Aalto University
School of Engineering

Operation Management in Construction
Lecture #2
Location-based planning systems

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Topics, Lecture #2

- **Learning objectives of Lecture #2**
- **Why is planning needed?**
- **Activity-based vs. location-based planning**
- **Location-based planning overview – two methods LBMS and takt**
    - LBMS planning process
    - Takt planning process
- **Production System cost**
- **Production System risk and buffers**

Intended learning objectives for this lecture

- ILO 2: **Students can compare and contrast** the similarities and differences of different production planning and control methods
  - *ILO emphasized for location-based planning systems*
- ILO 3**: Students can calculate** the production system cost of a schedule
  - *ILO introduced: theory of production system cost*
- ILO 4: **Students can explain** the factors related to production system risk of a schedule
  - ILO *emphasized – risk and buffers*
- ILO 5**: Students can explain** the significance of work and labor flow and how flow can be achieved in construction
  - *ILO introduced (planning)*
- ILO 9**: Students can analyze** the quality of a location-based schedule
  - ILO introduced

What is planning / production system design?

- **Production system = system for designing and making of products**
- **Production system design serves three goals of production systems:**
  - Do the work
  - Maximize value
  - Minimize waste
- **What should we do to achieve a goal?**
  - How should the work be divided?
  - Who should be responsible for each task?
  - How should each task be done to minimize waste?
  - Etc.

Ballard, G. , Koskela, L. , Howell, G. & Zabelle, T. 2001, 'Production System Design in Construction' In:, Ballard, G. & Chua, D., *9th Annual Conference of the International Group for Lean Construction.* Singapore, Singapore, 6-8 Aug 2001.

Two key planning methodologies

	Activity-based	Location-based
How the plan is modelled	Discrete activities joined by logical relationships	Individual activities in different locations are aggregated to task / wagon Tasks / wagons flow through locations of work.
Constraints of planning	Each individual activity is free to move in time as long as it maintains logical relationships	Requirement of continuous flow through locations.
Focus	Activity as the container of project data	Location as container of project data. Task/wagon as the method of control.

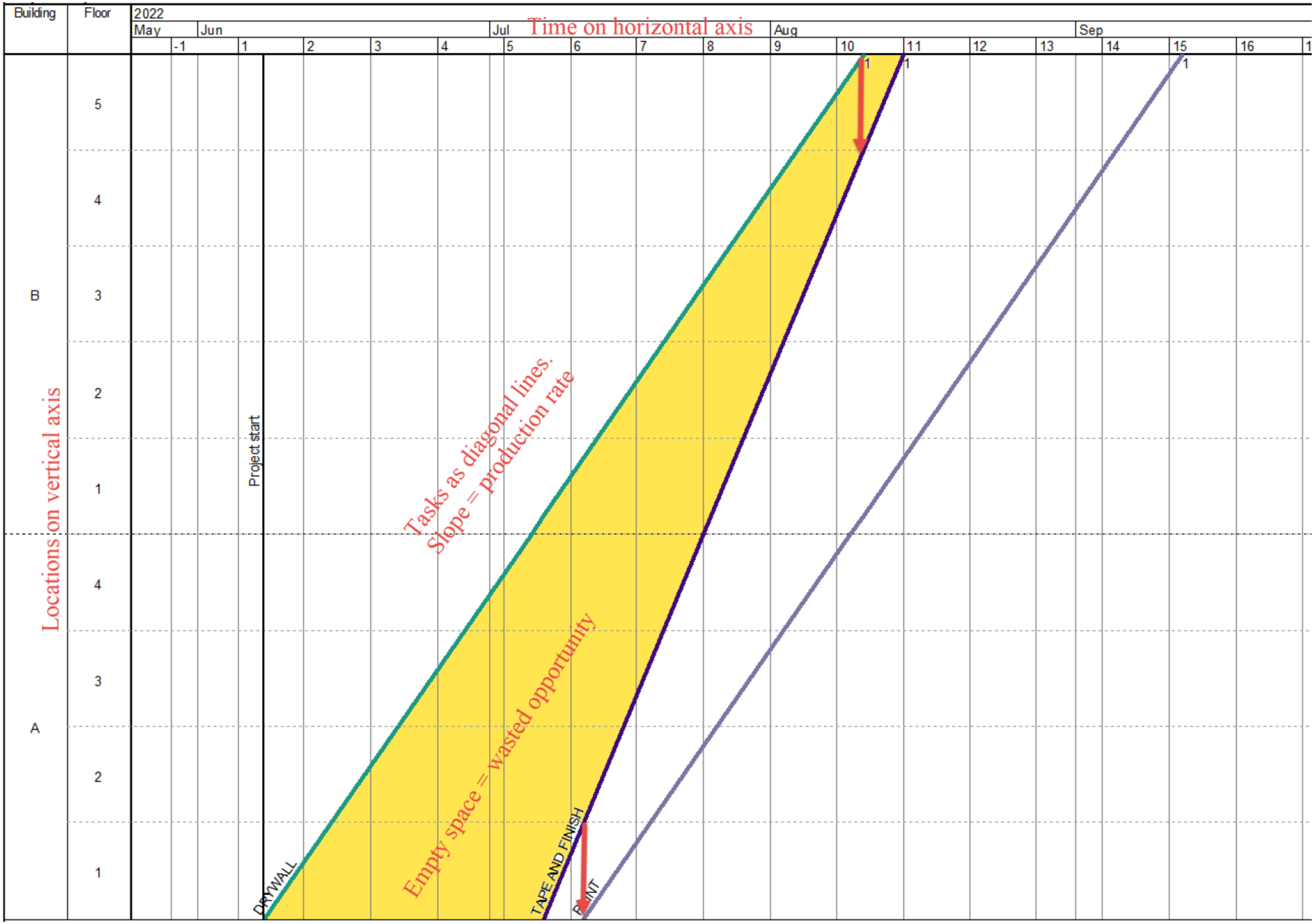
Kenley, R., & Seppänen, O. (2009, December). Location-based management of construction projects: Part of a new typology for project scheduling methodologies. In *Proceedings of the 2009 Winter Simulation Conference (WSC)* (pp. 2563-2570). IEEE.

LBMS planning process

How LBMS was developed?

- **Flowline was used in Finland since 1980s (professors Kiiras and Kankainen) and internationally in many locations**
- **However, software packages were still using CPM engine (e.g. Planet)**
- **A new software package was commissioned by Skanska, Hartela, NCC and SRV for planning**
  - Included LBMS algorithm
  - First versions in 2003, still widely used in 2022
  - Currently owned by Trimble and used as one option in planning assignment
- **Academic research followed, especially in IGLC conferences**
- **My Doctoral thesis developed the forecast (Seppänen 2009)**
  - Kenley & Seppänen 2010 was written as the textbook

Flowline visualization



Location-breakdown structure is key

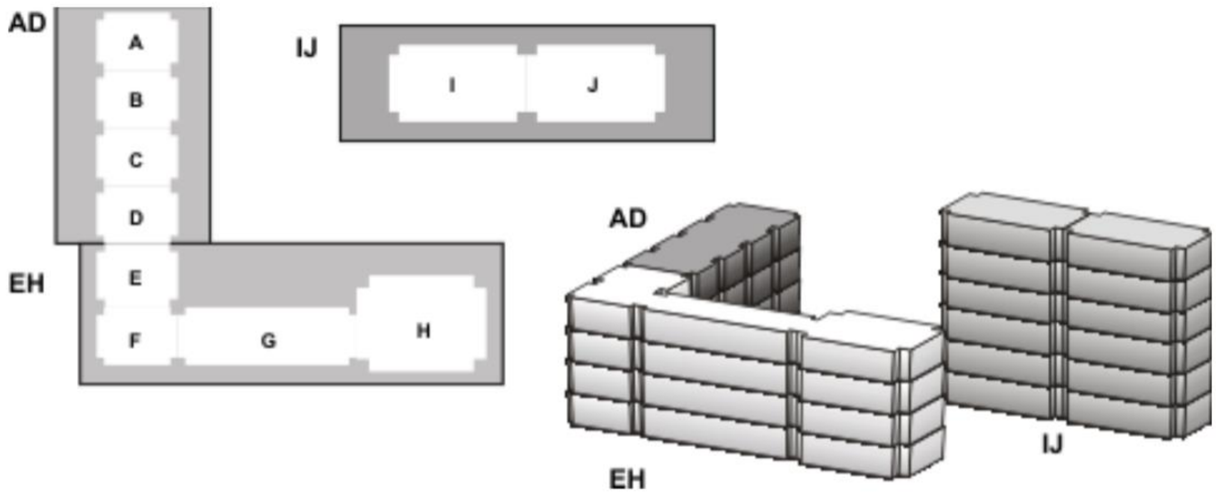


Figure 5: Typical project layout for preparing a LBS (Kenley and Seppänen, 2010)

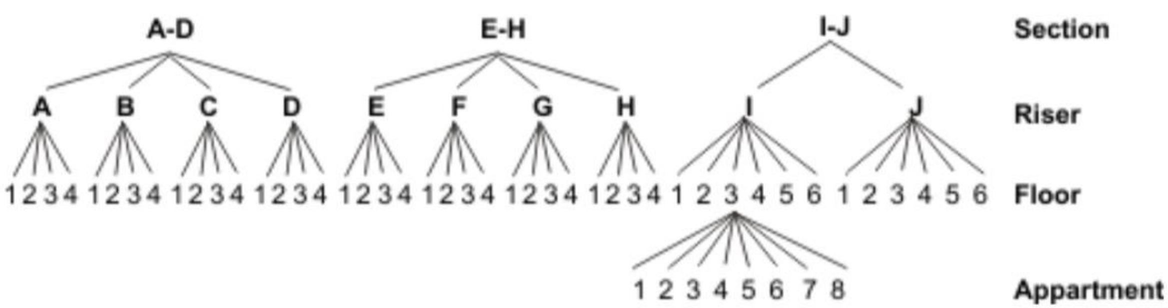


Figure 6: LBS for above typical project (Kenley and Seppänen 2010)

Some LBS guidelines (LBMS)

- **Locations must be physical and clearly defined**

- **Top level locations**
  - Structurally independent sections (building / part of building) that can be completed as one entity
  - Separate buildings or separated by module lines / joints

- **Lowest level locations**
  - Small areas where only one **space-critical** task happens at the same time

Location-based quantities

Same crew frames and installs

Item	mh/unit	Cost type	A 1	A 2	A 3	A 4	B 1	B 2	B 3	B 4	B 5	Unit
Frame drywall	0,12		200	200	200	200	300	400	400	400	400	M2
Board on one side	0,3		200	200	200	200	300	400	400	400	400	M2
	Total manhours		**84**	**84**	**84**	**84**	**126**	**168**	**168**	**168**		

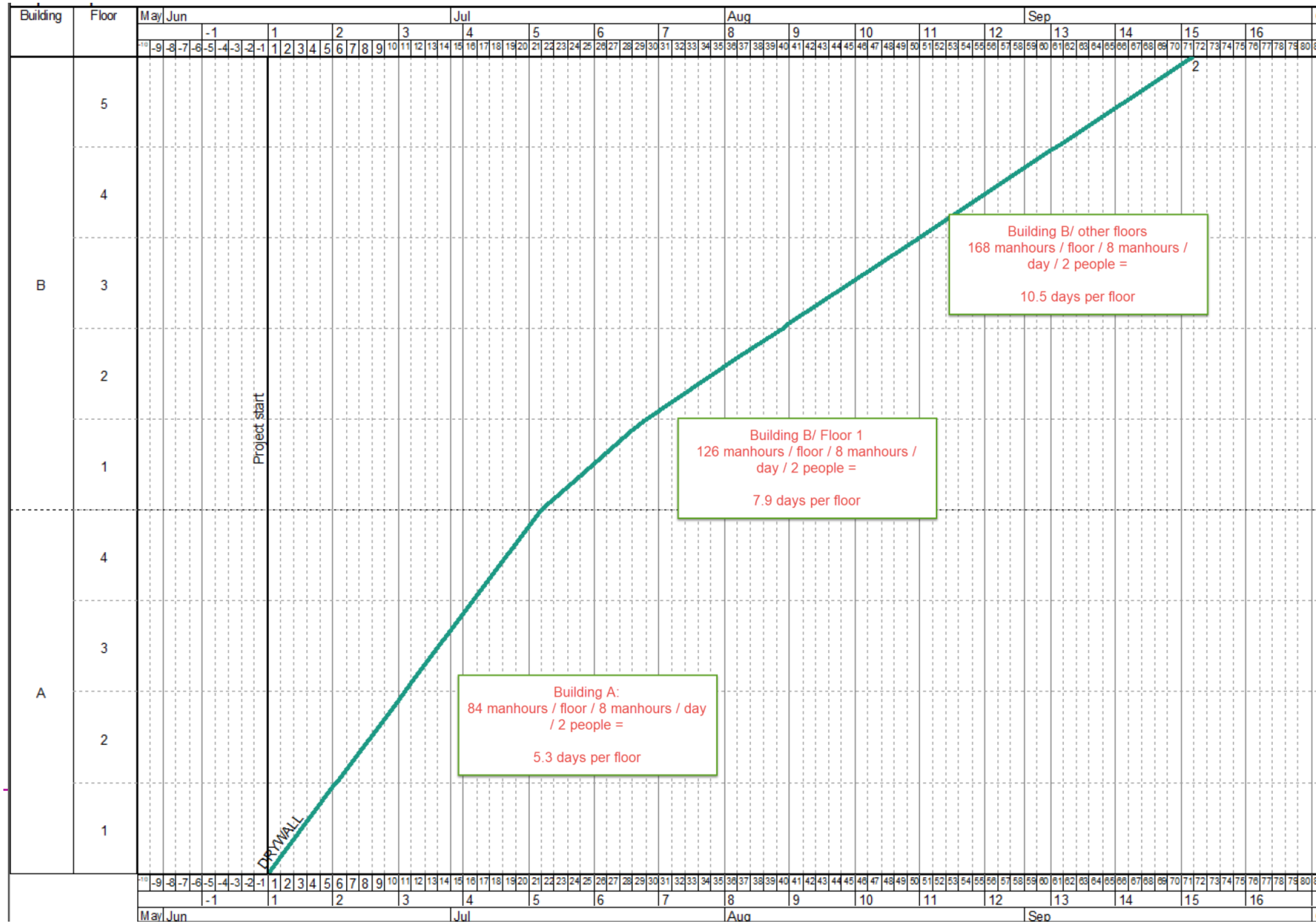
=200*0,12+200*0,3

Durations in Building B are larger due to larger quantities

- **Tasks should have scope that can be shown as quantity line items**
  - Quantities should be estimated by location, based on the LBS
  - Each line item has a labor consumption which is used to calculate manhours per location

- **Only combine scope if it:**
  - Can be done at the same time in one location
  - Has the same logic outside the task
  - Can be completely finished in one location before moving to the next location

LBMS: from quantities to duration



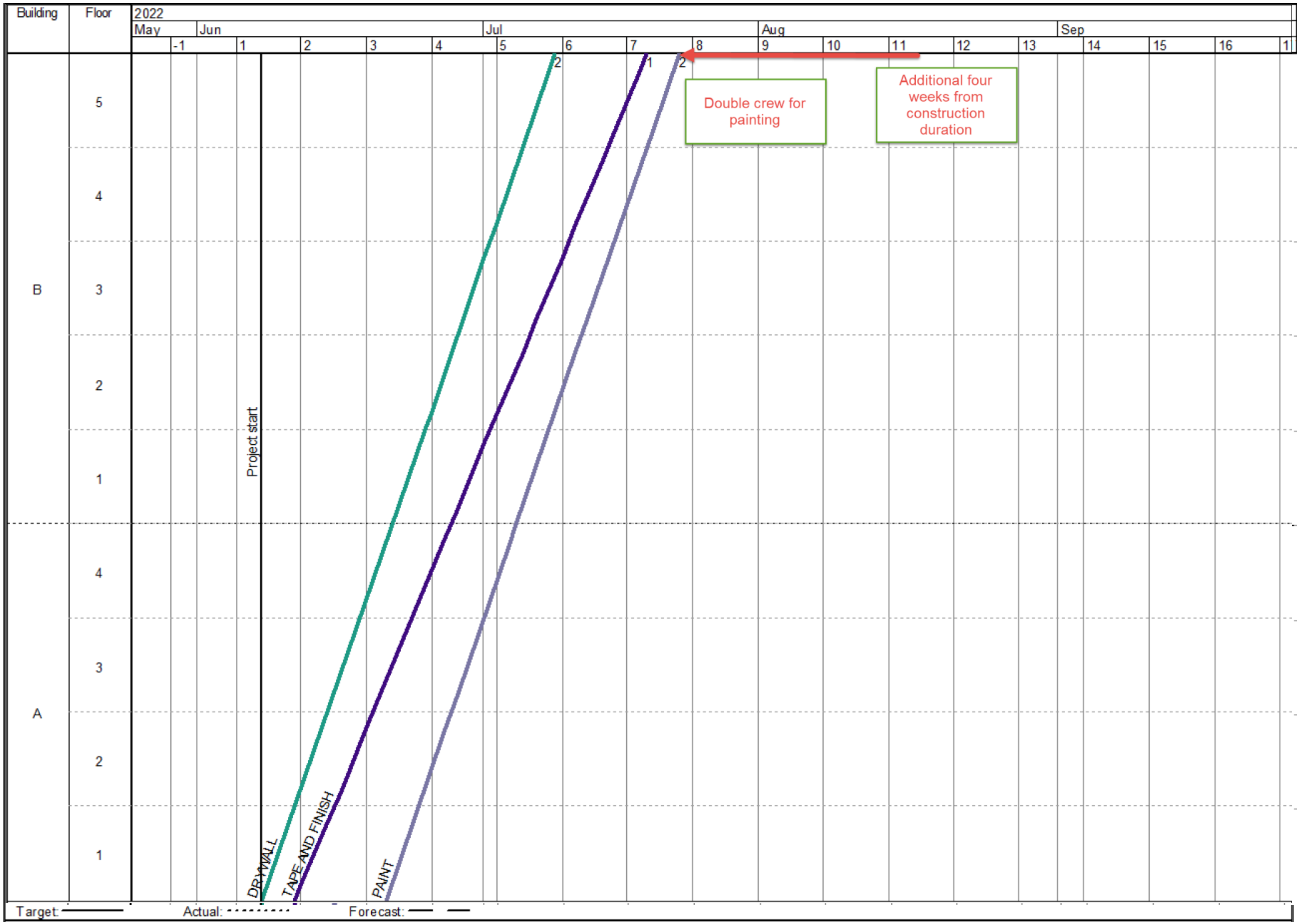
Notes about consumption rates

- **All consumption rates are based on historical averages**
- **There is no "right" consumption rate until the performance is measured on site**
- **Consumption rate depends on factors which are often unknown during planning:**
  - Skill level of installers
  - Success of logistics operations
  - Constructability of design
  - Other challenges of work
- **Consumption rate sets a reasonable target – it is not exact science!**
  - Not creating a schedule because consumption rate is unknown is an excuse!

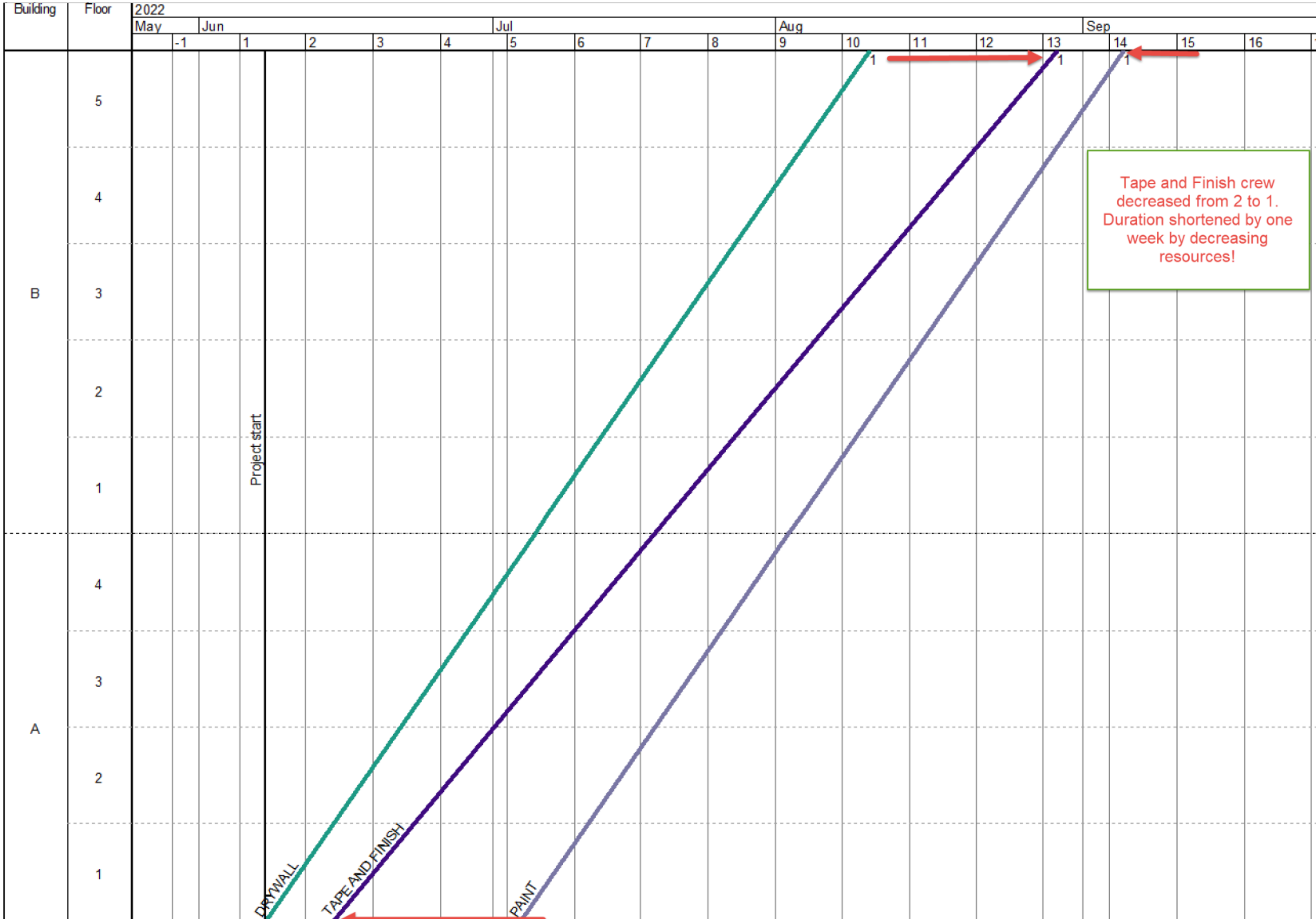
LBMS schedule optimization

- **Key goal: parallel flowlines, remove wasted time**
- **Optimization actions**
  - Changing manpower
  - Moving work steps from a task to another task
  - Selecting whether tasks should be continuous or discontinuous
  - Splitting tasks to multiple crews

Optimization example



LBMS planning paradox



Takt planning process

How takt was developed?

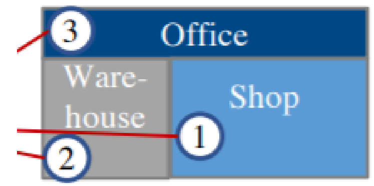
- **First implementations in manufacturing**
- **Porsche Consulting brought to construction and other industries**
- **Research activities first in UC Berkeley, Karlsruhe Institute of Technology, since 2018 Aalto University**
- **Conference papers 2013-, journal papers 2020-**

- **Strong industry implementation in Germany, California, Norway, Finland and other areas**
- **Building 2030 consortium of Aalto and 21 Finnish companies has been advancing research in Finland**
  - Over 200 projects per year in Finland

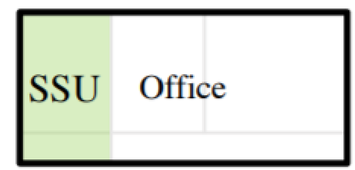
Takt areas

- **More emphasis on making small and equal size takt areas than in LBMS**

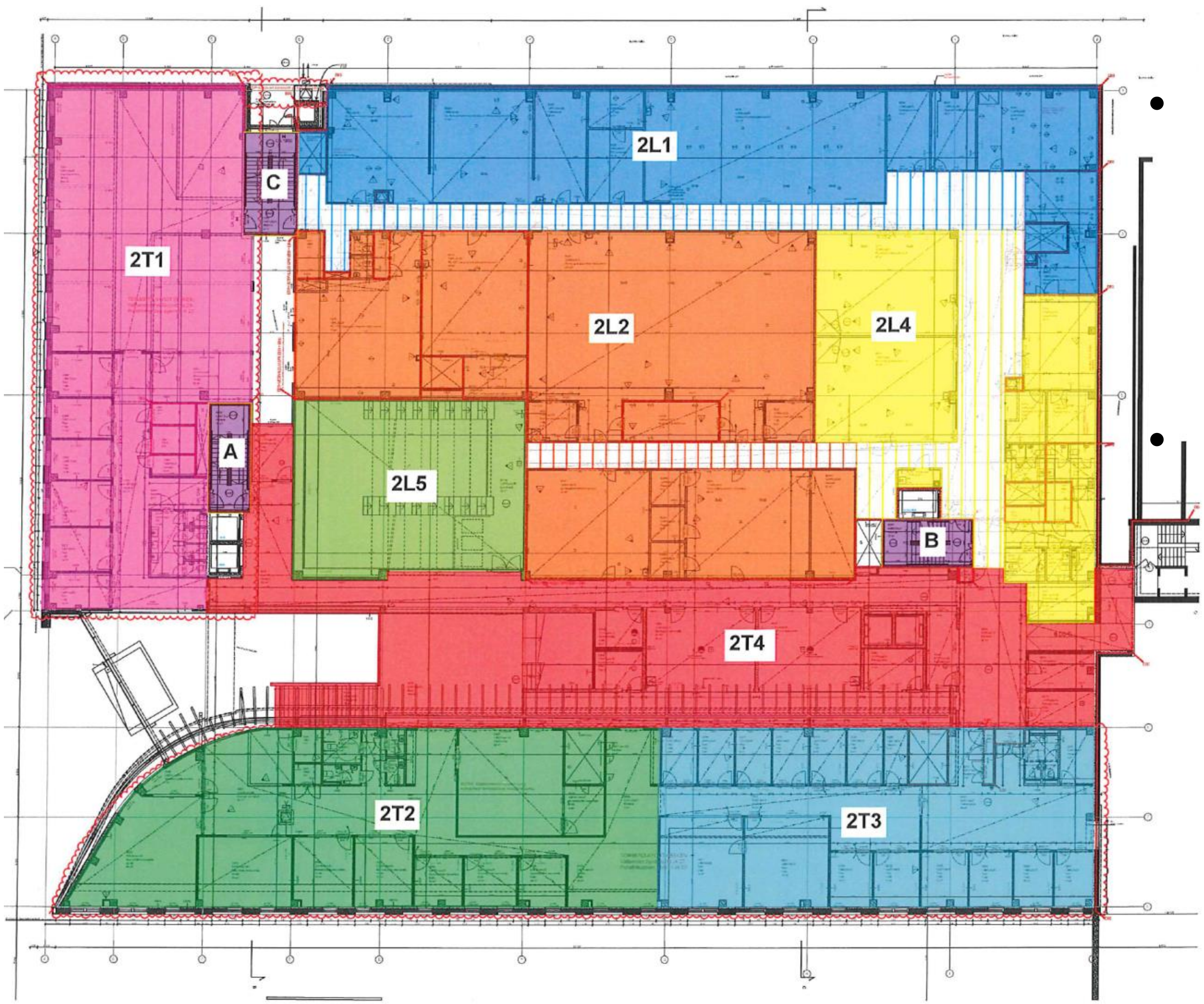
- **Different functional areas often are handled separately**



- **Takt areas are defined separately for each function / construction phase**



Example takt areas (real project)



- **Lab functions (areas with L) separated from office function (areas with T)**
- **Staircases separated**

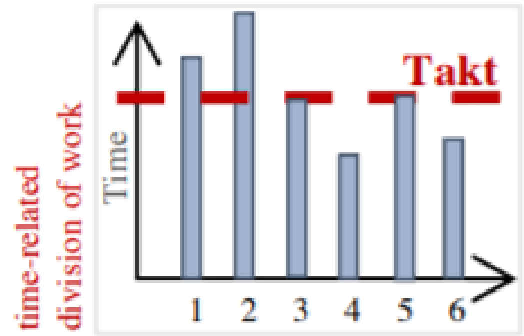
Wagons defined for each takt area

- **Wagons are analogous to LBMS tasks**

- **Amount of work calculated for each wagon in each area**

Takt duration calculation is different

- **Each phase has one takt time when all wagons move from one location to the next**
- **Takt time is selected so that all processes fit the takt time**
- **In LBMS, manhours in locations and crew size determine the duration of work in a location**
- **In takt, manhours in locations are used to arrive at the same takt time for all wagons**
  - Typically longer than is needed for the slowest task
- **Similar methods are used to get wagons below takt time**
  - More resources
  - Moving work steps from one wagon to another



Simplified durations allow easy formula-based optimization

Takt dimensions can be related through a formula (Nezval et al. 1960, Binninger et al. 2018)

$$(\textbf{Number of takt areas} + \textbf{Number of wagons} - 1) * \textbf{takt time} = \textbf{Lead time}$$

Smaller takt and more takt areas

+ Reduce lead time
+ Enables better control and transparency as the trades has to work closer together

- More things to control
- Becomes chaotic if external variance is high

Takt optimization – example of cycle times

$$(\textbf{Number of takt areas} + \textbf{Number of wagons} - 1) * \textbf{takt time} = \textbf{Lead time}$$

Normal 5day schedule: (5 + 10 -1)* 5 days = **14 weeks**

2 day takt: (12,5 + 10 -1)* 2 days = **8,6 weeks (-39%)**

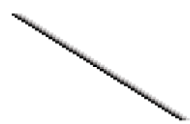
(takt time reduced by 60%)

1 day takt: (25 + 10 -1)* 1 day = **6,8 weeks (-51%)**

(takt time reduced by 50%)

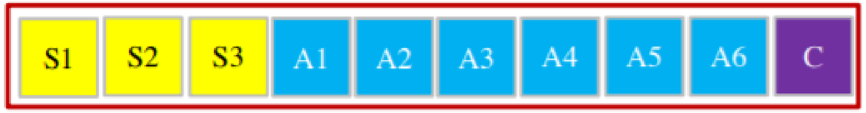
4hr takt: (50 + 10 -1)* 4 hours = **5,9 weeks (-58%)**

(takt time reduced by 50%)

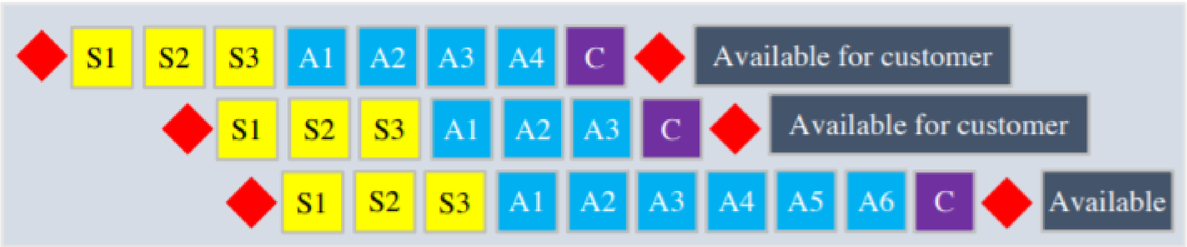


Takt – finalizing the schedule

- **Optimization done already when deciding takt areas, takt time and leveling**
- **Final steps easy:**
- Repeat the same process for all functional areas



- Finish the schedule by adding areas outside of takt, define backlog areas
- Fit the schedule to meet the fundamental flow and milestones (e.g. by iterating takt time and location size)



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Video 2

Production system cost

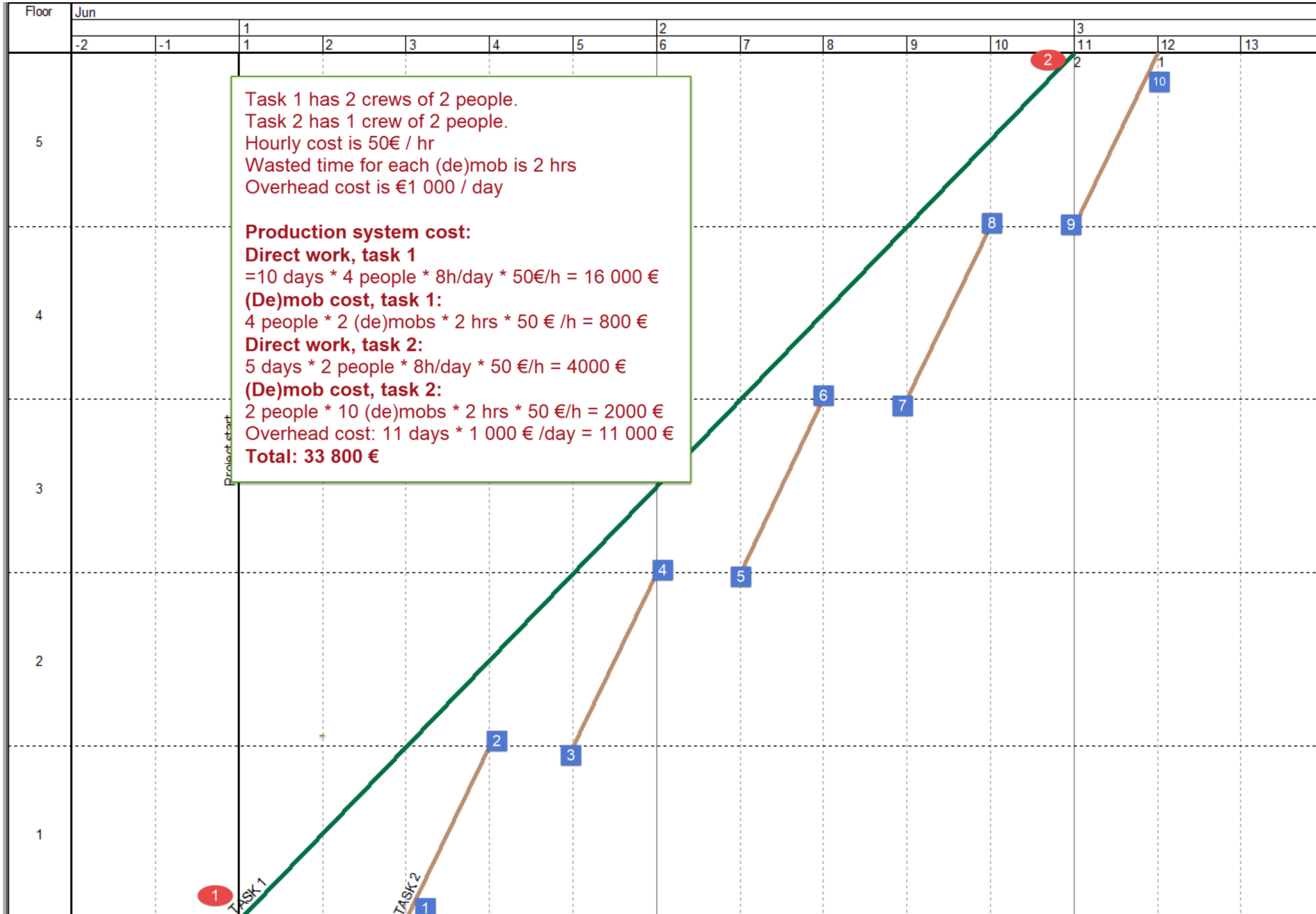
Production system costs are functions of the schedule

- Direct labor costs
- Estimates of wasted costs:
  - *Mobilization / Demobilization*
  - *Waiting*
  - *Moving around*
  - *Logistics*
- Overhead costs (costs for each day of the project)

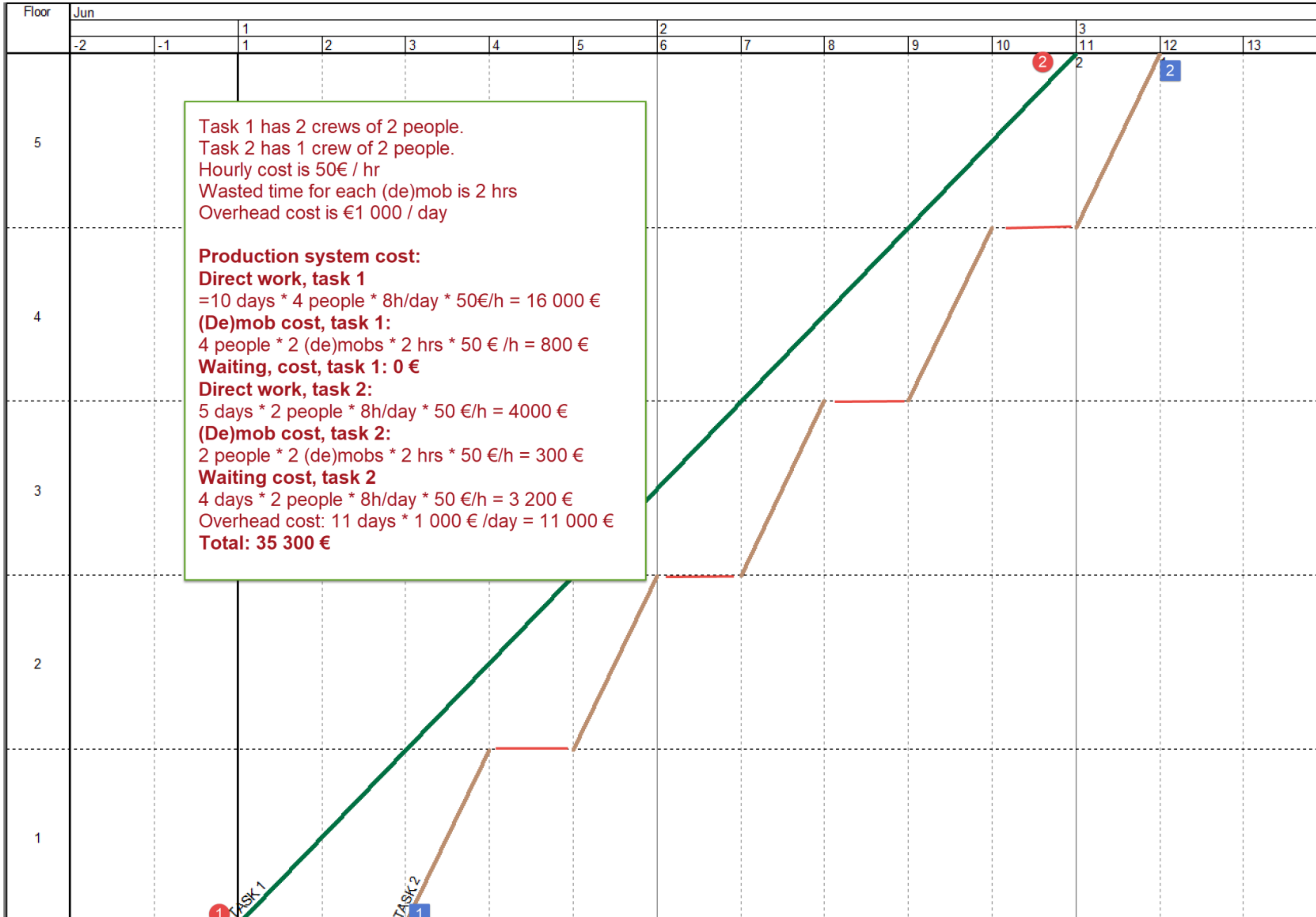
Production system cost is a measure of operations flow – emphasized in LBMS

- **Better schedule – lower production system cost**

Production system cost example – demobilization



Production system cost - waiting



Task 1 has 2 crews of 2 people.
Task 2 has 1 crew of 2 people.
Hourly cost is 50€ / hr
Wasted time for each (de)mob is 2 hrs
Overhead cost is €1 000 / day

Production system cost:
Direct work, task 1
=10 days * 4 people * 8h/day * 50€/h = 16 000 €
(De)mob cost, task 1:
4 people * 2 (de)mobs * 2 hrs * 50 € /h = 800 €
Waiting, cost, task 1: 0 €
Direct work, task 2:
5 days * 2 people * 8h/day * 50 €/h = 4000 €
(De)mob cost, task 2:
2 people * 2 (de)mobs * 2 hrs * 50 €/h = 300 €
Waiting cost, task 2
4 days * 2 people * 8h/day * 50 €/h = 3 200 €
Overhead cost: 11 days * 1 000 € /day = 11 000 €
Total: 35 300 €

Production system cost - conclusions

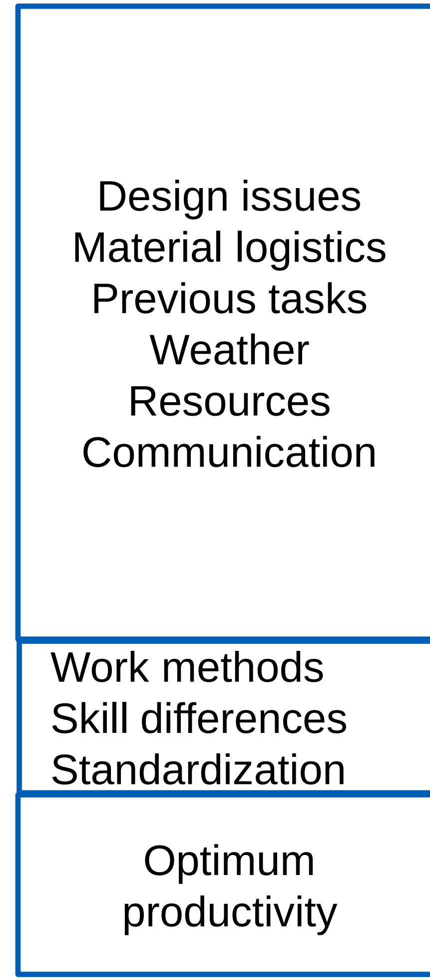
- **Smaller crews have smaller costs from starts and stops**
- **Starts and stops for large crews are EXPENSIVE**
  - If starts and stops are unavoidable, focus them on small crews!

- **Waiting is generally speaking more expensive than (de)mob**
  - However, decreases production system risk because the workers are available when needed

- **To minimize production system cost, focus on continuous operations flow!**

Production system risk

- **Construction has high variability**
  - Most of the variability is coming from external issues (60%)
  - Worker skills / work methods explain a small amount of variability (40%)
- **Variability can be analyzed with risk analysis. LBMS divides variability to:**
  - Variability in start dates
  - Variability in durations
  - Variability in productivity
  - Variability in resource availability
  - Variability caused by return delays



Variability in start dates

- **Do we have everything that is needed to start a task?**
  - Procurement done
  - Contract agreed
  - Design available
  - Materials available
  - Tools available
  - Suitable weather / conditions

- **Depending on project and task, start dates can vary from plans**

Variability in durations

- **Do different locations have different problems?**
  - Changing / unique design solutions or details
  - Logistic challenges
  - Different types of installations
  - Detailed design not available

- **This variability type does not include those problems that will repeat in all locations (e.g. skill levels)**

- **Often first location is slower due to learning effects**

Variability in productivity

- **Can we accurately predict the consumption rate?**
  - Do we know the workers who will do the work?
  - Do we have experience of similar work?
  - Do we know the capability of the contractor?

- **This variability type impacts all locations with similar work (= effects the slope of the flowline)**

Variability of resource availability

- **Can the supplier of resources supply all resources when needed?**
  - Depends on contractor and their overall resource availability and how many projects they have ongoing
  - Typically large crews will not be mobilized all on the first day of contract but they trickle in over a period of several weeks
    - *Contractor does not wish to mobilize large crews before potential problems have been resolved*

- **Often causes slower start than planned**

Variability caused by return delays

- **It is generally cheaper to let resources leave the site if they run out of work**
- **However, getting them back when work is again available causes variability**
  - Do they come immediately when called? (probably not)
  - How many weeks later than called?

- **Return delays often cause significant schedule impacts**

Variability always exists

- **How can variability be decreased?**
  - Better design management
  - More investments in logistics
  - Partnering with subcontractors
  - Self-performing critical work
  - Planning smaller crews

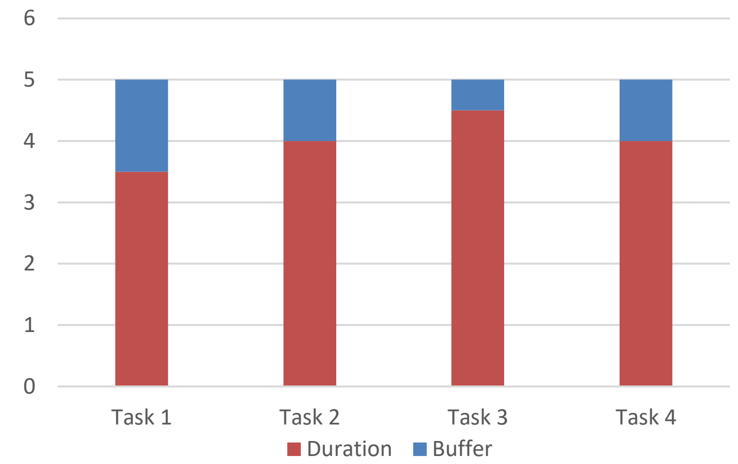
- **For remaining variability, how can the production system be protected?**
  - Accept longer duration, flexibly adjust schedules
  - Have reserve capacity (e.g. hourly workers)
  - Use buffers

Buffers to protect against risk – capacity buffer

- **CAPACITY BUFFER is one way of buffering**
  - Plan with fewer resources than are available for the project

  OR

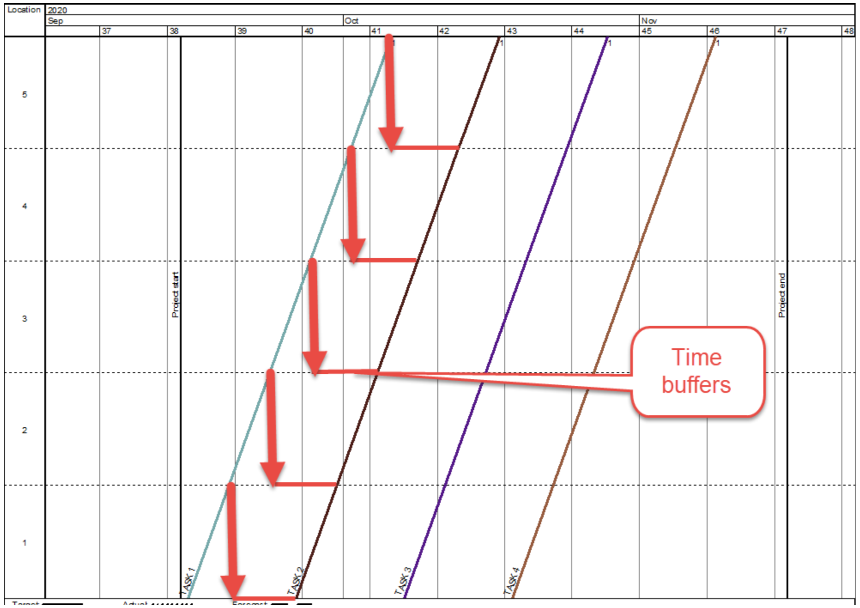
  - Plan with lower production rate (longer duration than needed)



- **Potential problem: setting goals low may result in low production (Parkinson's law)**
- **Preferred buffer in takt – takt time set longer than needed for tasks**

Time buffer

- **Leave empty space between tasks**
    - If predecessor has problems, it does not immediately impact the successor
- **Preferred method in LBMS**



Workable backlog

- **For each crew, have non-critical work available that can be done at any time**
- **If the crew runs out of work in their “main task”, they can work on the backlog without having to leave the site or wait**
- **Both LBMS and takt recommend workable backlogs**
- **Examples: parking hall work, switchboards for electricians, HVAC machine room work, staircase work, non-standard locations**

Benefits and costs of buffers

	Capacity buffer	Time buffer	Workable backlog
Benefits	Easy to use	Gives time to react and solve problems	Gives flexibility to production system
Costs	Requires fast reaction and problem solving, Parkinson's law	Increases project duration, makes everything less "urgent"	Workable backlog tasks may become critical if there is no time to do them
Method where emphasized	Takt	LBMS	Both – in addition to other buffers

Takt – paradox in production system cost

- **Although capacity buffers are used in takt, labor costs in takt projects have not increased!**

- **In theory, we would expect an increase because the workers have no work during capacity buffer – i.e. if everything goes according to plan, workers of a five day takt would leave on Thursday (20% capacity buffer)**

- **Possible explanations:**
  - Contractors are flexibly adjusting workforce
  - Parkinson's law fills the capacity buffer
  - Less waste in the process (Lecture #5)

Takt – paradox in production system risk

- **In LBMS risk simulations, it has been assumed that variability is not influenced by buffers**
  - In high variability projects, takt should not be used (Seppänen 2014)

- **However, using capacity buffers rather than time buffers seems to decrease variability**
  - Management prepares more because they do not have time to react later
  - Psychological impact on all crews and managers is large

Two location-based systems – with similarities and differences

Factor	Location-based management system / LBMS	Takt planning & control
Planning concepts	Locations, tasks, production rates	Takt areas, takt process, takt time
Buffers	Time buffers preferred	Capacity buffers preferred
Location / area size	Generally larger	As small as possible
Durations	Calculated and vary in locations depending on quantities	Takt time fixed
Emphasis	Operations flow	Process flow
Repeatability	Not required but beneficial	Very beneficial

Thank you
Questions & Comments