Aalto University
School of Engineering

Operation Management in Construction Lecture #3 Location-based production control

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Topics, today's lecture #3

- **Learning objectives of Lecture #3**
- **Progress data for controlling systems**
- **Control actions in location-based systems**
- **Assumptions of controlling LBMS vs. takt**
- **Controlling case studies**

Intended learning objectives for this lecture

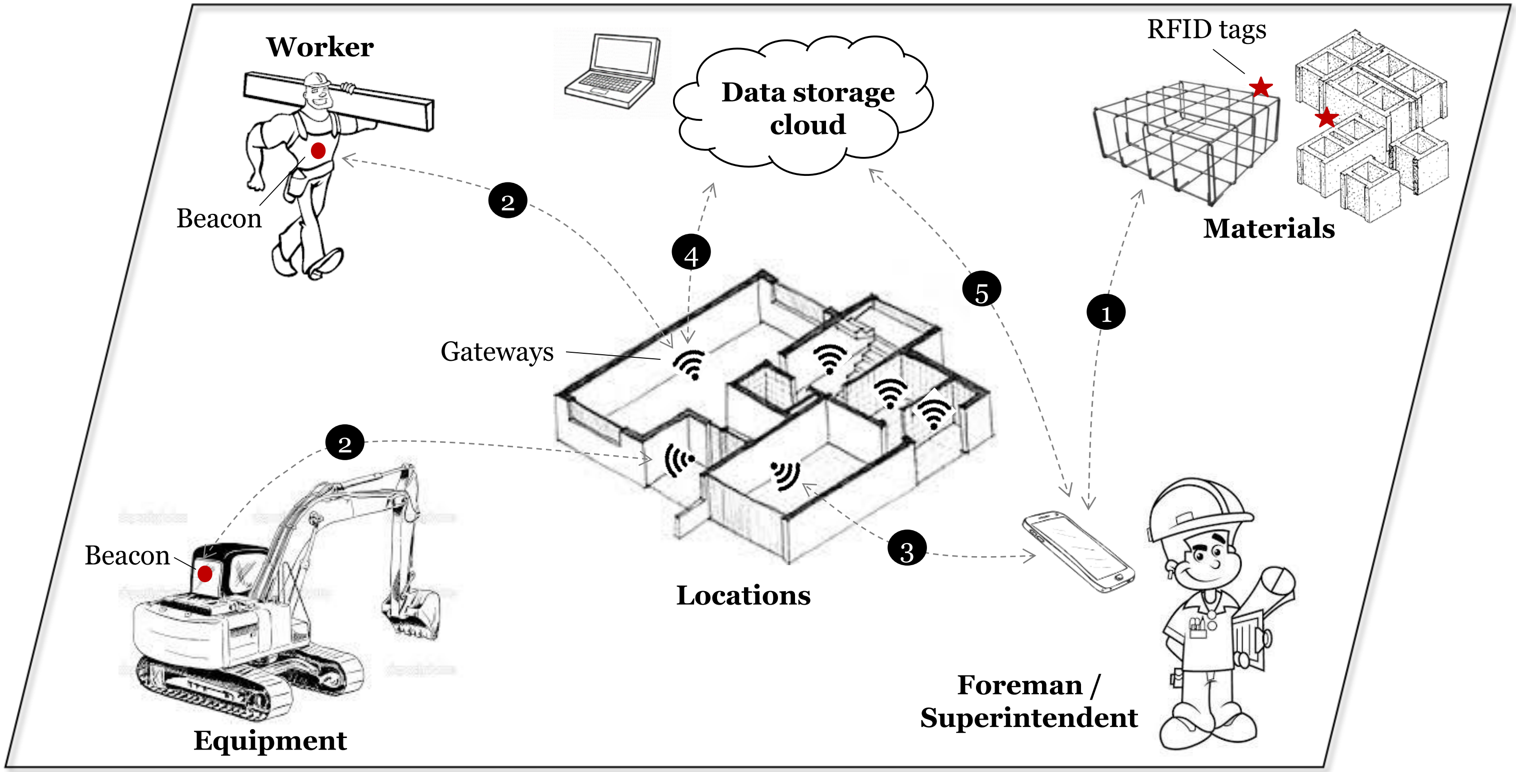
- ILO 2: **Students can compare and contrast** the similarities and differences of different production planning and control methods
  - *ILO emphasized for controlling*
- ILO 5**: Students can explain** the significance of work and labor flow and how flow can be achieved in construction
  - *ILO reinforced*
- ILO 8**: Students can** make production control decisions based on the schedule using the Location Based Management System
  - *ILO emphasized*

Progress data

- **Traditionally collected manually**
  - Often centralized: Project Engineer / Superintendent walk the site and enter status into scheduling software / app
  - Distributed approaches getting more common: Workers enter progress and problems in their own apps

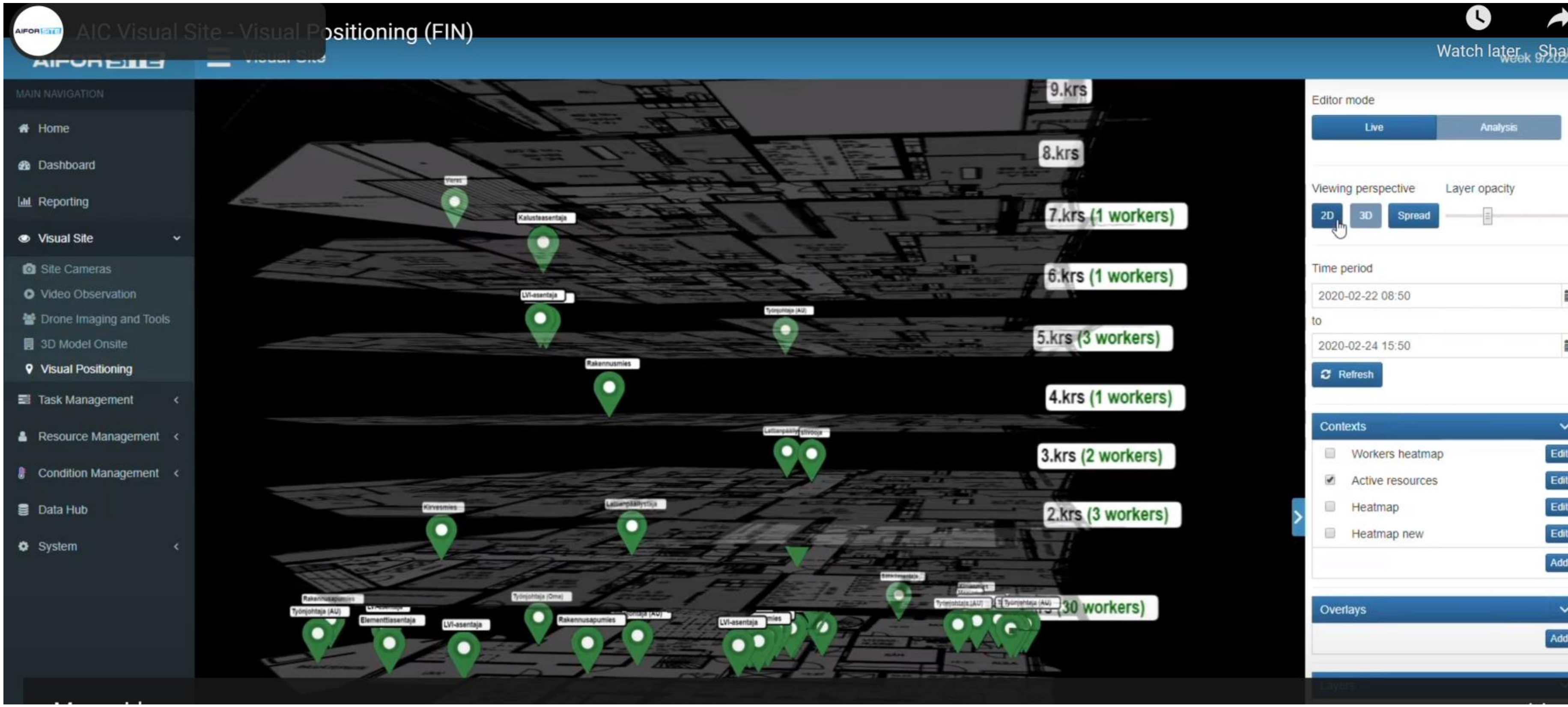
- **Automatic data collection is becoming more common**
  - Sensors / positioning systems
  - Machine vision
  - Reading tags etc.

Technology 1 – resource positioning

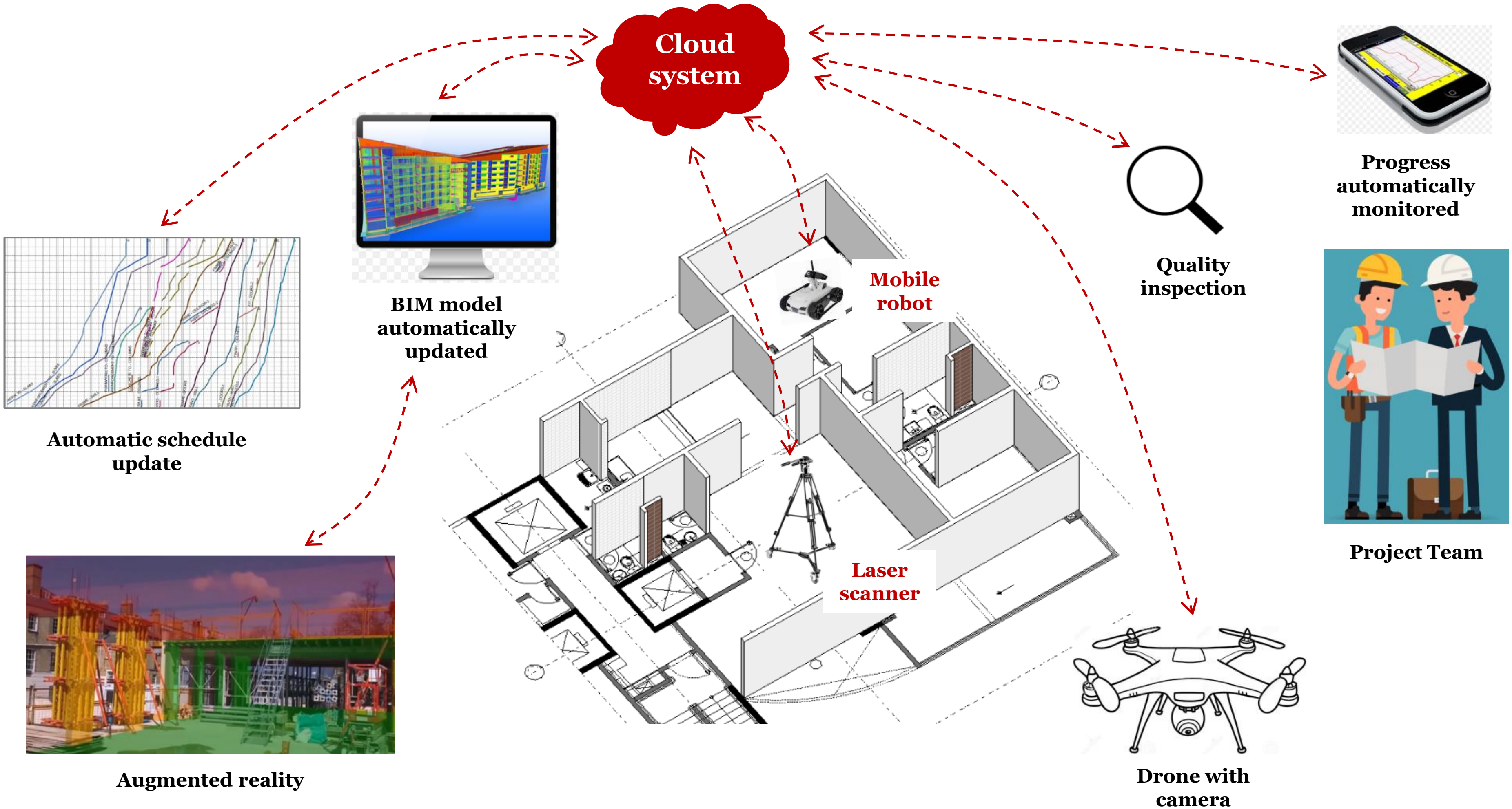


- Positioning can be used to evaluate start and finish times
- Are the workers in the correct locations?
- How much movement is there?

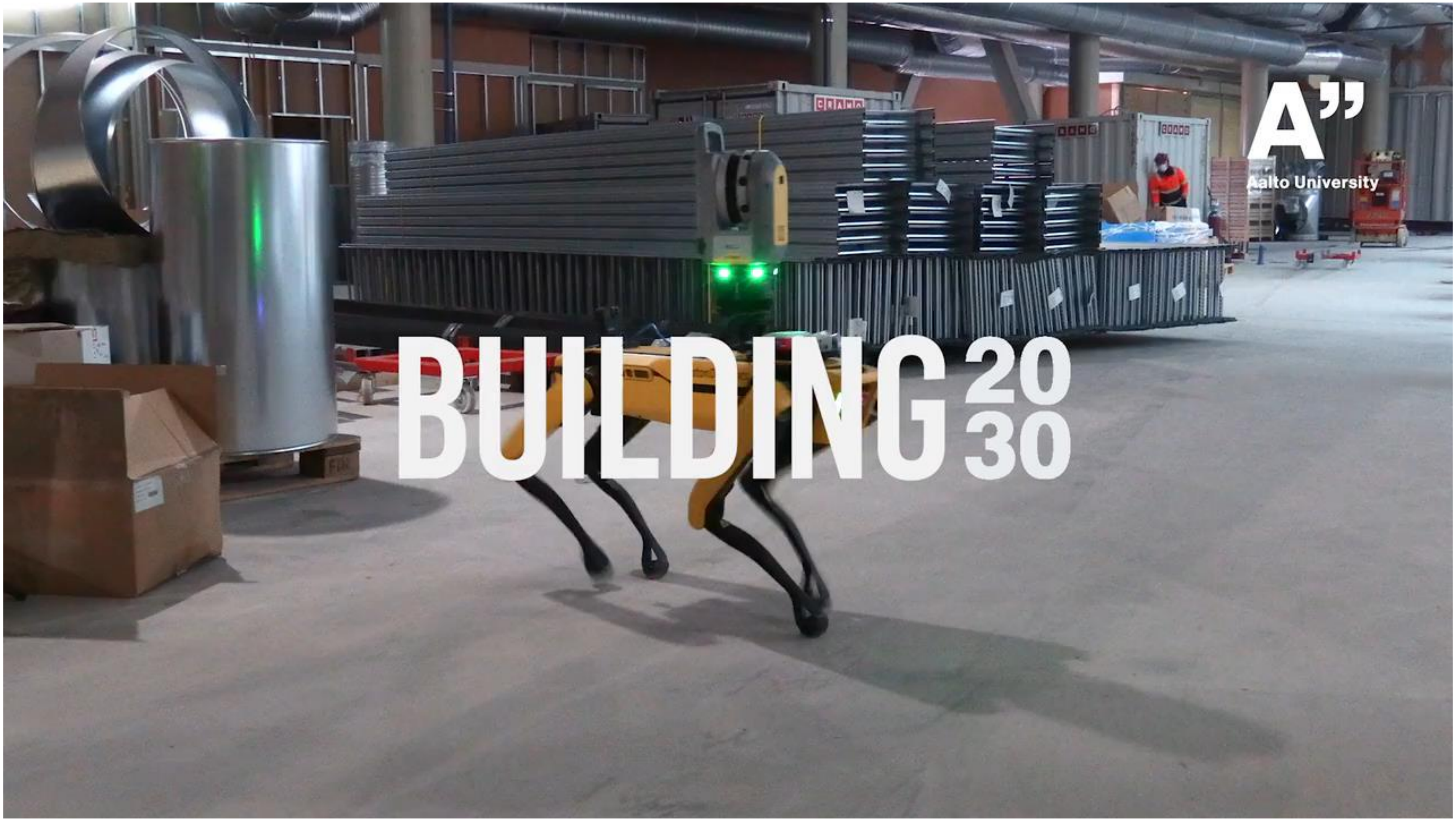
Commercial solutions for positioning becoming available



Technology 2: Reality Capture

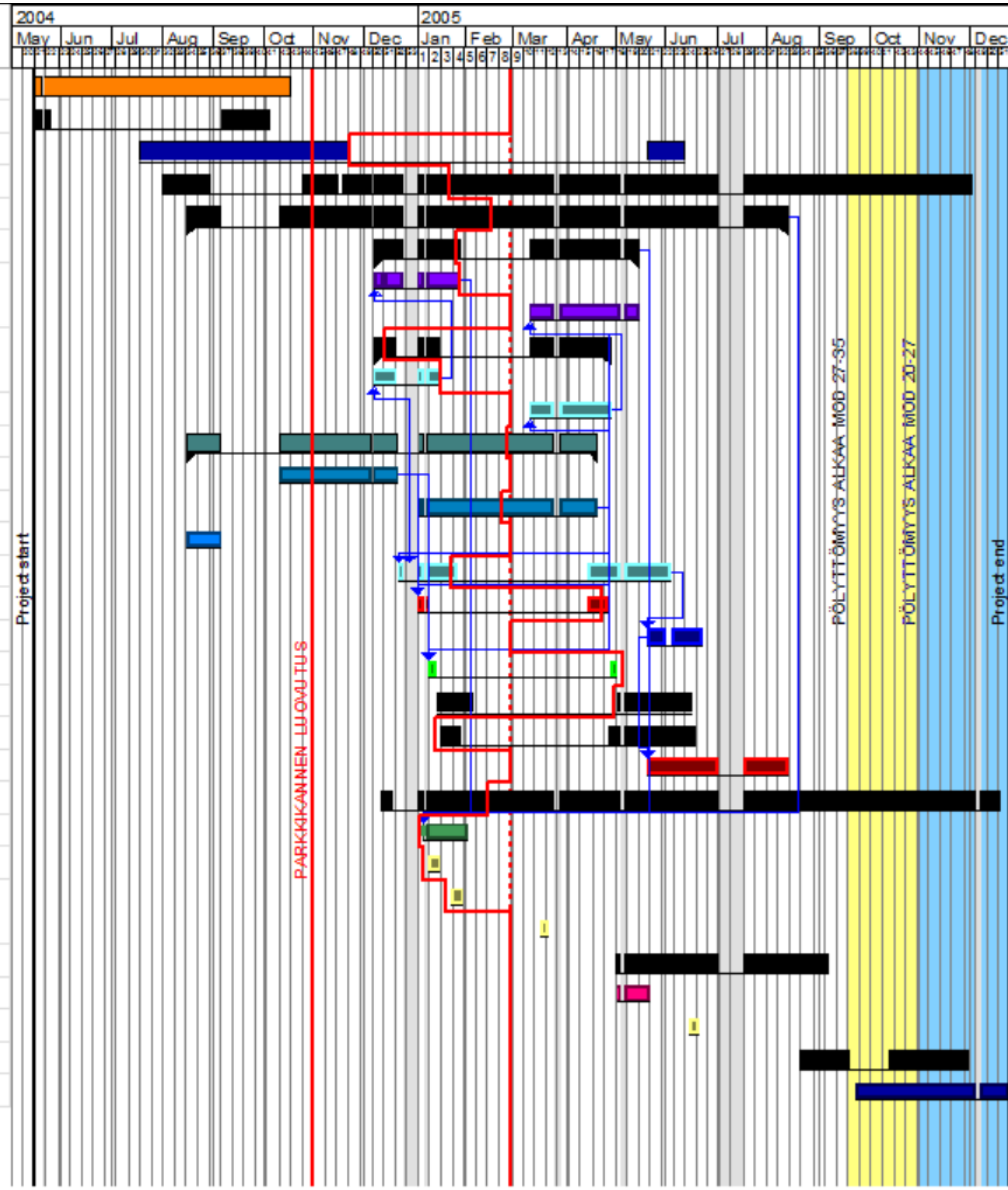


Spot robot for automatic data collection

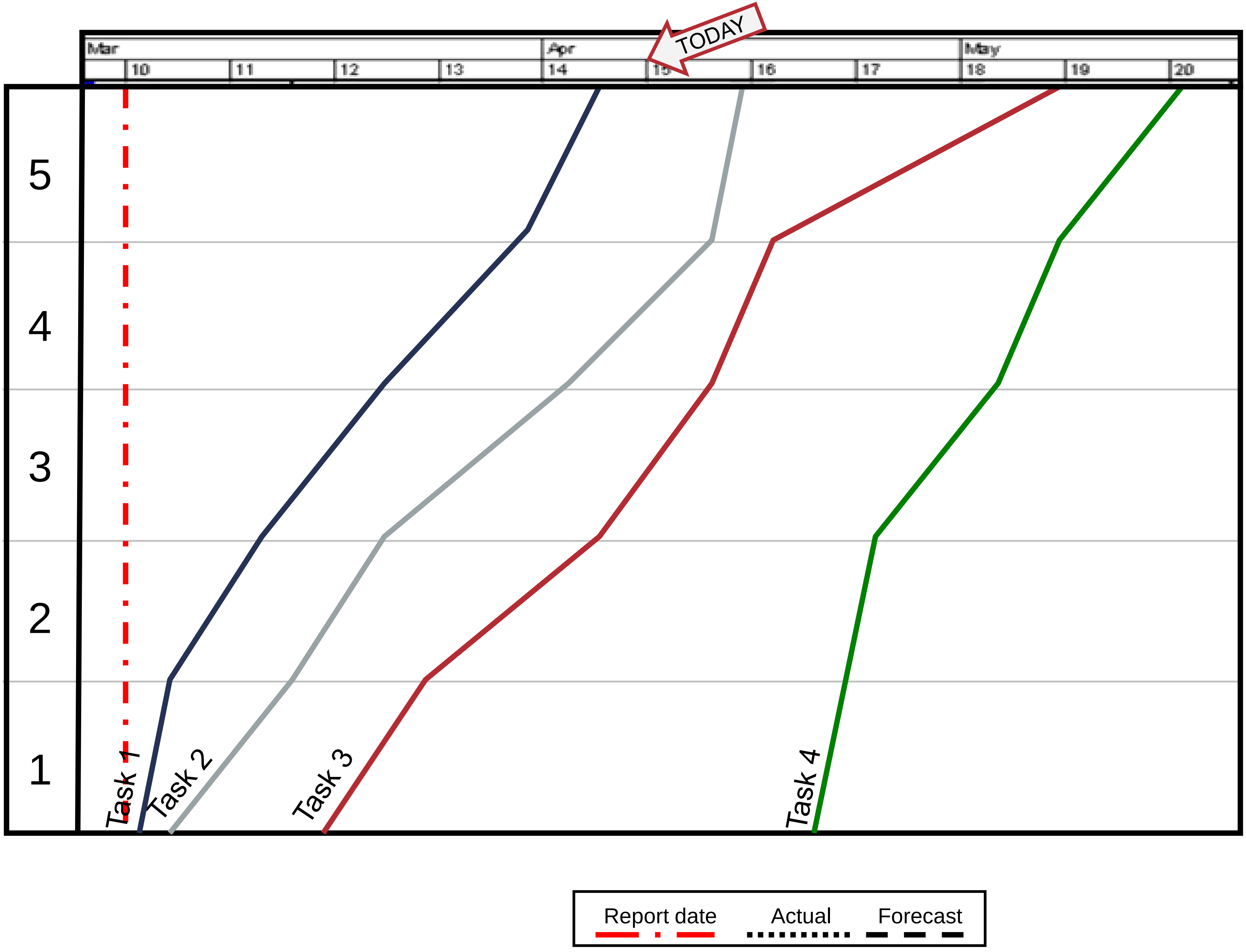


Traditional visualization of progress

Hierarchy	Code	Name
+1		**Maanrakennus**
+2		**PARKINKANSIRAKENTEET**
+3		**PERUSTUKSET JA PAIKALLAVALURAKENTEET**
+4		**TALOTEKNISET TYÖT**
-5		**RUNKO JA VAIPPA**
-5.1		Pintabetonilattiat
+5.1.1	*5610*	*PINTABETONILATTIAT1*
+5.1.2	*5610*	*PINTABETONILATTIAT2*
-5.2		Puuikkunat
+5.2.1	*4110*	*PUUIKKUNAT1*
+5.2.2	*4110*	*PUUIKKUNAT2*
-5.3		Betonielementtirunko + julkisivu
+5.3.1	*3050*	*BET.ELEMENTTIRUNKO + JULKISIVUMOD 30-27*
+5.3.2	*3050*	*BET.ELEMENTTIRUNKO + JULKISIVUMOD 27-20*
+5.3.3	*3050*	*BETONIELEMENTTIRUNKO PARKKI*
+5.4	5120	VESIKATE
+5.5	3760	VESIKATONPUUTYöT
+5.6	5014	PELTITYöT
+5.7	3030	TERäSRAKENTEET
+5.8		Paroc-elementit
+5.9		Metalli-ikkunat ja lasiseinät
+5.10		JULKISIVUNVERHOUKSET JA SäLEIKöT
+6		**SISÄVALMISTUS**
+7	**4520**	**KUILUMUURAUKSET1**
+8	**700**	***LJH / SPRINKLERKESKUSA SENNUSVALMIS**
+9	**700**	**SäHKöPääKESKUS JA MUUNTAMOA SENNUSVALMIS**
+10		**SäHKöNOUSUKOMEROT ASENNUSVALMIITMOD 27-28**
+11		**PIHANRAKENTEET**
+12		**PARKKIHALLINMAALAUS**
+13		**SäHKöNOUSUKOMEROT ASENNUSVALMIITMOD 20-27**
+14		**Vuokralaismuutokset**
+15	**7600**	**TARKASTUKSET,SÄÄDÖT JA MITTAUKSET**



Takt visualization of progress

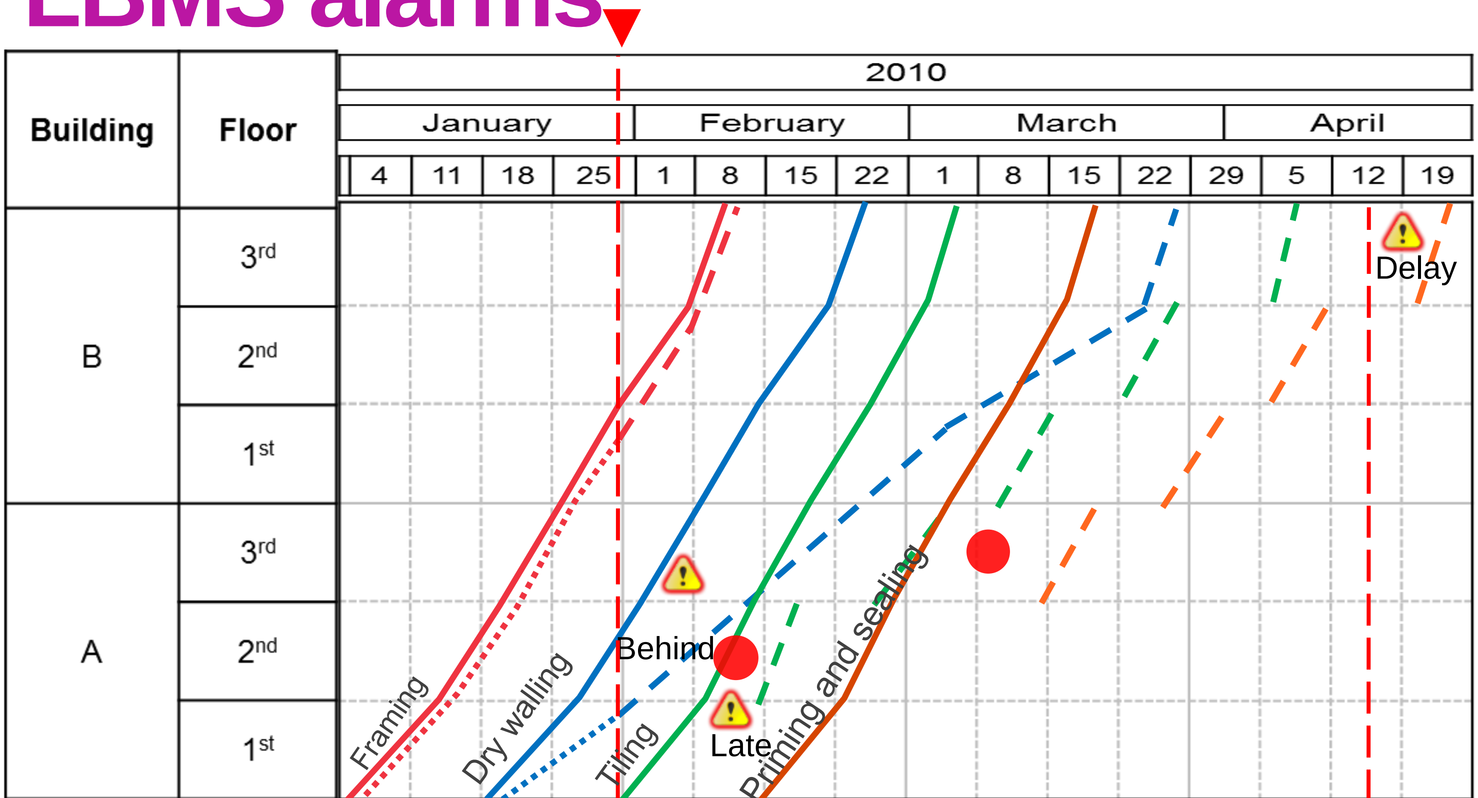


TODAY
Mar
Apr
May
10
11
12
13
14
15
16
17
18
19
20
5
4
3
2
1
Task 1
Task 2
Task 3
Task 4
Report date
Actual
Forecast

LBMS controlling calculations

- **Progress KPI's**
  - Actual production rate (units / hr)
  - Actual labor consumption (manhours / unit)
- **Progress KPI's are used to calculate the forecast**
  - How production will proceed if everything continues with the same speed?
- **Calculations are automated in e.g. Schedule Planner software**

LBMS alarms



- **Forecasts trigger alarms which are generated when predecessor forecast impacts successor forecast**
- **Management in LBMS is preventing alarms from becoming real problems - proactive**

LBMS control actions

- **Alarms are prevented by taking control actions, e.g.**
  - Improve productivity e.g. by reorganizing logistics, clarifying instructions etc.
  - Increase / decrease production rate by
    - *changing crew size (sometimes slow to increase, depends on contractor size)*
    - *work weekends / overtime (often quicker fix but costs more money)*
  - New crews are often less productive and are often not immediately available
- **Discussions with contractors are important to determine what can be done**
- **Contract penalties are never enough to compensate for delay, and contractors often have excuses**

Takt problem analysis

Lehtovaara, J., Tommelein, I., Seppänen, O. (2022)
HOW TAKT PLAN CAN FAIL? APPLYING FAILURE MODE AND EFFECT ANALYSIS INTO TAKT CONTROL

Examples of potential failures

Realized errors or defects

Wagon content	Wagon handoff	Takt train
Work is finished late	Quality defects	Excess work in progress
Work is left unfinished	Cognestion due to other workers	Excess resource fluctuation
Overburden of workers	Inadequate preconditions to start work	Accumulating delays

Examples of potential failure modes and their possible root causes

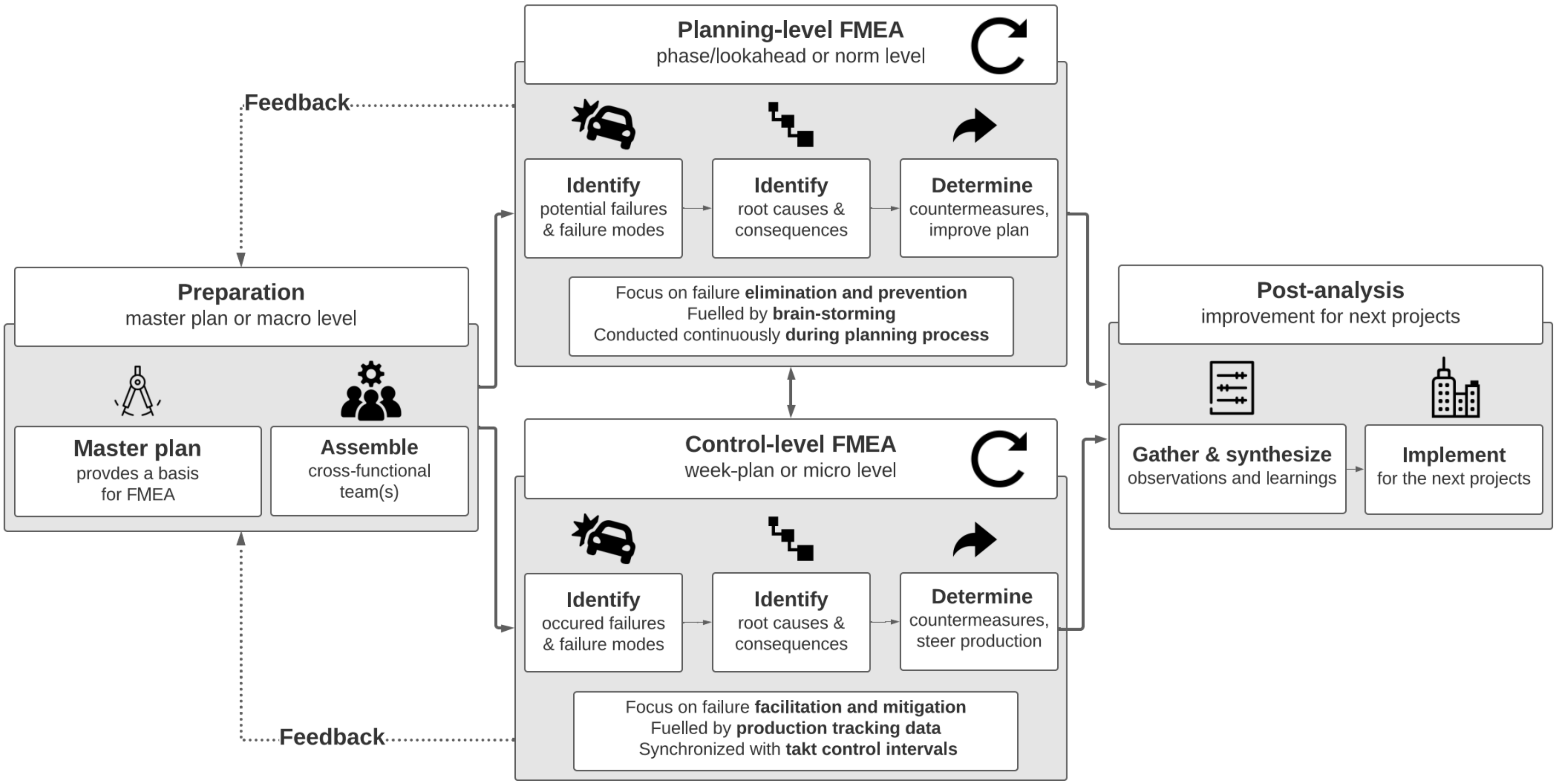
Ways of something "going wrong", causing the failure

Wagon content	Wagon handoff	Takt train
Too little or too much resources for wagon	Unoptimal takt area distribution	Wrong or unoptimal production sequence
Interrupted work or too small production rate	Too little or too much buffers between wagons	Inadequately coordinated phase transitions
Too small or too large takt time	Missing definition of needed value or quality	Largely missing design or process information
Crew unable to mobilize on time	No information of the adjacent wagons' status	Materials provided on wrong time/locations
Possible root causes:	**Possible root causes:**	**Possible root causes:**
Miscalculations in work density	Inadequate quality protocols	Large amount of cascading, small problems
Failure to supply enough resources	Missing mutual awareness of production status	No alignment between production and design/logistics schedules

Examples of potential control actions

Wagon content	Wagon handoff	Takt train
Change work content or sequence in wagons	Change takt area size or distribution	Rethink work sequence / train composition
Change production rate or resourcing	Swift tasks between wagons or swift task order	Pull-plan design and logistics schedules
Increase or decrease takt time	Split or combine wagons	Decouple logistics from wagon management
Ensure committment by more intense involvement of site crews to planning	Communicate progress through continuous production tracking and daily status updates	Stop train until cascading problems are solved

Proposed failure mode and effect analysis for takt



Takt Control actions

#	Name	Pl	C	Ca	Description	Effect
1	Decoupling of Takt areas	X	X	A	Reorganising the sequence for completing Takt areas	Change in the order areas are completed
2	Empty waggon	X	X	A	Planning of buffer times (slack); for example drying-out periods	Visualisation of required buffer; lengthening of the construction time
3	Phase interlinking	X		A	Different process phases require different sizes for Takt areas. Adjustment for these differences results in efficiencies.	Optimisation of the construction process
4	Soft start	X		A	Delaying following trains, if more than one train is used. This allows learning from the starting train.	Lengthening of the construction time, stabilisation of site processes
5	Train stoppage		X	A	Stopping the construction process due to a problem	Longer duration of construction
6	Combining handover times	X	X	B	Arranging the handover by combining Takt areas to lager areas.	Bundling of Takt areas for handover
7	Coupling into and onto	X	X	B	Adding or Removing waggons to change the process sequence.	Lengthening of the construction time
8	Jumpers	X	X	B	Using flexible labor to deal with peaks in required work	Harmonisation of the work process
9	Split of train order	X	X	B	Splitting the construction sequence, because conditions demand for extended process durations.	Lengthening of the construction time
10	Takt time reduction	X	X	B	Reducing the Takt time	Harmonisation of the process sequence; shortening of the throughput time
11	Takt time increase	X	X	B	Extending the Takt time	Harmonisation of the process sequence; lengthening of the throughput time
12	Train split	X	X	B	Paralleling multiple trains with similar sequences to pass the construction site.	Shortening of the construction time

Binninger et al. 2017: Adjustment mechanisms for demand-oriented optimization of takt planning and takt control

- **Takt has a lot of options for controlling too!**
- **Trigger is often missing a takt**

Control actions – LBMS vs. takt

	LBMS	Takt
Trigger	Calculated alarms	Missed takts / going to miss a takt
Calculations	How to restore forecast: • Productivity improvement • Additional resources (of same productivity) • Longer days / cancelled holidays	Social process / calculations not defined yet.
Typical control actions	Increase / decrease crew size, delay start times, longer / shorter days	Root cause analysis, use of buffer wagons, stopping of train

End of video 1

Key assumptions of LBMS controlling

1. **Production problems are dangerous – they cause productivity loss, return delays, slowdowns, confusion**

   → Focus management efforts on preventing problems by reacting to alarms

2. **Reacting to alarms takes time**

3. **Resources leave when they have no work – concept of return delay**

4. **Separating the crews with time buffers is mandatory**

5. **Proactive control – prevent collisions**

Control actions prevent cascading delays (Seppänen 2009)

Project type	M2	Start-up delays	Discontinuities	Slowdowns	Total effect of cascading delays / total duration (months)
Retail	6,800	34	36	54	1.5 / 8.5
Retail	10,638	8	20	94	1 / 12
Office	14,528	96	129	132	1.5 / 15

- Cascading delays cause 10+ % increase of project duration
- Productivity loss of 30+ %

•Only 12% of problems discussed in site meetings!

Cascading delays

- **Collisions between tasks cascade and get worse from one tasks to the next**

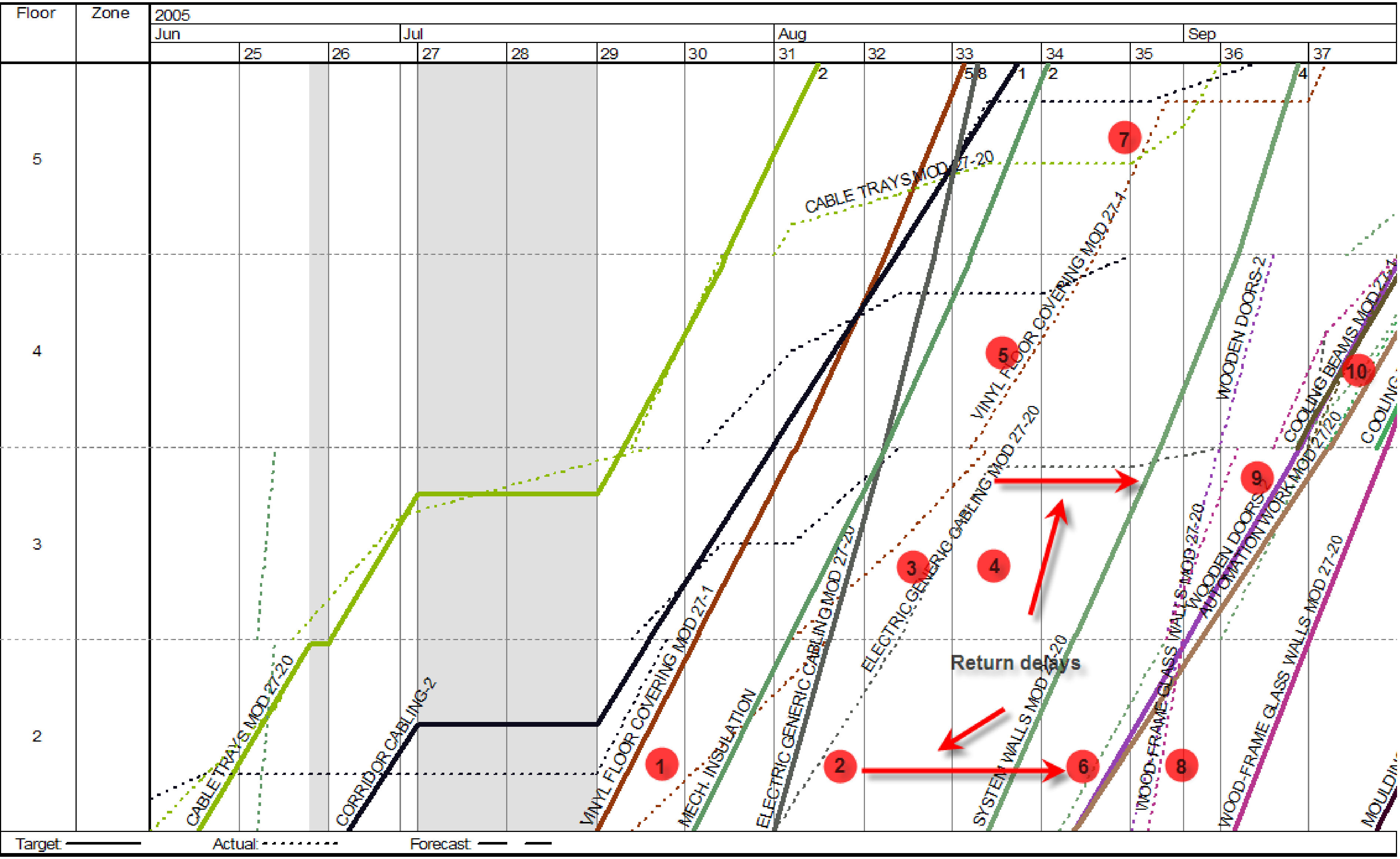
- **Especially interior construction phase has cascading delays**

- **Cascading delays lead to end-of-project rush**
  - Projects still finish on time but at large cost and poor quality
  - Profitability of projects is sacrificed during the rush months

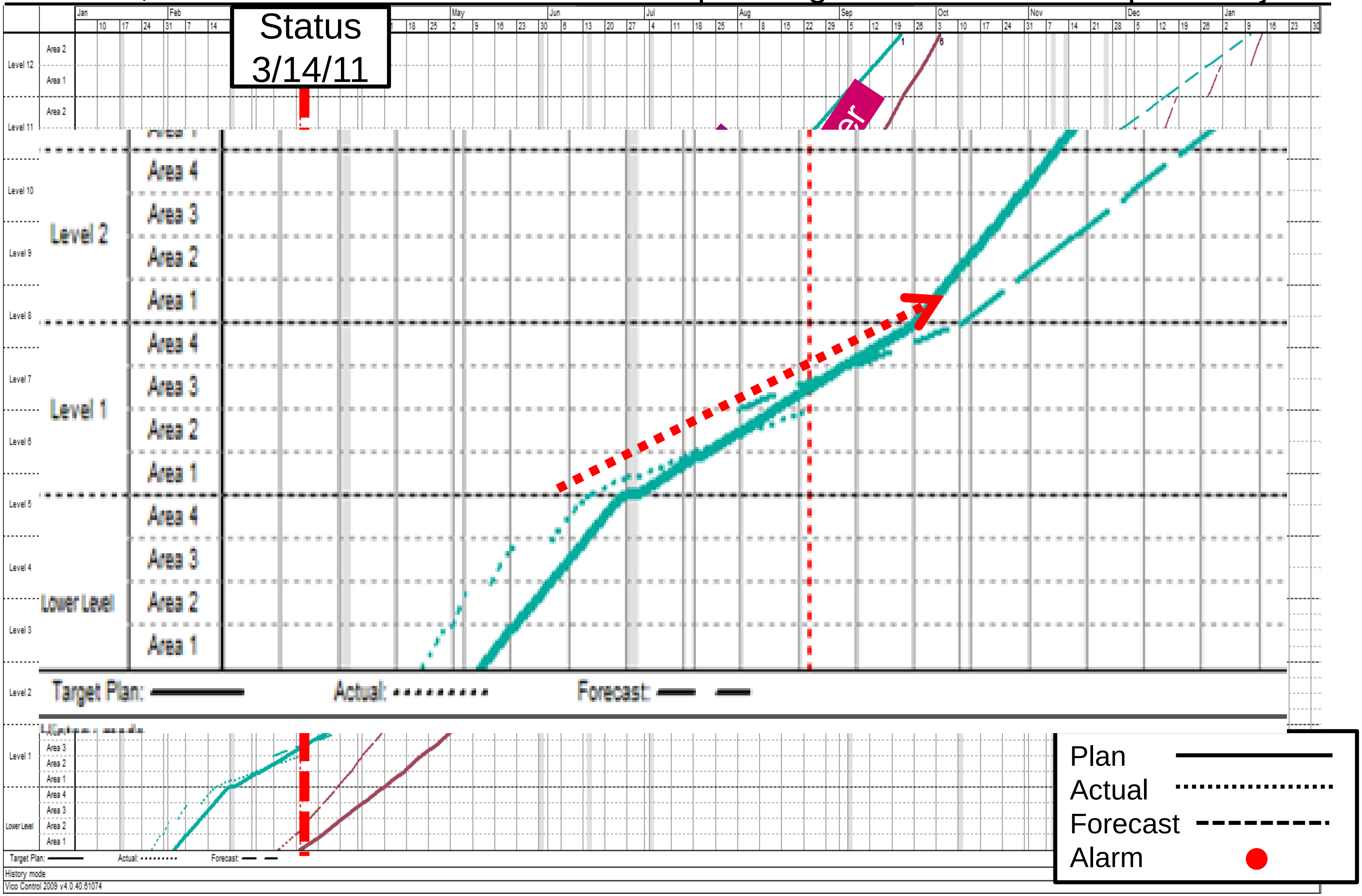
- **Cascading delays made projects unpredictable and chaotic**

- **It is impossible to recover the costs through penalties – active production control is required**

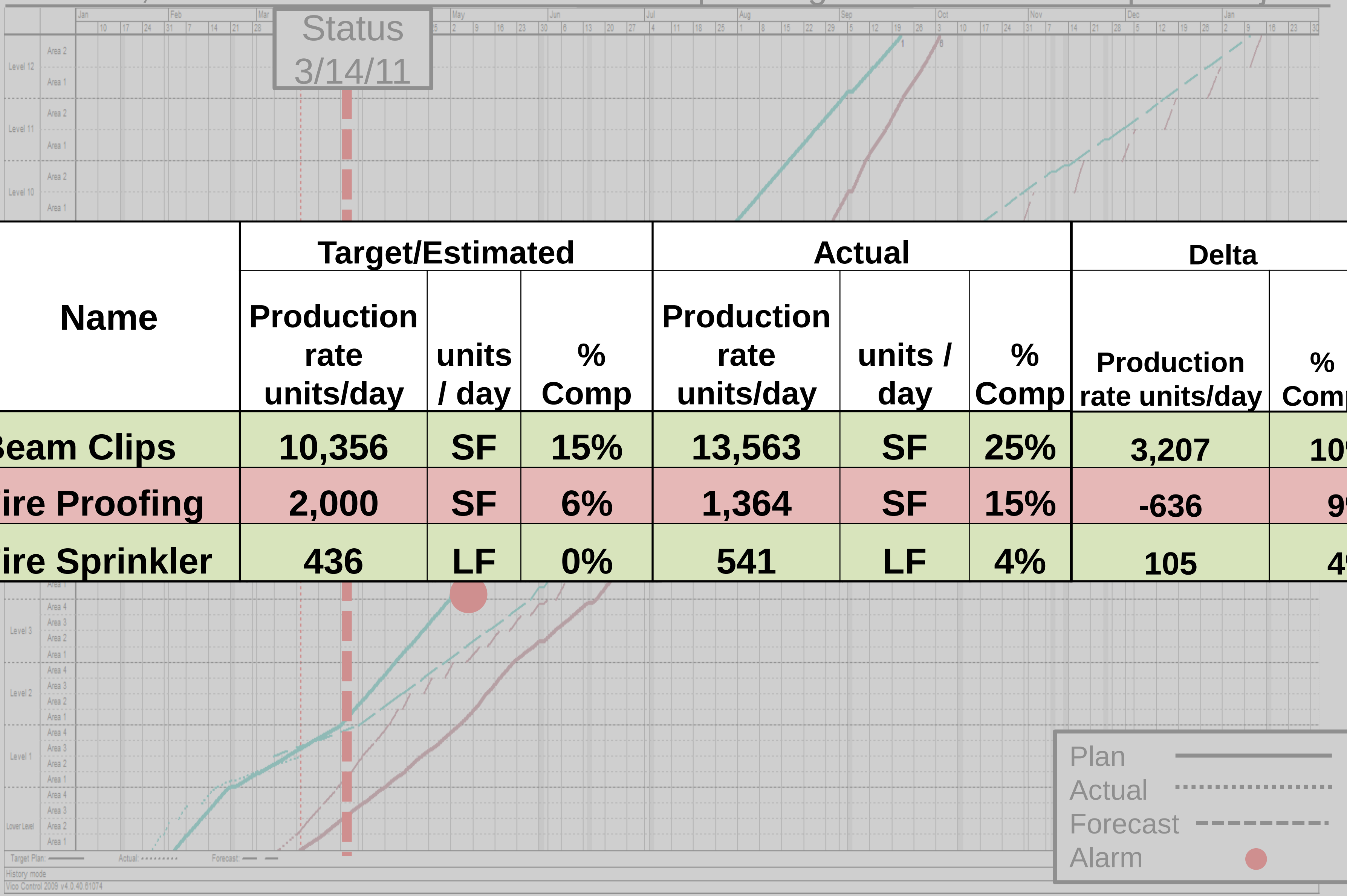
Example of cascading delays (Seppänen 2009)



Mar. 14, 2011 Fireproofing Hospital Project



Mar. 14, 2011 Fireproofing Hospital Project



Name	Target/Estimated			Actual			Delta	
	Production rate units/day	units / day	% Comp	Production rate units/day	units / day	% Comp	Production rate units/day	% Comp
Beam Clips	10,356	SF	15%	13,563	SF	25%	3,207	10%
Fire Proofing	2,000	SF	6%	1,364	SF	15%	-636	9%
Fire Sprinkler	436	LF	0%	541	LF	4%	105	4%

No.	Date	Production Opportunity/Alarm
PAI-076	14-Mar-11	

Recommendation	Status
Deploy 3rd gun to do focus gun 2 on produ	

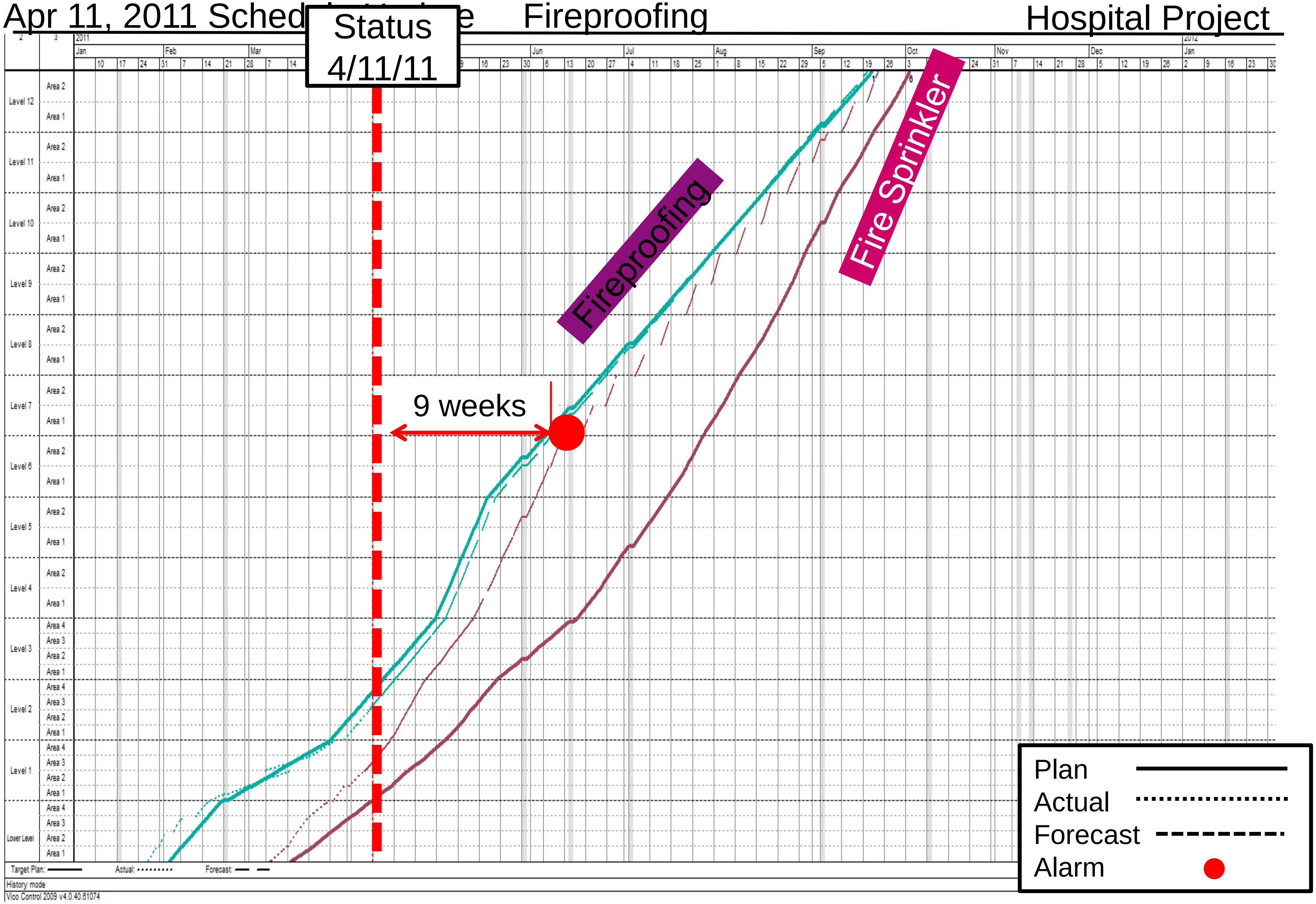
Response	Owner
Focus 3rd gun on pickup/focus 1st and 2nd gun on pure production	General Super, Fireproofing Sub, Area Super

Log

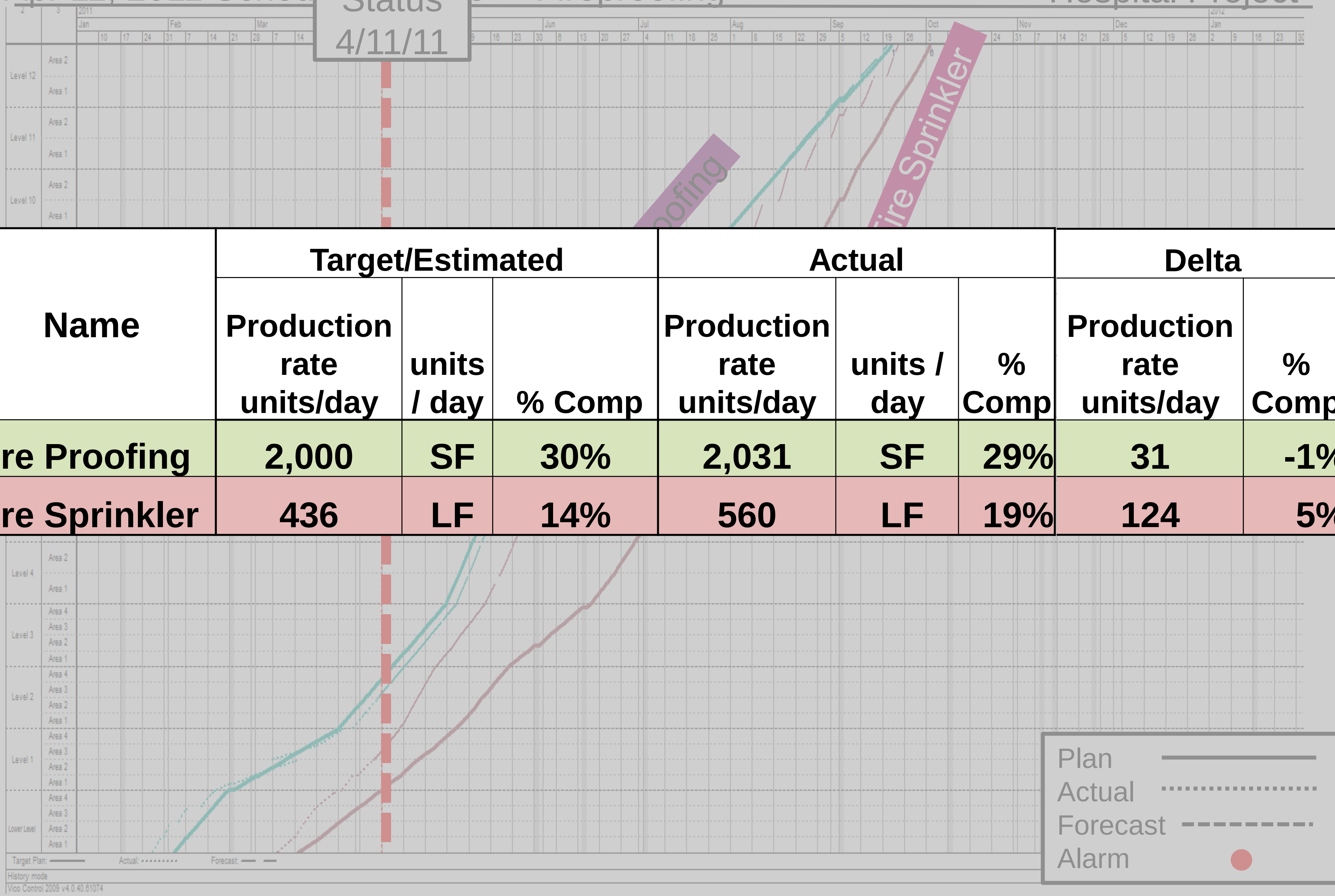
					Owner
48	P			ebfore moving to new	Nels, Mike W
49	P		consumption rate (taking longer p		Nels, Mike W
50	PAI-137	20-Mar-12	Duct Mains LL Areas 1 and 4 have systems are holding up the compl		
51	PAI-136	20-Mar-12	Insulation of ductwork production unnecessarily. Further, the foreca working across the odd tower floo		
52	PAI-135	20-Mar-12	In-wall copper is driving the produ the podium of level 3 is trending production drywall from LVL 1 to		
53	PAI-134	14-Mar-12	Ductwork insulation task is trendi Milestone.		
54	PAI-133	14-Mar-12	In wall plumbing on the even and affect the production drywall continuity.	still	
55	PAI-132	14-Mar-12	HVAC Branch Piping and Duct Branch tasks are trending too slowly in level 2 podium. This is influencing the start of Insulation and headwall tasks -> in turn this may affect the 80% OH Milestone and Production drywall continuity.	Con clos sug cre Pip	
56	PAI-131	06-Mar-12	Forecast suggests a late March start for lower level HVAC below duct. A forecasted finish is in early July. This may also influence the Duct Branch and Production Framing tasks.	Incr	

Dashboard | Log

Apr 11, 2011 Sched[illegible]e Fireproofing Hospital Project



Apr 11, 2011 Sched e Fireproofing Hospital Project



Name	Target/Estimated			Actual			Delta	
	Production rate units/day	units / day	% Comp	Production rate units/day	units / day	% Comp	Production rate units/day	% Comp
Fire Proofing	2,000	SF	30%	2,031	SF	29%	31	-1%
Fire Sprinkler	436	LF	14%	560	LF	19%	124	5%

No.	Date	Production Opportunity/Alarm
PAI-084	11-Apr-11	

Recommendation	Status
Reduce fire proection by 1 journeyman	

Response	Owner
Production rate in line with target by reducing by 1 resource	General Super, Fire Protection Sub, Area Super

Empirical results about LBMS controlling

Study	Key result
30 Master's theses 1980's, 1990s + empirical research on 6 projects (Seppänen & Kankainen 2004)	Just planning continuity is not enough, controlling is critical. Discontinuities are the hardest deviation type to recover from. Starting too early leads to slowdowns
Seppänen (2009)	Improved forecasting, identified cascading delay chains
Kala et al. (2012)	LBMS provides better information for superintendents than CPM Subcontractors overestimate their resource consumptions by 30-40%
Evinger et al. (2013)	CPM floors had 18% higher labor consumption and 10% slower production than LBMS floors
Seppänen et al. (2014)	39% of alarms resulted in control actions 65% of control actions increased production rate, 50% successfully prevented production problems It is possible for GC to control production rates of subs!

First look at takt (Seppänen 2014)

- **With LBMS assumptions, takt cannot work!**
  - Capacity buffers lead to waiting and waiting leads to cascading demobilization and return delays → trainwreck!
  - Paying workers for doing nothing would be very expensive (production system cost)

- **Lack of takt empirical evidence**

- **However, some companies in California and Germany were really successful in it, so we started looking deeper**

Key differences of assumptions

Assumption	LBMS	Takt
Focus of management effort	Prevent alarms from turning into production problems	Finish every process within takt time, solve all problems within takt
Buffers	Time buffers give time to react and are needed	Time buffers extend durations and cause lack of urgency. Time buffers are used also when things are going well and they extend project durations
Communication	Tasks are isolated from each other with buffers, communication between management and workers	Wagons are close to each other, communication also between wagons

Takt Maturity Levels

Level i)	**TECHNICAL TAKT PLANNING (project-level) -> first takt implementation cases, 30% duration reduction**
R1	The production plan fits the client's requirements
R2	Takt areas, takt time and wagons with resourcing are unambiguously determined
R3	Effective visual management is ensured
Level ii)	**SOCIAL INTEGRATION & TAKT CONTROL (project and organizational level) -> flow in projects, -50% dur.**
R4	Training and involvement of the project participants is ensured
R5	The logistics are integrated and takted with the production plan
R6	The design process is integrated and takted with the production plan
R7	The common situational awareness during production is ensured
R8	Barriers are tackled through continuous and collaborative improvement
R9	Quality control is systematic and takted
Level iii)	**CONTINUOUS IMPROVEMENT (organizational and regional level) -> flow in portfolios, productivity leap**
R10	Formulation and development of teams
R11	Contractual integration
R12	Systematic waste elimination over projects
R13	Industrialized logistics and material flow
R14	Standardized, takt-based work quantity libraries
R15	Improving through KPI's and data-driven decision making

Lehtovaara et al. 2020

Level i) example – Case Keinulauta

- **Fira residential project**
  - 79 rental apartments
  - Floor plans vary from 28 to 41 m2
- **Intensive takt planning phase**
  - 1-day takt, 60 takt wagons
- **Challenges in control phase**
  - Missing daily management, communication issues
- **However, significant benefits**
  - ~15% duration reduction
  - Increased quality
  - Increased profit (+40%)

Level ii) example – Case KYT

- **Skanska commercial project**
  - 40'000 m2 multi-store office building
  - Floor plans vary from 28 to 41 m2
- **Collaborative takt planning and control**
  - Over 20 collaborative planning workshops
  - Daily huddles and weekly plan updates with 5d takt
- **Benefits included**
  - Tight schedule delivered in time
  - Production stability

Level iii) example – Case Folks Hotel

- **NCC hotel renovation project**
  - 75 hotel rooms with high repetition
- **Intensive takt planning and control**
  - 50% duration reduction
- **However, continuous observation revealed high amount of waste**
  - The plan was achieved with 37% room utilization rate
  - ~80 entries to a room per day by various people
- **Even though waste was not removed within the project, several ways for continuous improvement were established**

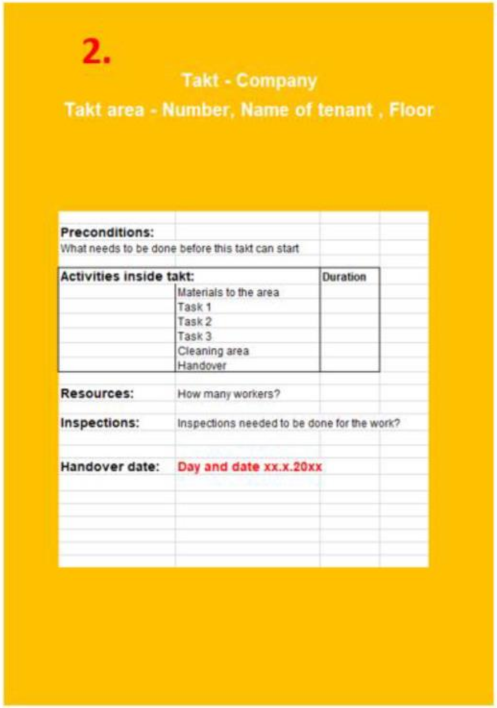
Table 3. The number of visits and the number of workers entered to the two observed hotel rooms.

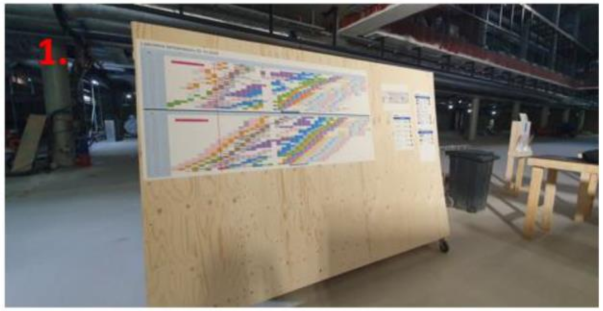
	Room 1				Room 2			
Day	Visits	Avg. visit time	St.dev of visits	Amount of different workers	Visits	Avg. visit time	St.dev of visits	Amount of different workers
1	103	0:03:27	0:06:41	13	133	0:02:10	0:04:19	14
2	82	0:01:58	0:06:03	12	72	0:03:22	0:09:41	17
3	76	0:01:28	0:04:44	18	89	0:01:06	0:02:29	24
4	78	0:01:05	0:02:06	13	63	0:01:38	0:04:45	18
5	50	0:02:38	0:08:45	7	65	0:02:17	0:08:41	14
6	81	0:04:43	0:11:28	14	62	0:02:02	0:03:58	10
7	76	0:02:54	0:06:12	15	67	0:04:47	0:10:58	14
8	105	0:01:38	0:04:34	18	102	0:02:14	0:06:38	10
9	89	0:01:25	0:02:47	21	105	0:03:32	0:10:25	12
10	36	0:02:19	0:04:26	14	56	0:02:04	0:05:46	9

Lehtovaara et al. (2020)

Visual management is important for takt

- Workers need to understand takt plan and takt areas
- Daily goals for each worker
- How to digitalize visual management?





Grönvall, M., Ahoste, H., Lehtovaara, J., Reinbold, A., and Seppänen, O. (2021). "Improving Non- Repetitive Takt Production with Visual Management." *Proc. 29th Annual Conference of the International. Group for Lean Construction (IGLC29),*

Visual management is currently rare in Finland

- **Schedule information is only visible in construction trailers**
- **Workers need to know their daily goals and how their work relates to other work**
- **Good visual devices:**
  - Marking takt area boundaries on site
  - Takt boards on every floor for schedule-related discussion and coordination
- **Daily takt meetings become important to solve all problems within takt time**

Current status in Finland

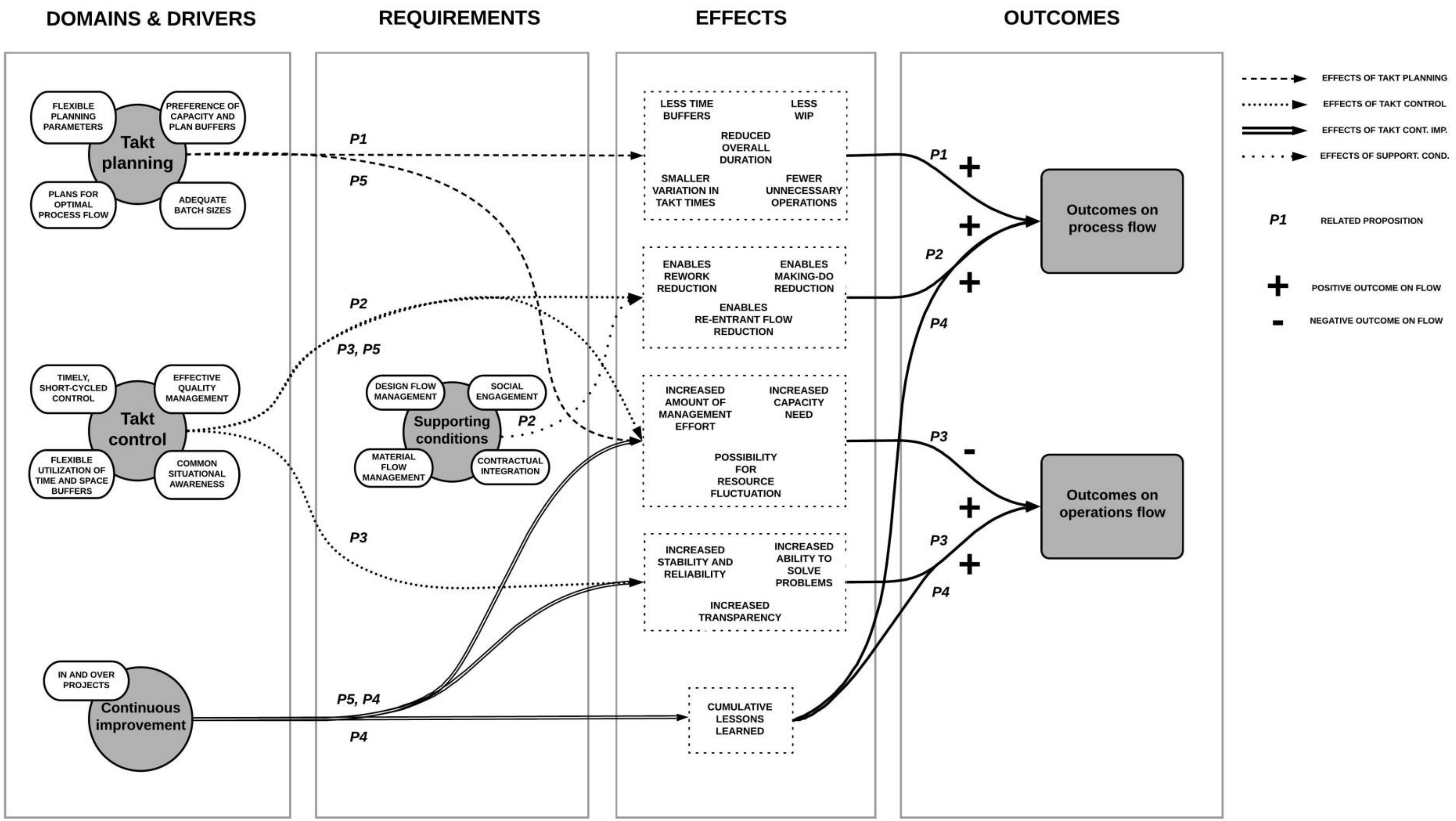
- **Over 200 takt projects in Finland in 2021**

- **Most large general contractors are training their staff, piloting and implementing takt**

- **New software packages enabling takt are coming on market**
  - Takt.ing
  - Flow Technologies SiteDrive

- **Many companies have made takt part of their strategy**

Impacts of takt – a theoretical model



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Lehtovaara et al. (2021). How takt production contributes to construction production flow: A theoretical model. *Construction Management and Economics.*

Key differences between controlling systems

Factor	"Traditional" / CPM	LBMS	Takt controlling
Emphasis	Detect delays and replan to **mitigate delays on critical path**	Predict delays and try to **prevent cascading delays**	**Solve problems during the takt**
Calculations	CPM algorithm / comparison of dates	Production rates, productivity and forecasts	Not specified, more of a social process
Typical control actions	Additional resources on critical path	Increase / decrease production rates to prevent cascading delays	Buffer wagons or even stopping of production until problem solved

Thank you
Questions & Comments