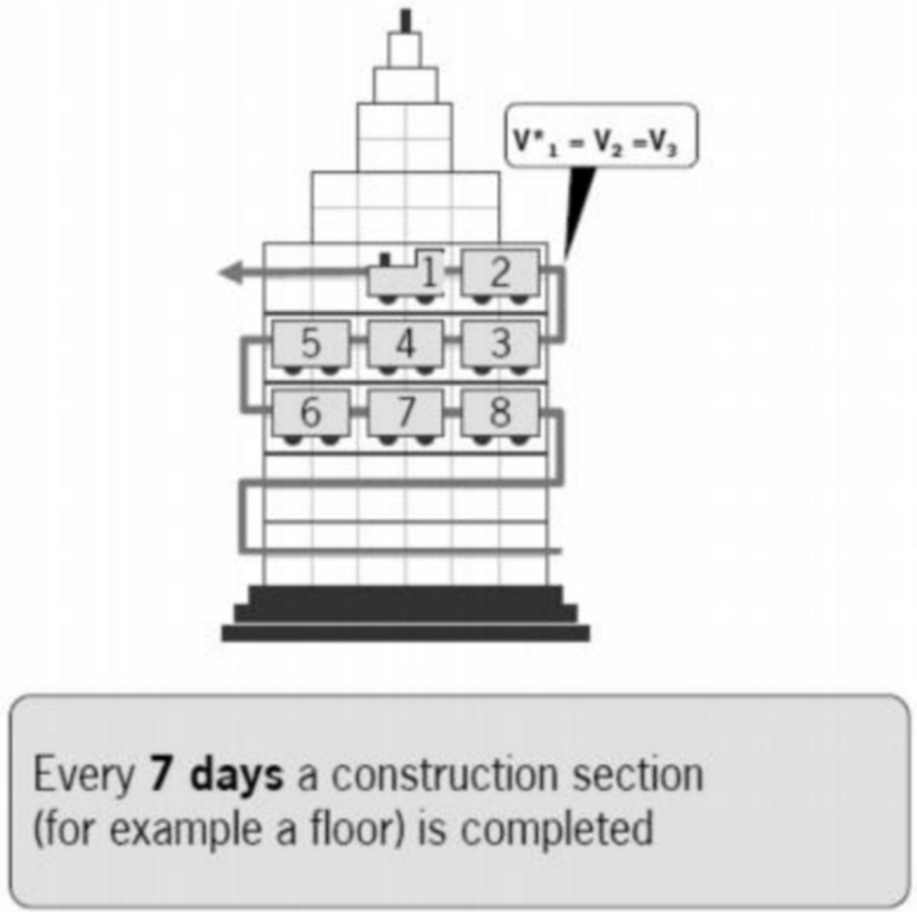
- This type of planning is done through **takt planning**, based on the following definition:
  – Takt-time is the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate



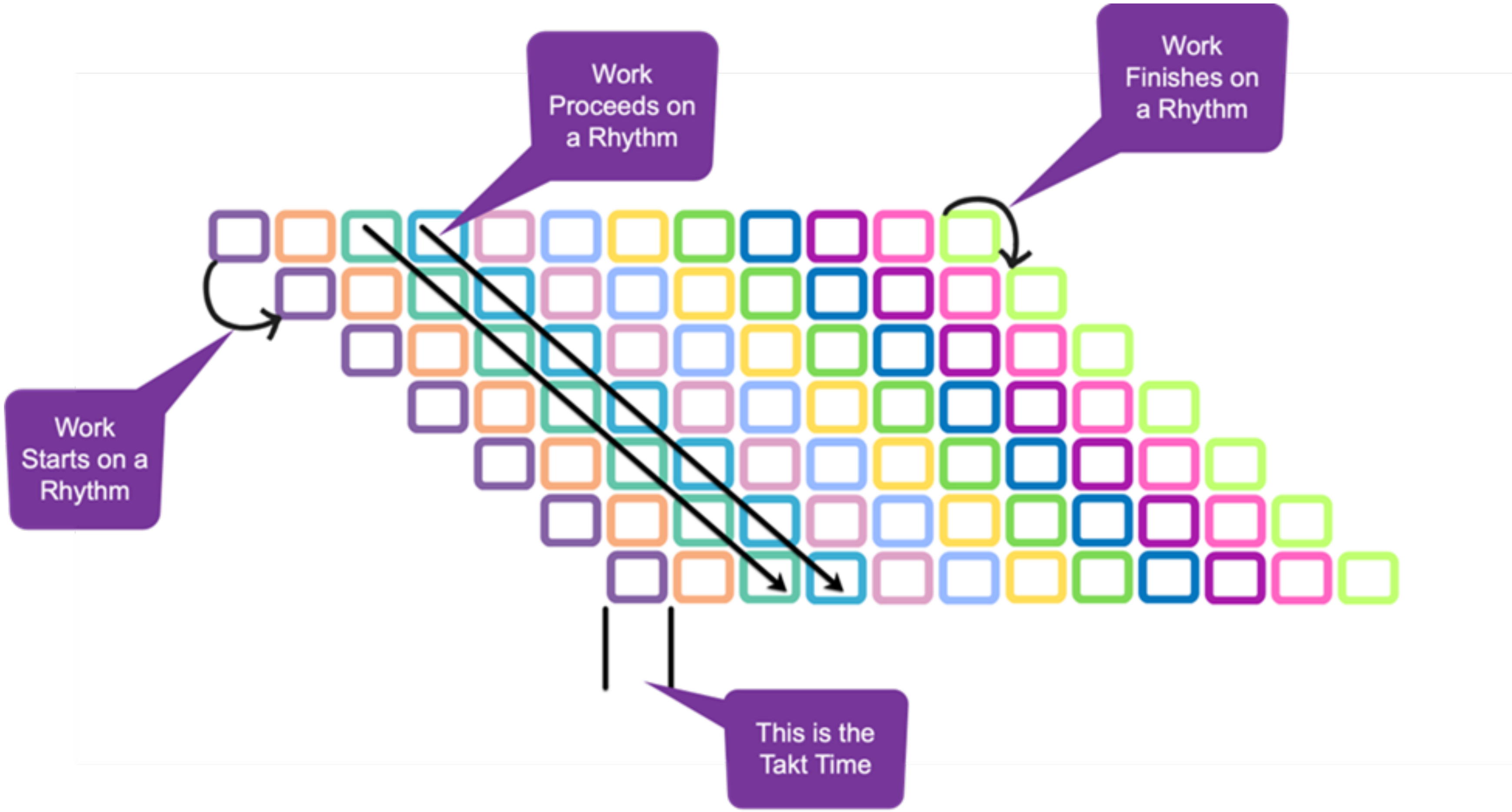
Every **4.7 minutes** a complete automobile exits the production hall

Takt Planning in Manufacturing vs. Construction

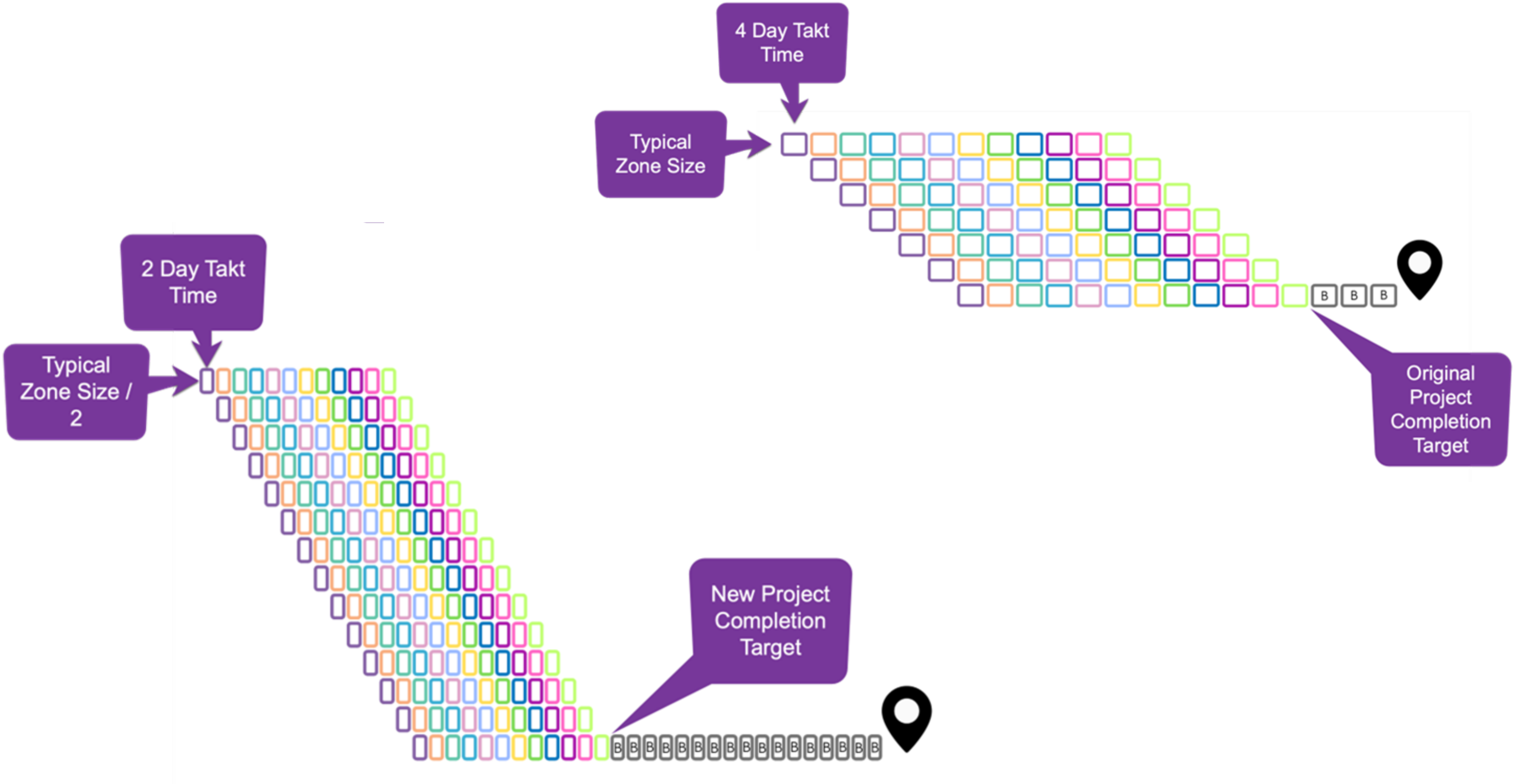
- In traditional manufacturing, the planning is about scheduling the flow of products through resources
- In construction projects, we must schedule the flow of resources (materials, crews and equipment) throughout the building
- A visually compelling way to picture this is that of a train with a number of wagons moving through the building, where each wagon represents a task (performed by one trade, such as carpenters, electricians, plumbers, etc.)
- The capacity and load of each wagon/discipline is adjusted so that the whole train can move through the building at a constant pace



Takt = the Rhythm of the Work



The Rhythm Can Be Increased



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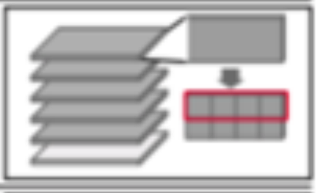
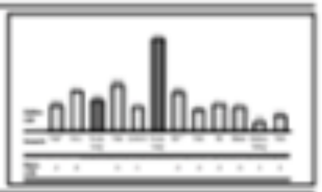
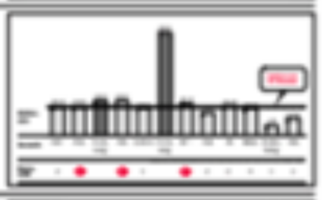
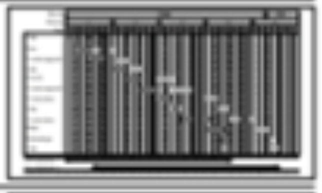
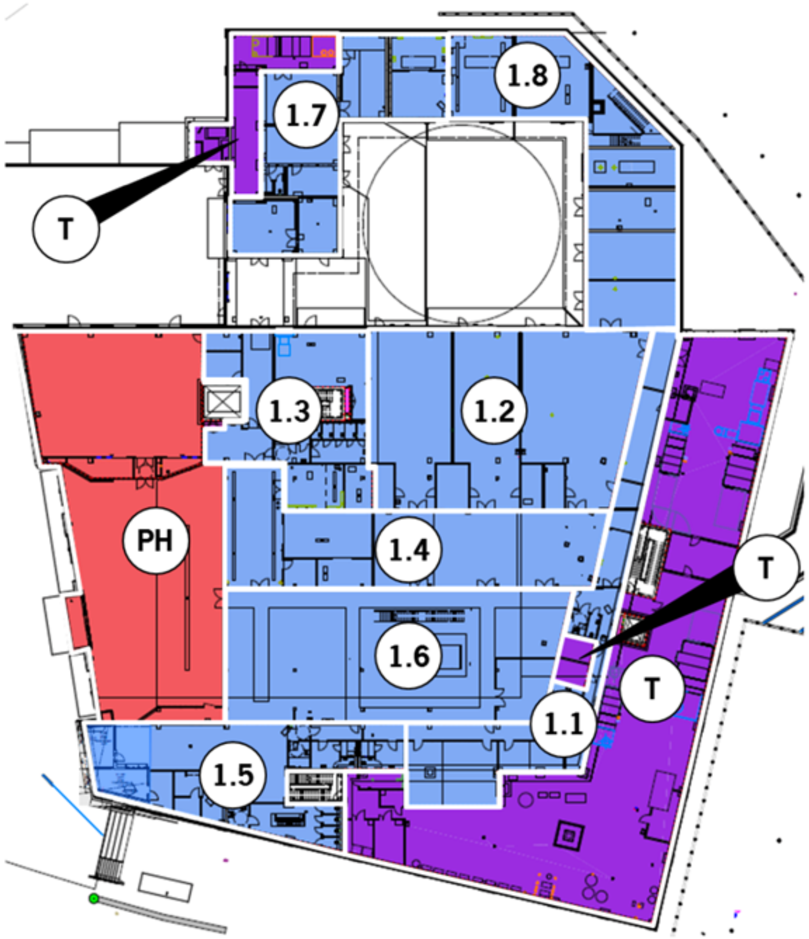
Takt Planning in 10 Steps

Step	Content	
1	Identification of repeatable and non-repeatable elements	
2	Identification of construction sections	
3	Division of construction sections in subsections	
4	Definition of the trade sequence	
5	Definition of the work content of each trade	
6	Compilation of a work content chart	
7	Definition of a takt and adjustment of capacities	
8	Preparation of a production schedule$_{FEIN}$	
9	Adjustment of the production schedule$_{FEIN}$ with subcontractors	
10	Definition of the frozen zone	

Campus Building, Steps 1-3



The construction sections of one floor of the building:

- purple sections technical rooms
- blue sections regular rooms
- white a large atrium

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Campus Building, Step 4

The logical/ optimal sequence of the trades is determined based on the construction work to be undertaken

Trade sequence: Concrete pouring → Carpenter I → Electrician → Ventilation → Plumber → Carpenter II → Other trades

Campus Building, Step 5

- To determine the work content of each trade, the calculations depend on whether the construction sections are repeated throughout the building
- Or different sections represent unique/complicated tasks for each trade
- For the college building, the latter was the case, and the sections were classified as “easy”, “medium”, and “hard”

Complexity	Description	Task duration per trade	
Easy	- Surface: 540 m2 - Light technical installations	- Concrete: - Carpenter: - Plumber	5.06 days 4.00 days 4.07 days
Medium	- Surface: 445 m2 - “Medium” technical installations	- Concrete: - Carpenter: - Plumber	4.17 days 4.80 days 4.83 days
Difficult	- Surface: 400 m2 - Complex technical installations	- Concrete: - Carpenter: - Plumber	3.75 days 3.99 days 4.83 days

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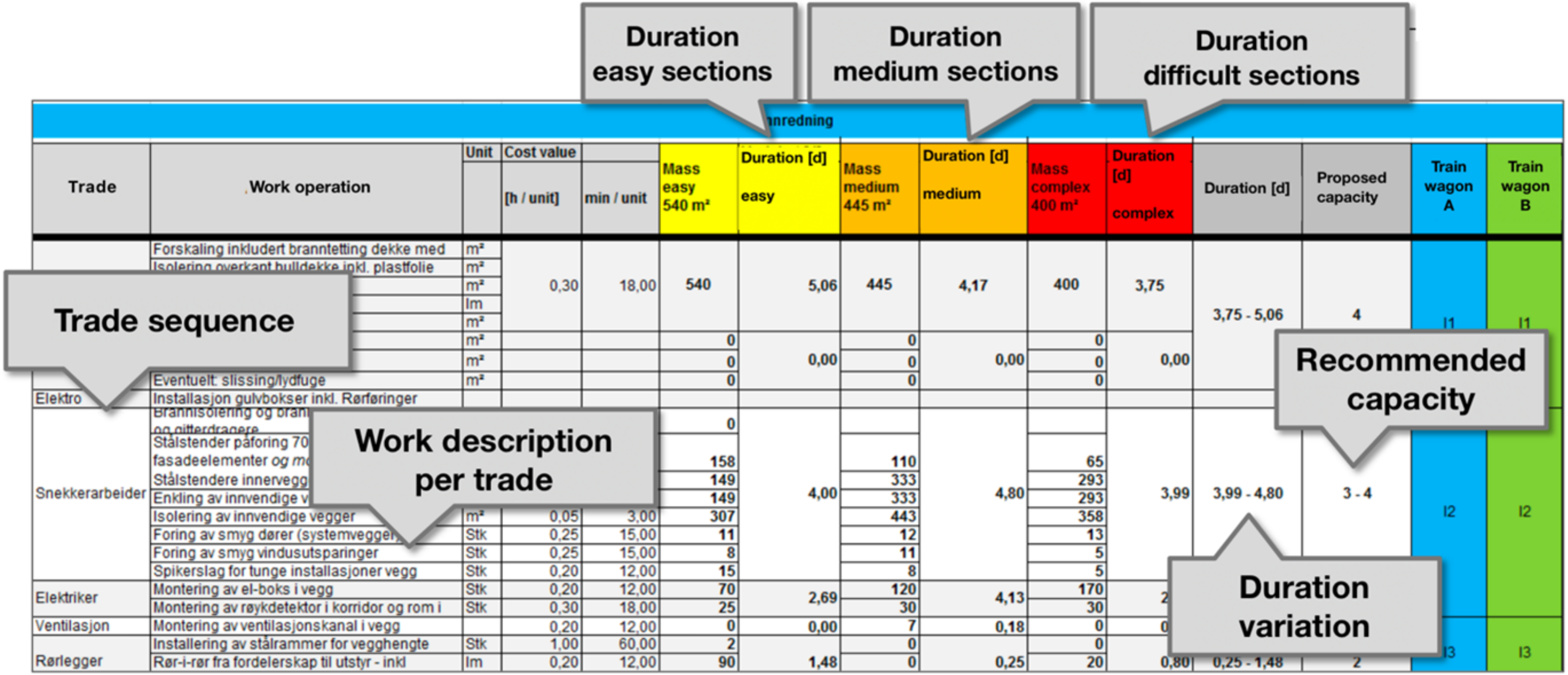
Detailed Task Duration Calculations



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Trade	Work operation	Unit	Cost value [h / unit]	min / unit	Mass easy 540 m²	Duration [d] easy	Mass medium 445 m²	Duration [d] medium	Mass complex 400 m²	Duration [d] complex	Duration [d]	Proposed capacity	Train wagon A	Train wagon B
	Forskaling inkludert branntetting dekke med	m²	0,30	18,00	540	5,06	445	4,17	400	3,75	3,75 - 5,06	4	I1	I1
	Isolering overkant bulldekke inkl. plastfolie	m²												
		m²												
		lm												
		m²												
		m²			0	0,00	0	0,00	0	0,00				
		m²			0		0		0					
	Eventuelt: slissing/lydfuge	m²			0		0		0					
Elektro	Installasjon gulvbokser inkl. Rørføringer													
Snekkerarbeider	Brannisolering og brann... og gitterdragere				0									
	Stålstender påforing 70... fasadeelementer og m...				158	4,00	110	4,80	65	3,99	3,99 - 4,80	3 - 4	I2	I2
	Stålstendere innervegg...				149		333		293					
	Enkling av innvendige v...				149		333		293					
	Isolering av innvendige vegger	m²	0,05	3,00	307		443		358					
	Foring av smyg dører (systemvegger)	Stk	0,25	15,00	11		12		13					
	Foring av smyg vindusutsparinger	Stk	0,25	15,00	8		11		5					
	Spikerslag for tunge installasjoner vegg	Stk	0,20	12,00	15		8		5					
Elektriker	Montering av el-boks i vegg	Stk	0,20	12,00	70	2,69	120	4,13	170	2...				
	Montering av røykdetektor i korridor og rom i	Stk	0,30	18,00	25		30		30					
Ventilasjon	Montering av ventilasjonskanal i vegg		0,20	12,00	0	0,00	7	0,18	0	0...				
Rørlegger	Installering av stålrammer for vegghengte	Stk	1,00	60,00	2		0		0					
	Rør-i-rør fra fordelerskap til utstyr - inkl	lm	0,20	12,00	90	1,48	0	0,25	20	0,80	0,25 - 1,48	2	I3	I3

Calculating Takt Time

Dlouhy and Binninger's Takt time formula*:

Duration = (Takt Wagons + (Takt Zones -1)) * Takt time

$$\text{Takt time} = \frac{\text{Total construction time}}{\text{Number of sections} + \text{Number of wagons} - 1}$$

Dlouhy, J., Binninger, M., Oprach, S. and Haghsheno, S. (2016). "Three-level Method of Takt Planning and Takt Control – A New Approach For Designing Production System in Construction." In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.2 pp. 13–22.

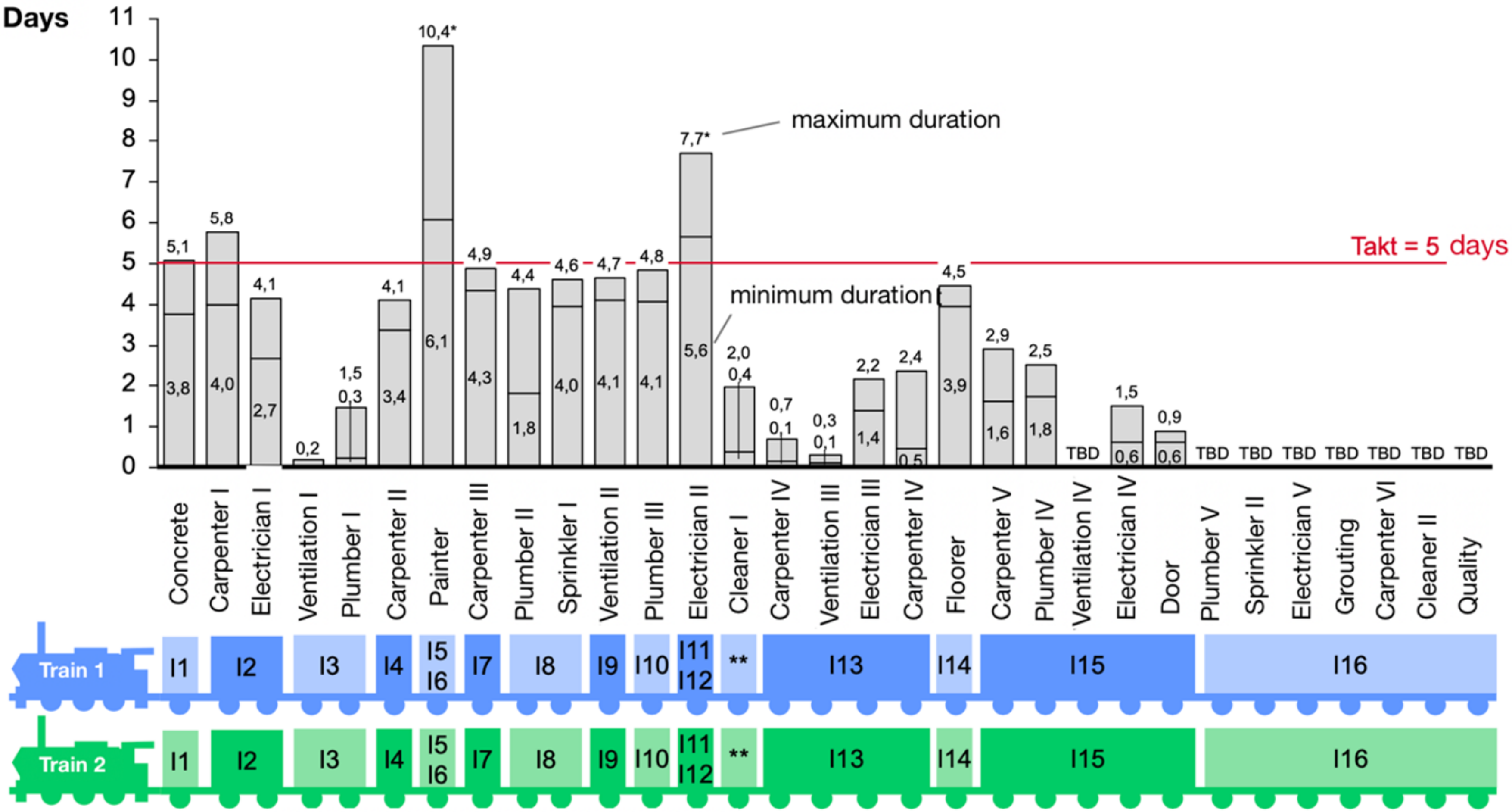
Campus Building, Steps 6-7

It was determined that two parallel trains were required, containing 19 wagons each

$$\text{Takt time} = \frac{\text{Total construction time}}{\text{Number of sections} + \text{Number of wagons} - 1}$$

Takt time = 230 days / 28 + 19 - 1 = 5 days

Campus Building, Steps 6-7

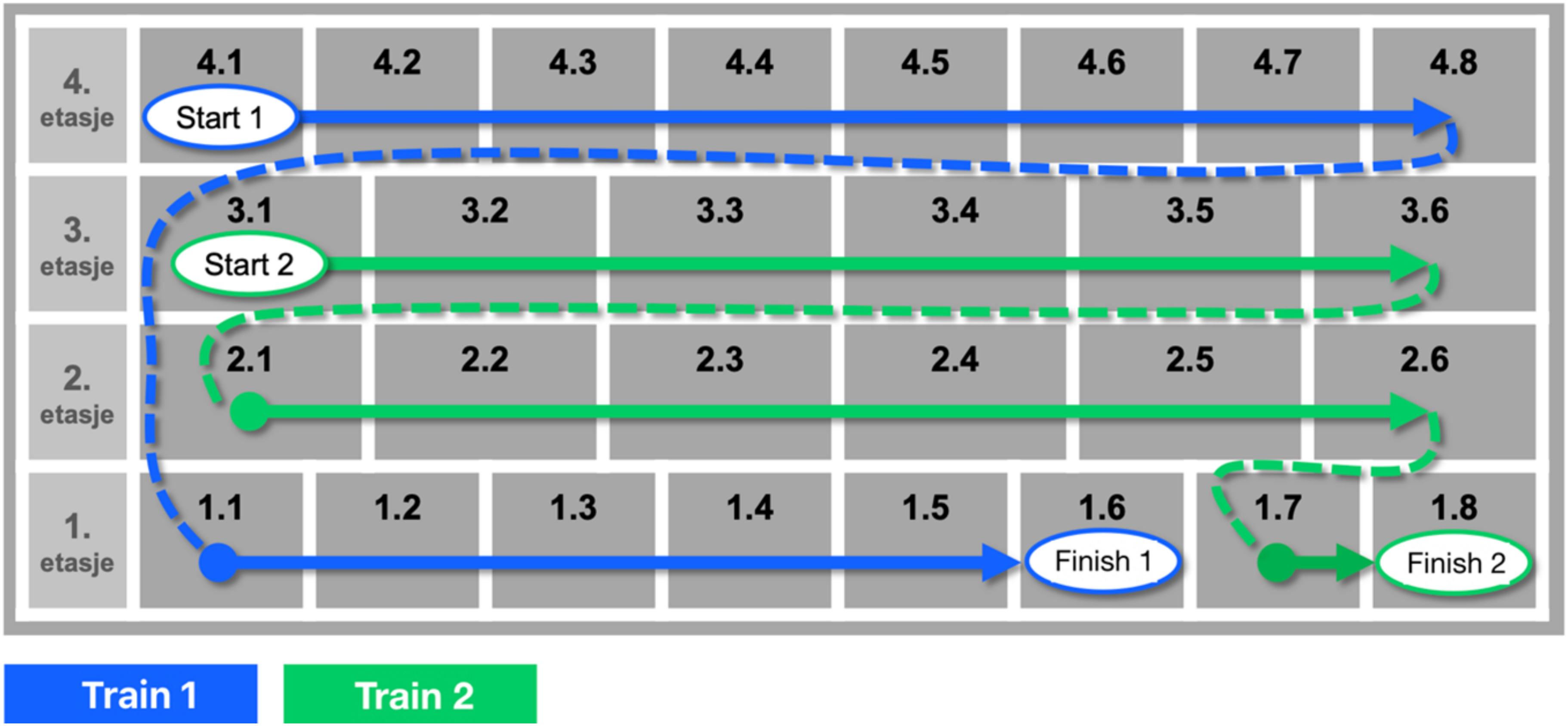


* The activity is performed as a dual wagon

** The activity is performed during weekends

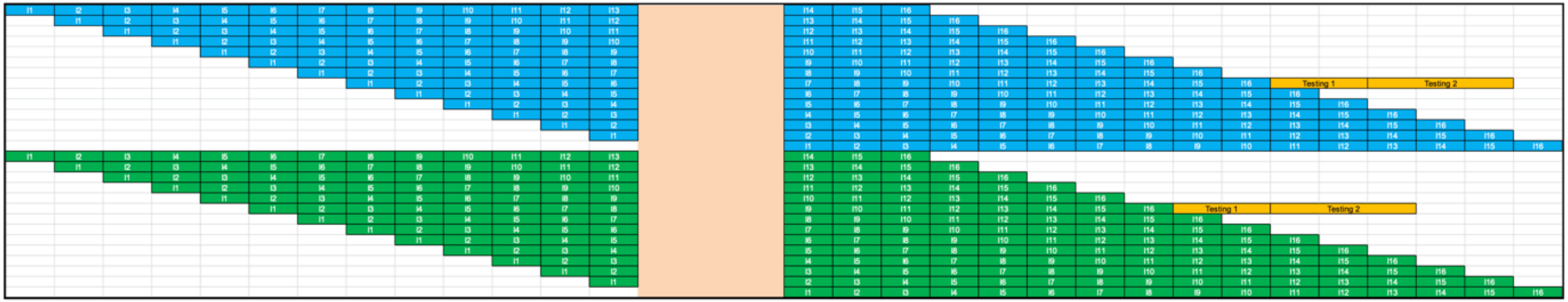
Campus Building, Step 8

The production sequence of the sections is determined, utilizing the two trains:



Campus Building, Steps 9-10

- This plan could be further adjusted in steps 9-10, but there was no need for this
- The complete location-based production plan for the main area of this quite complex building, at 14.800 m2:



- The construction work was completed according to the plan, with a significant reduction in construction time compared with similar buildings