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**
- **Location-based controlling overview**
- **Cascading delays in construction**
- **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*

LBMS technical system

Planning system

- Location Breakdown
- Quantities
- Duration calculation
- Layered logic
- LBMS algorithm (CPM+)
- Production system cost
- Production system risk

Controlling system

- Progress data
- Performance metrics
- Detailed planning
- Forecasting
- Control actions

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

Progress data for controlling systems

Type of data	CPM / Gantt	Takt	LBMS
Start and finish dates	Current status most important (exact dates do not matter)	Did we hit the takt or not? (exact times do not matter)	Accurate start and finish dates needed for calculations
Actual resources	No impact on calculations	No impact on calculations	Needed for forecast calculations
Actual workhours	No impact on calculations	No impact on calculations	Needed for forecast calculations
Suspensions	No impact on calculations	No impact on calculations	Needed for forecast calculations
Timeliness	Often monthly	For each takt	Daily/weekly

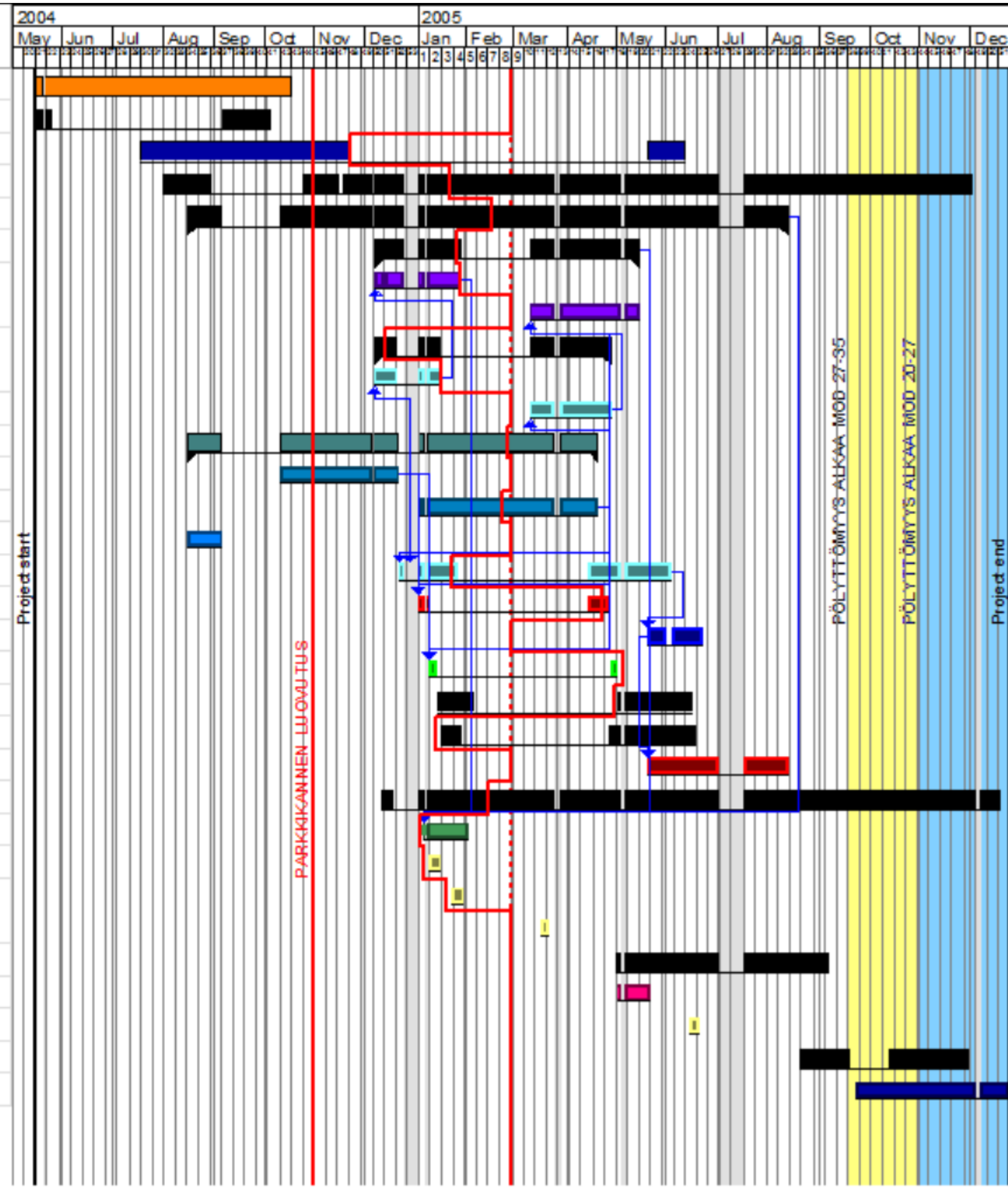
Progress data

- **Manual data collection**
  - *Distributed*
  - *Centralized*
- **Digital data collection**
  - *Distributed*
  - *Centralized*

- **Automation in the (near) future?**

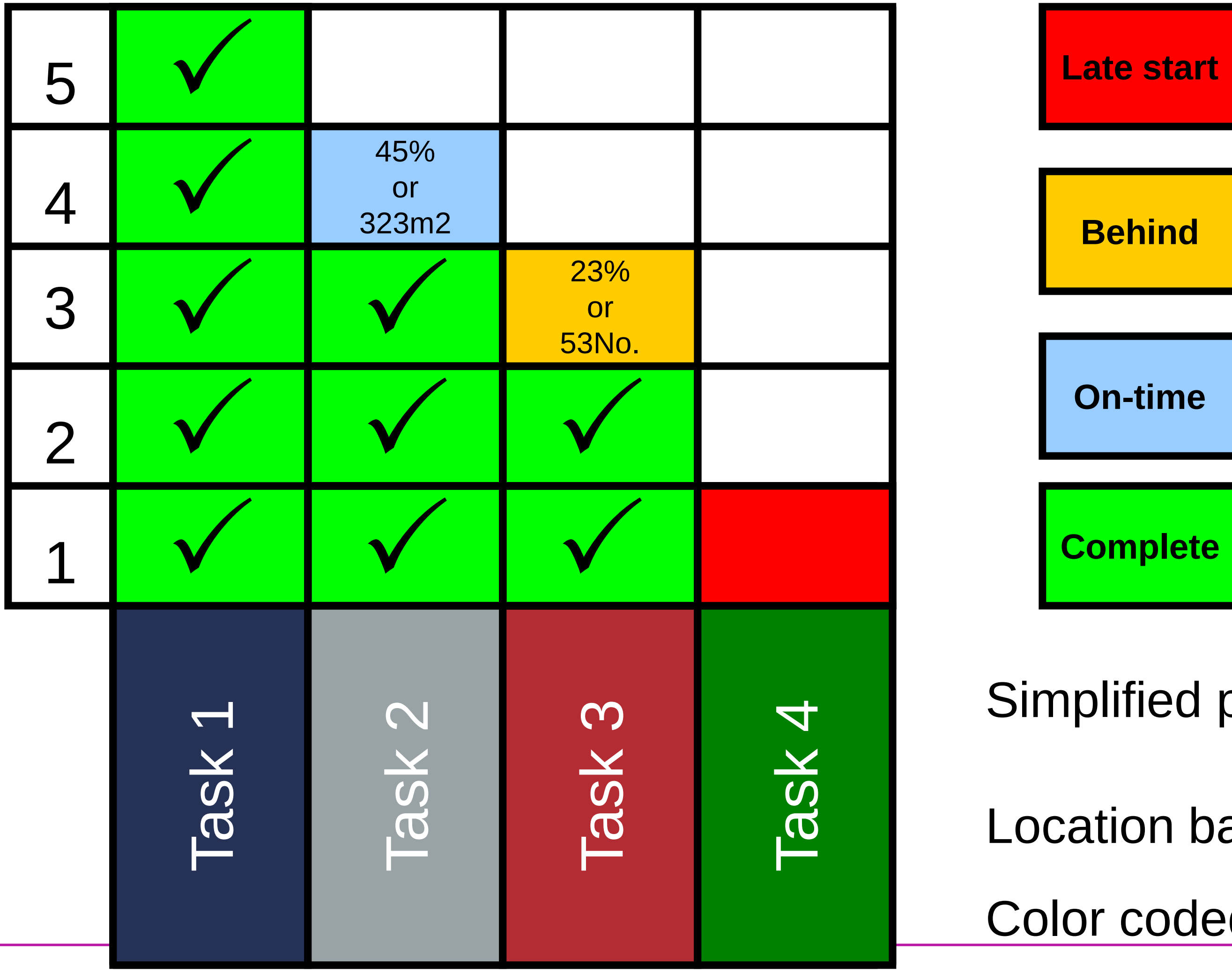
Traditional visualization of progress

Hierarchy	Code	Name
+1		Maanrakennus
+2		PARKKIKANSIRAKENTEET
+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 + JULKISIVU MOD 30-27*
+5.3.2	3050	*BET.ELEMENTTIRUNKO + JULKISIVU MOD 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 / SPRINKLERKESKUS A SENNUSVALMIS
+9	700	SäHKöPääKESKUS JA MUUNTAMOA SENNUSVALMIS
+10		SäHKöNOUSUKOMEROT A SENNUSVALMIIT MOD 27-28
+11		PIHANRAKENTEET
+12		PARKKIHALLINMAALAUS
+13		SäHKöNOUSUKOMEROT A SENNUSVALMIIT MOD 20-27
+14		Vuokralaismuutokset
+15	7600	TARKASTUKSET, SÄÄDÖT JA MITTAUKSET



Takt visualization of progress

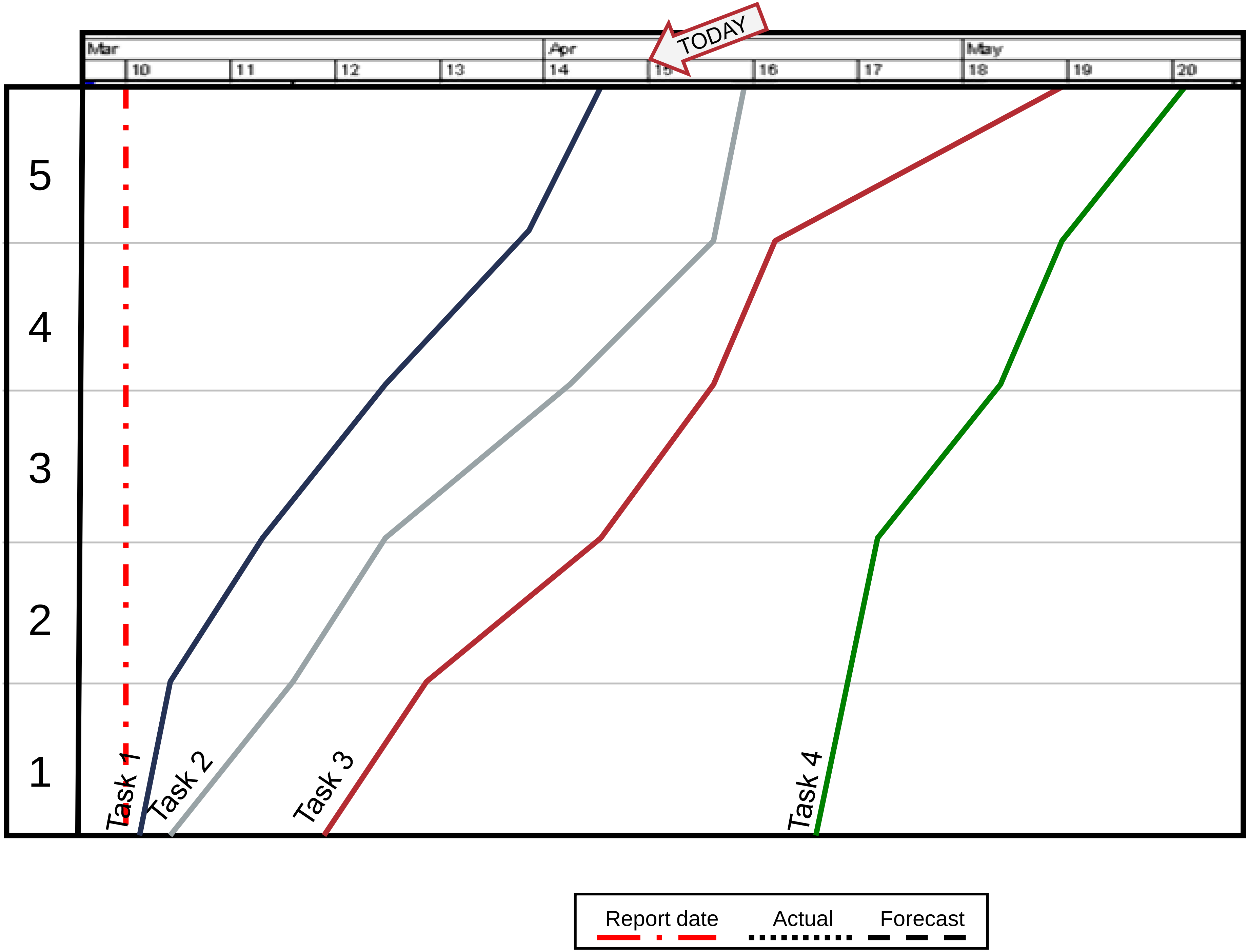
LBMS: Visualization of progress



Simplified project control

Location based updates

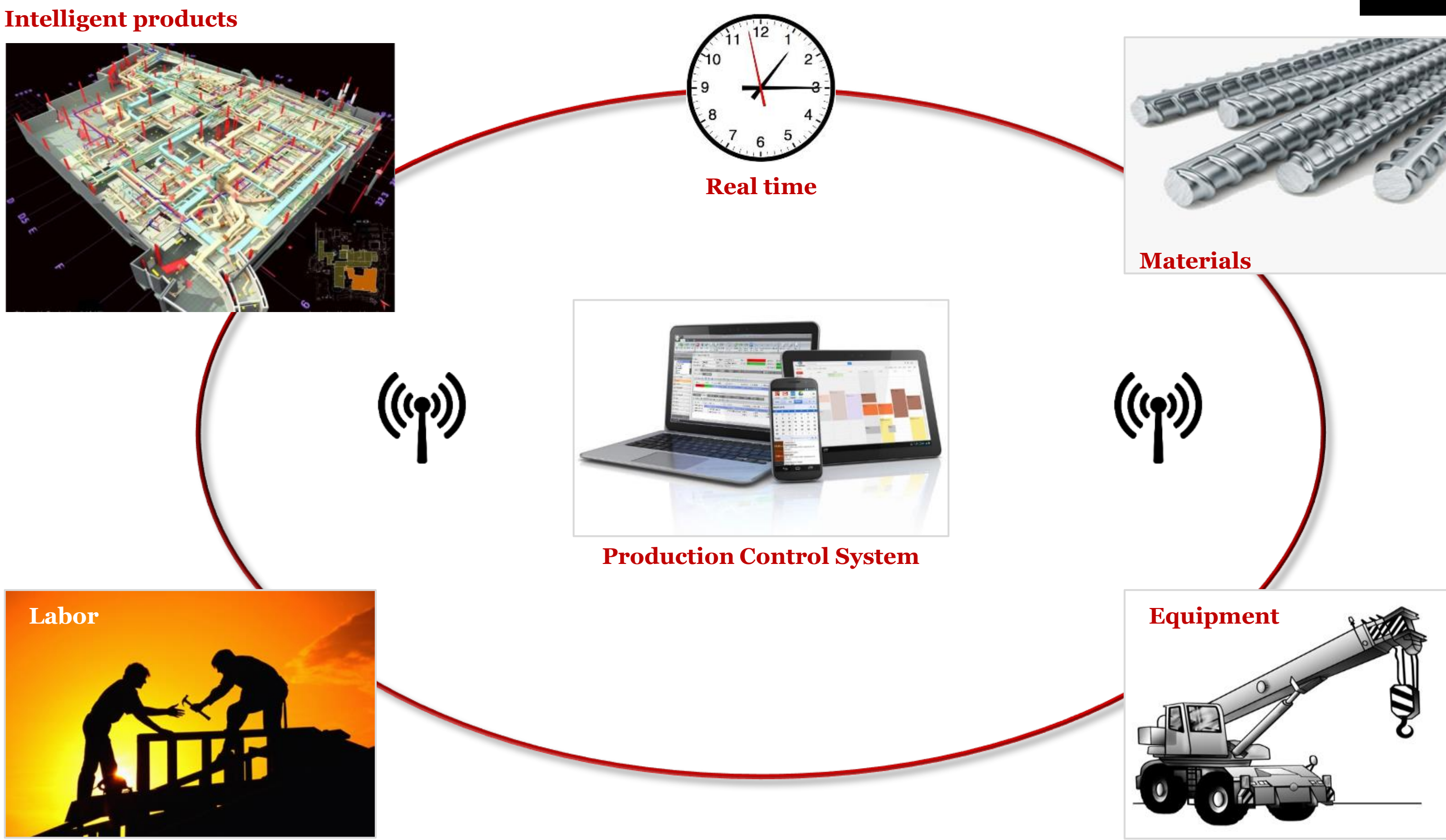
Color coded for clarity



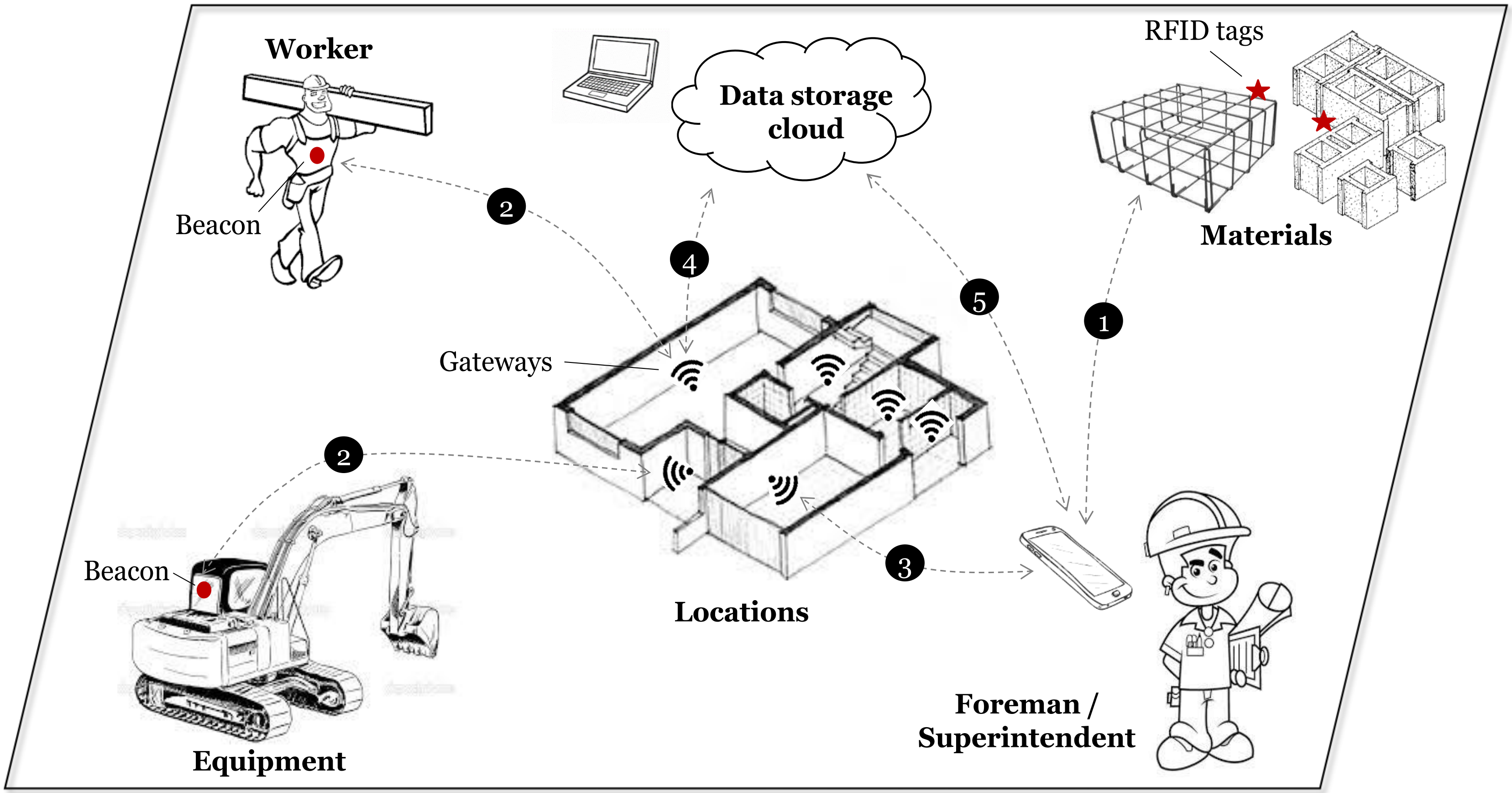
Mar
Apr
May
10
11
12
13
14
16
17
18
19
20
TODAY
5
4
3
2
1
Task 1
Task 2
Task 3
Task 4
Report date
Actual
Forecast

Resource positioning for automated data

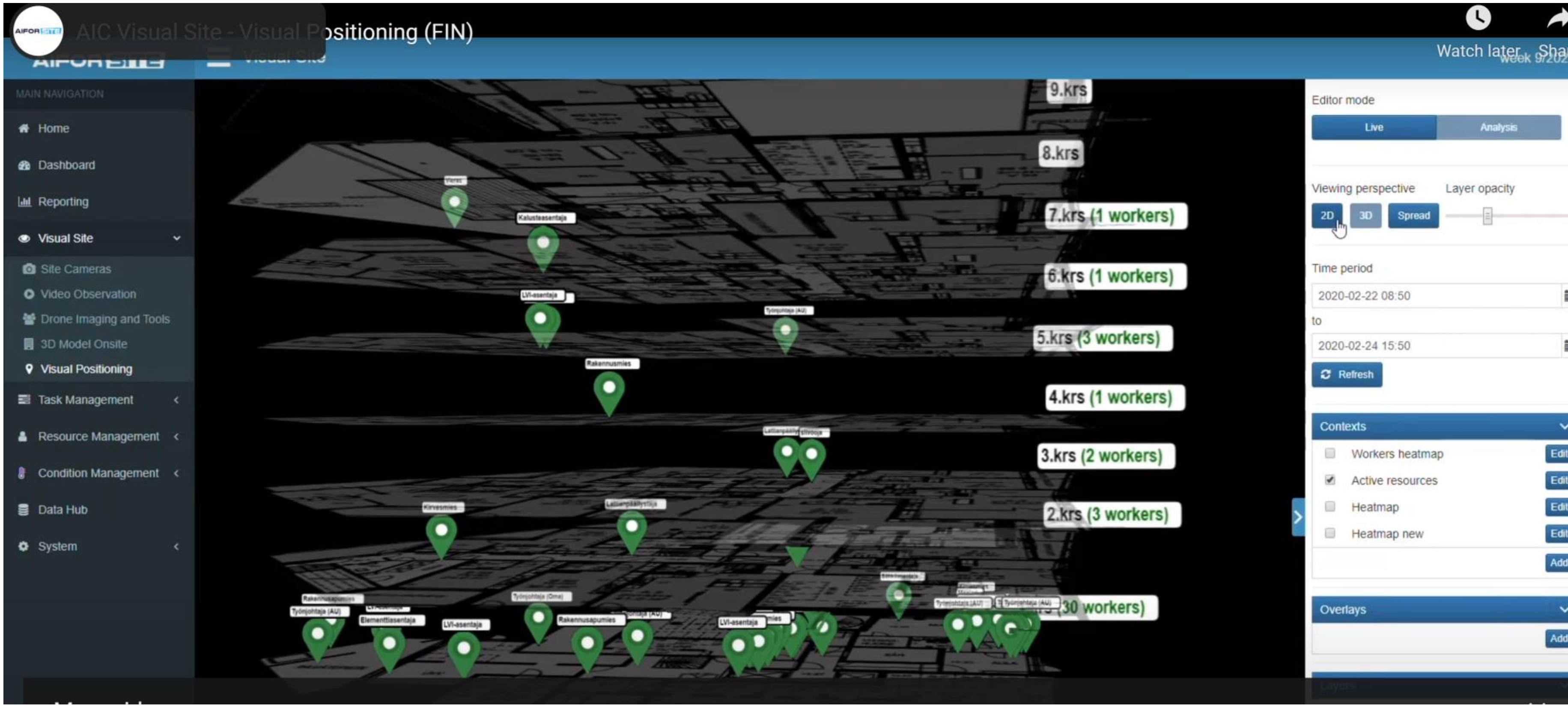
1. What is Intelligent Construction Site?



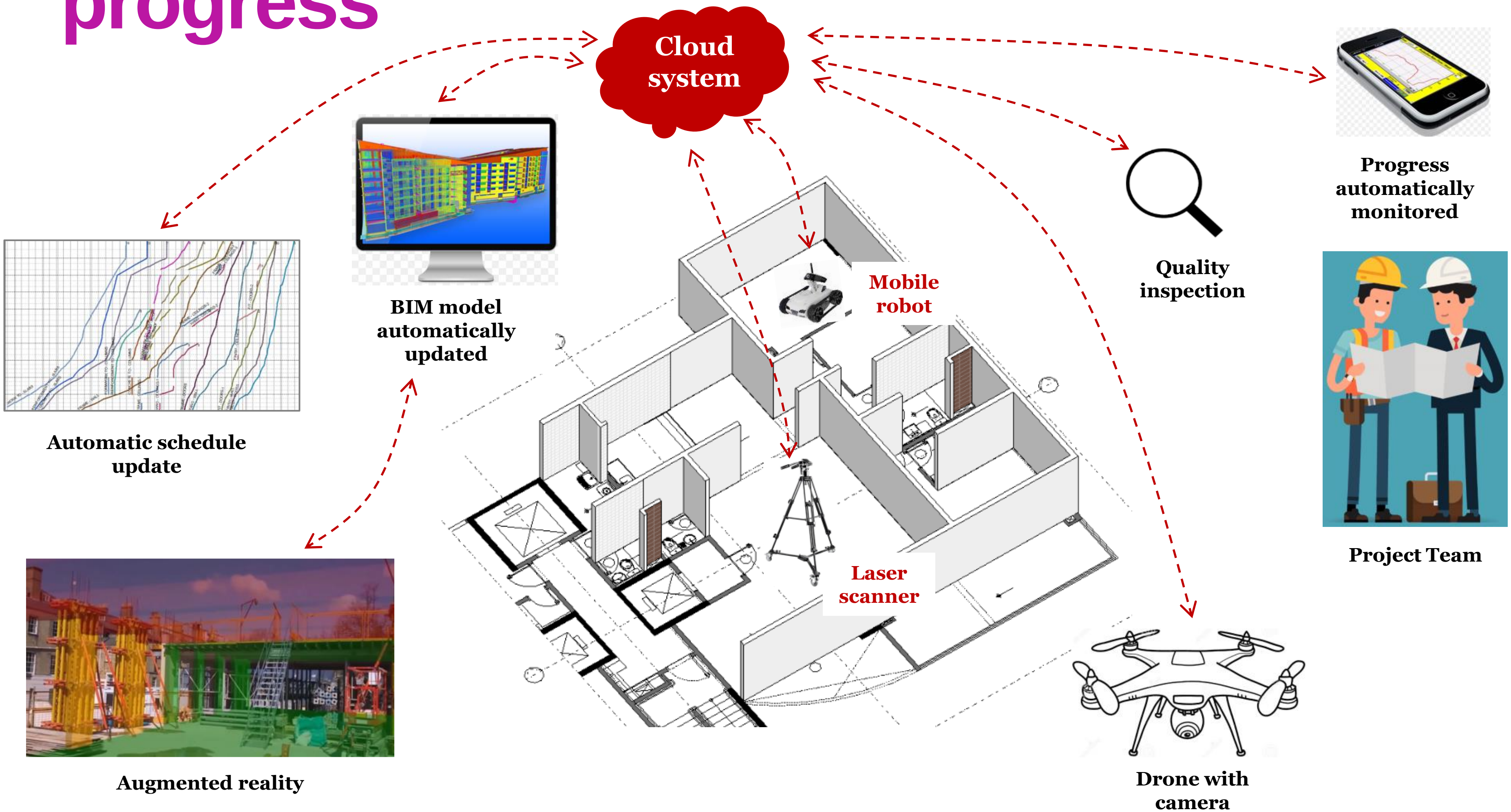
iCONS


Worker
Beacon
Data storage cloud
RFID tags
Materials
Gateways
Locations
Beacon
Equipment
Foreman / Superintendent
1
2
2
3
4
5

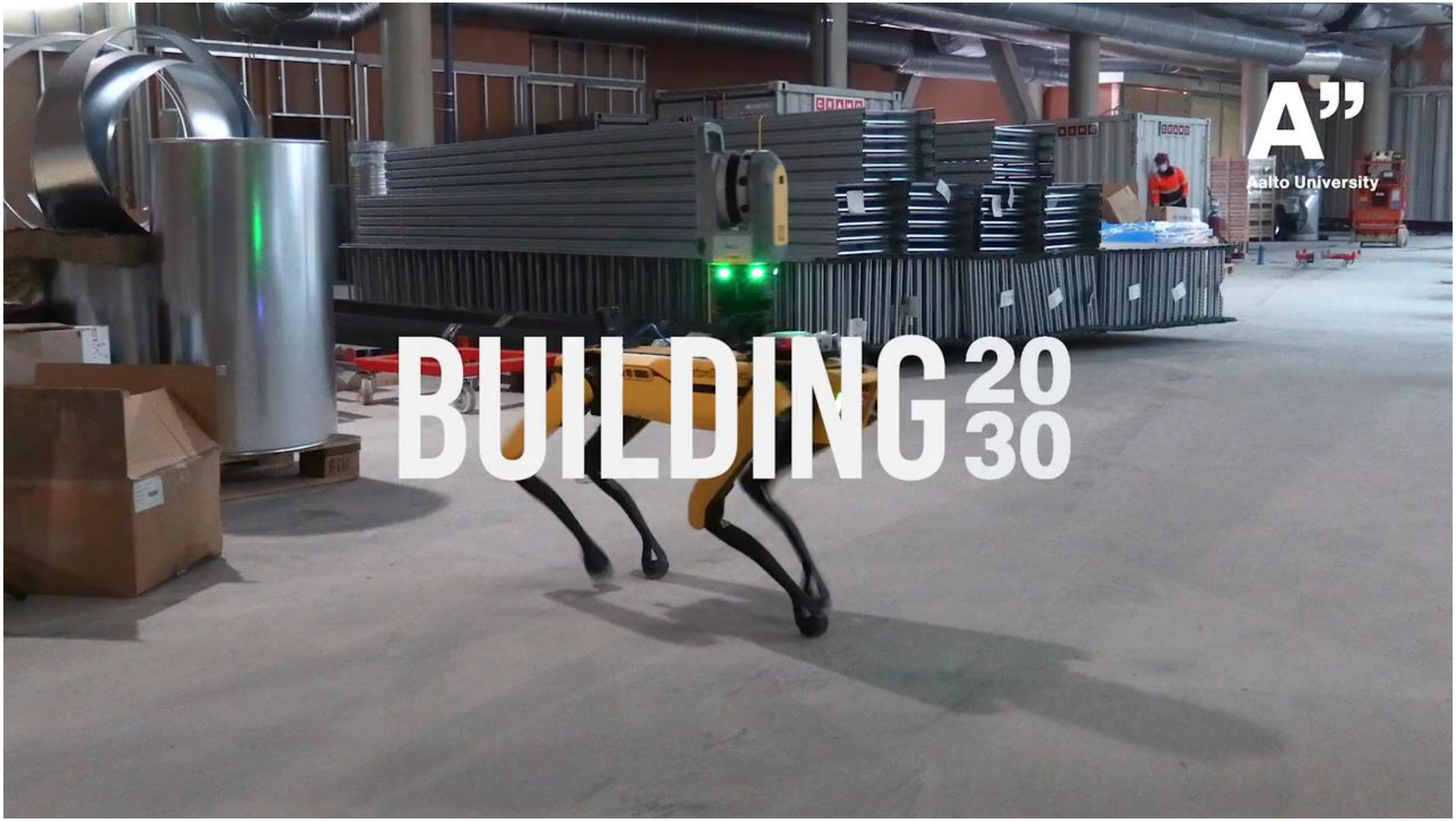
Commercial solutions for positioning becoming available



Reality Capture for automated progress



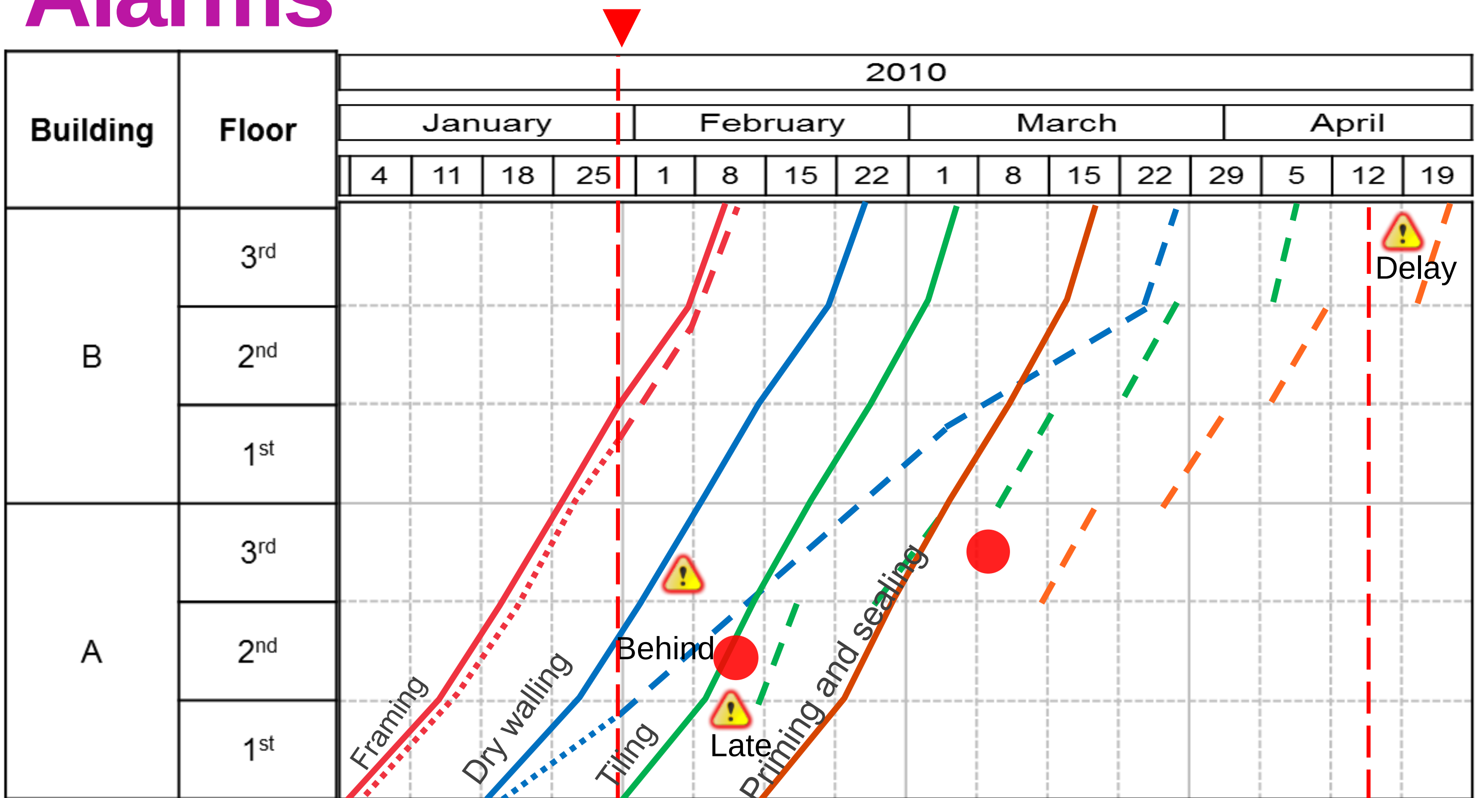
Spot robot for automatic data collection



LBMS Key Performance Indicators

KPI	Calculation	Use
Actual production rate	**Actual quantity / actual duration** (not including suspensions)	How fast production is moving? General Contractor's main interest
Actual labor consumption	**Actual manhours / actual quantity**	How **productive** is work. Trade contractor's main interest. Informs control action decisions. Hard to get data

Alarms



- **LBMS alarms are generated when predecessor forecast impacts successor forecast**
  - Delaying start
  - Causing a discontinuity

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
Typical control actions	Increase / decrease crew size, delay start times, longer / shorter days	Root cause analysis, use of buffer wagons, stopping of train

• Control actions are responses to alarms

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!**

End of video 1

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

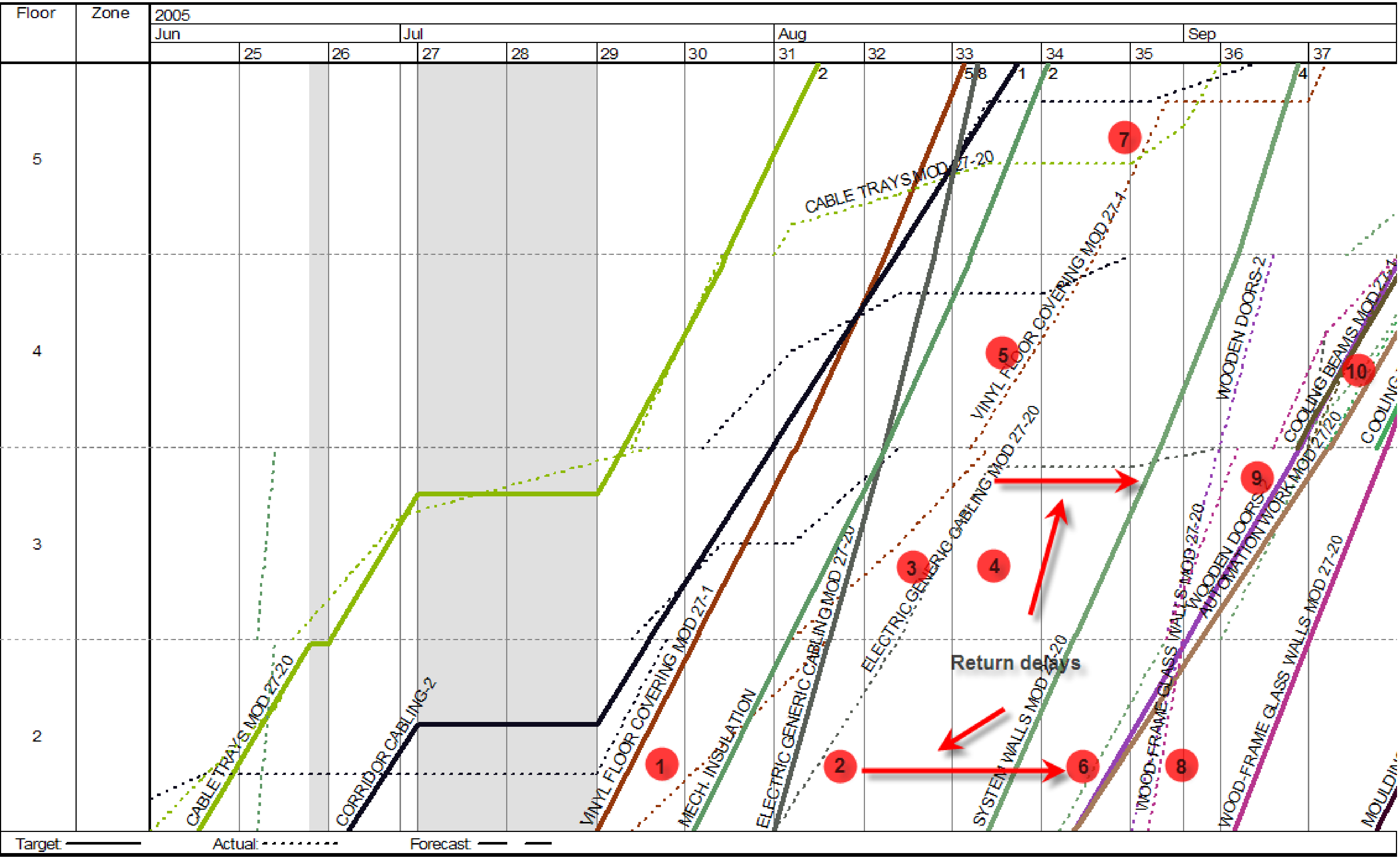
- **Problems especially in projects without buffers**

- **All investigated building projects had cascading delays in interior construction phase (MEP + rough-in + finishes)**

- **Delays caused by multiple subcontractors in the same space**
  - *Slowdowns (large, open locations)*
  - *Discontinuities (constrained spaces)*
  - *Start-up delays*

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

Example of cascading delays (Seppänen 2009)



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!

Key assumptions of LBMS controlling

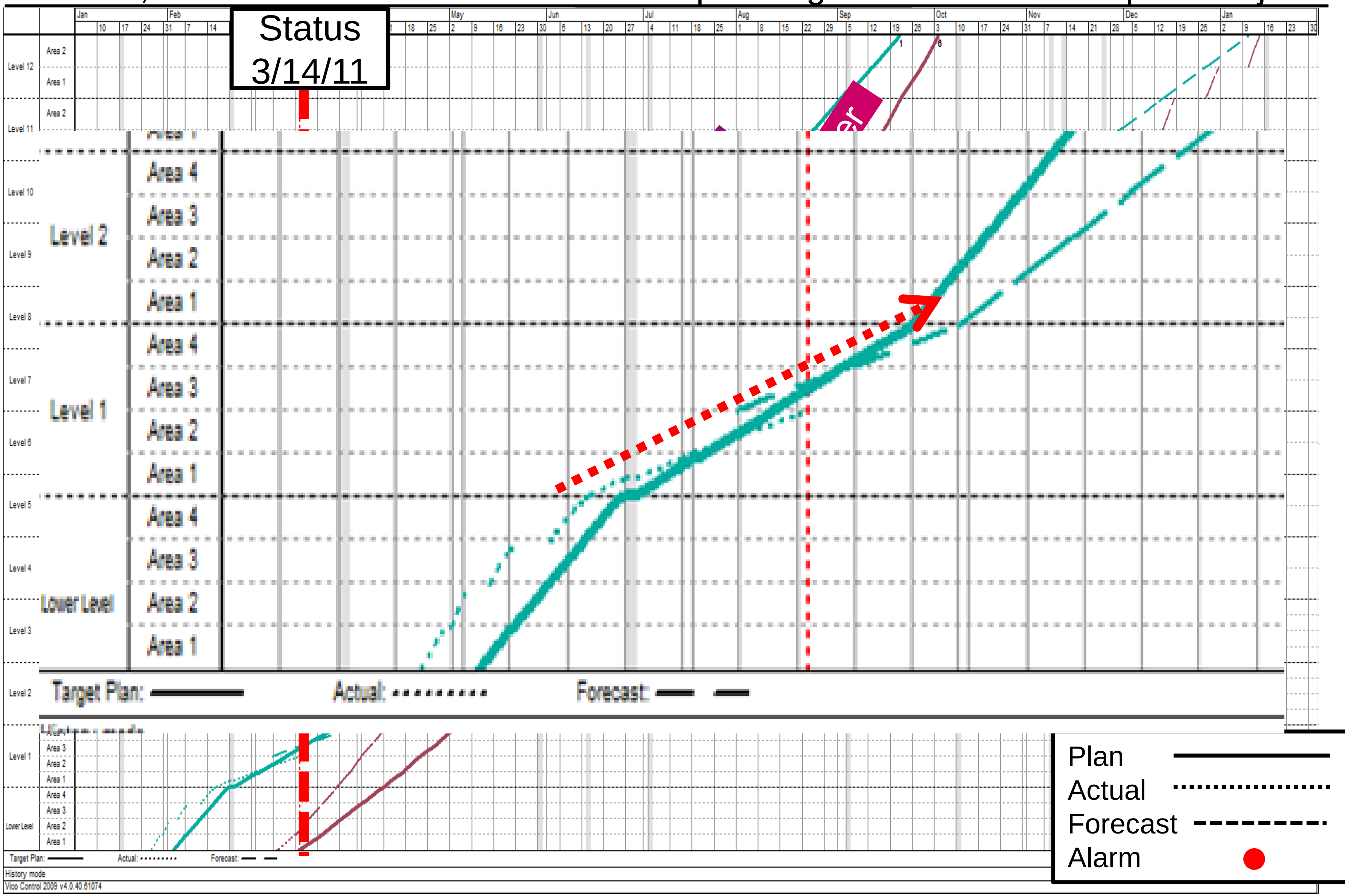
1. Reacting to alarms takes time

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

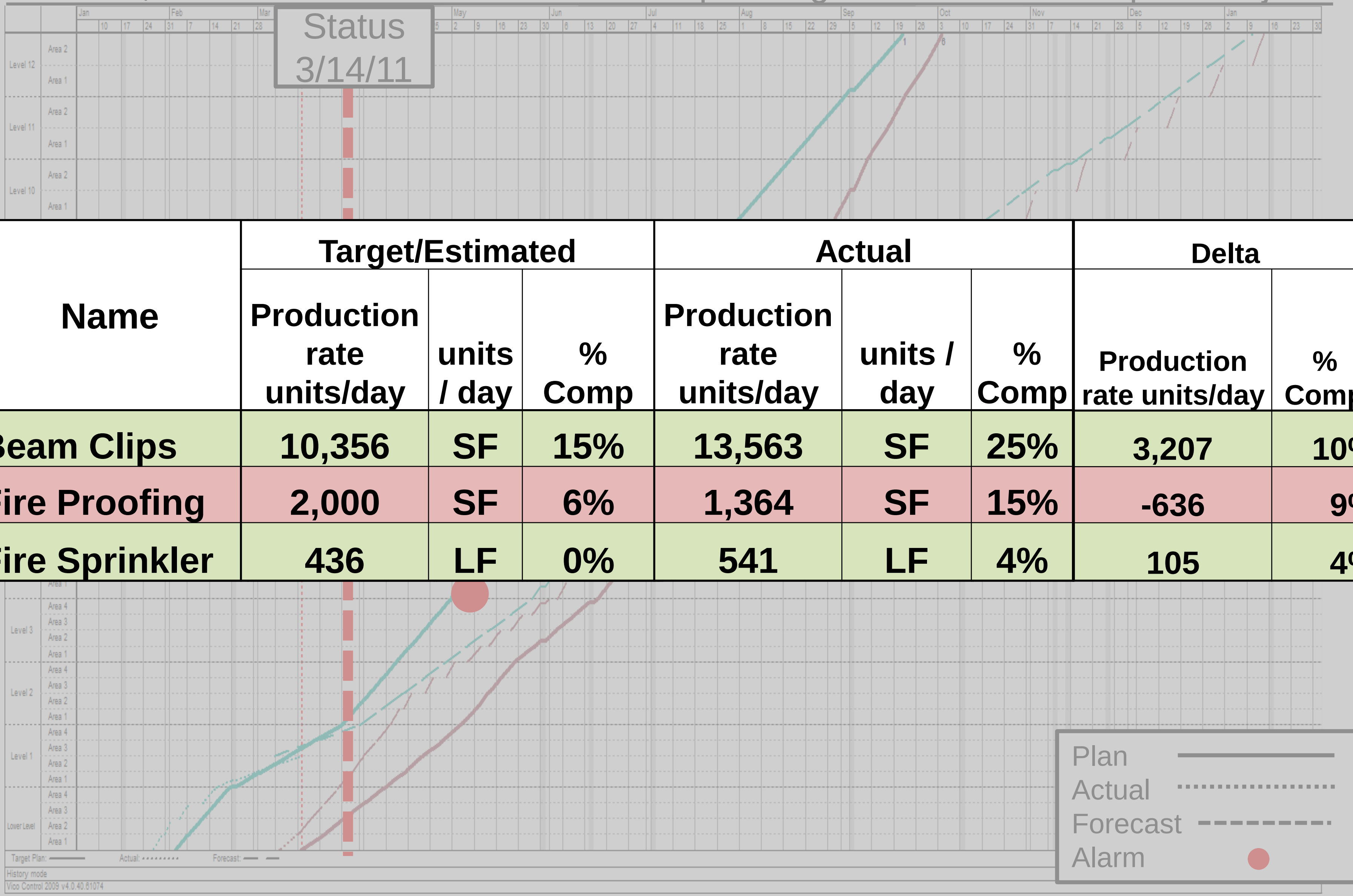
3. Separating the crews with time buffers is mandatory

4. Proactive control – prevent collisions

Mar. 14, 2011 Fireproofing Hospital Project



Mar. 14, 2011 Fireproofing Hospital Project



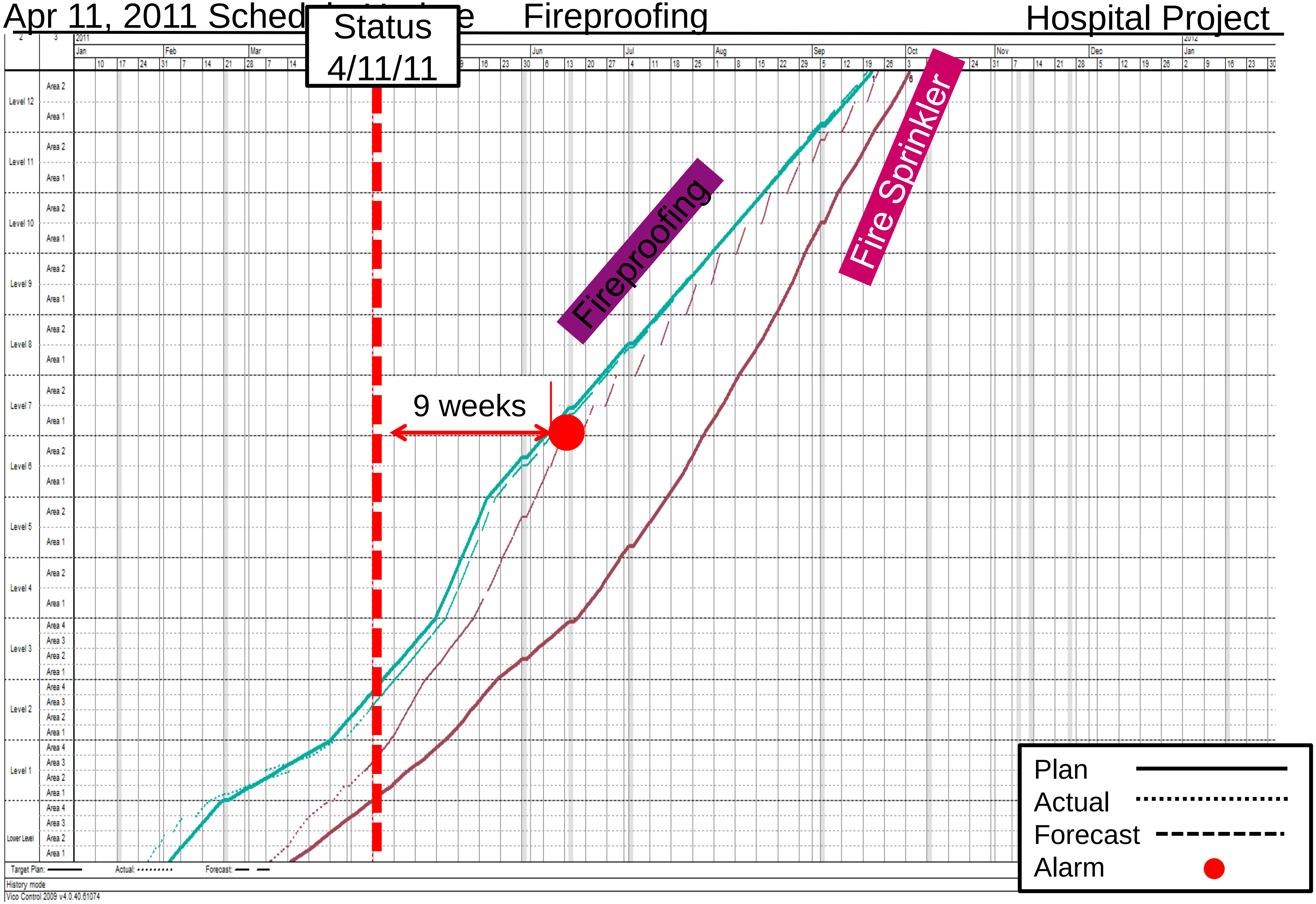
Name	Target/Estimated			Actual			Delta	
	Production rate units/day	units / day	% Comp	Production rate units/day	units / day	% Comp	Production rate units/day	% Comp
Beam Clips	10,356	SF	15%	13,563	SF	25%	3,207	10%
Fire Proofing	2,000	SF	6%	1,364	SF	15%	-636	9%
Fire Sprinkler	436	LF	0%	541	LF	4%	105	4%

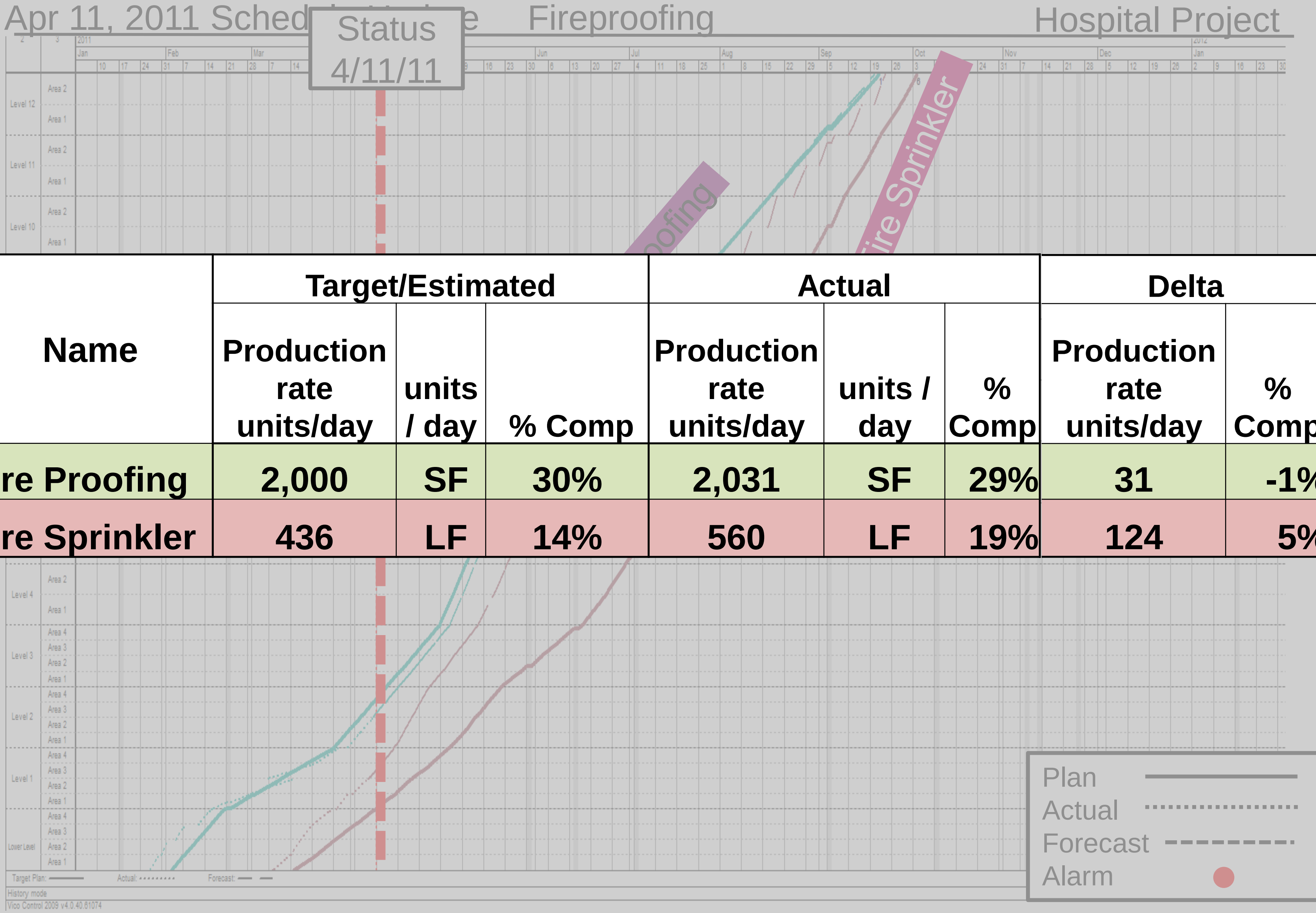
No.	Date	Production Opportunity/Alarm
PAI-076	14-Mar-11	

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

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

First look at takt (Seppänen 2014)

- **With LBMS assumptions, takt cannot work!**
  - Capacity buffers lead to waiting and waiting leads to demobilization and return delays → trainwreck!
  - Paying workers for doing nothing would be very expensive
- **Lack of takt empirical evidence did not help**
- **However, some companies in California and Germany were really successful in it, so we started looking deeper**

Key assumptions of LBMS did not hold

- **Time buffers were used also when everything was going well**
- **Lack of urgency led to being delayed all the time**
- **Lack of trade communication**
- **Resource flow optimized without considering process flow**
- **Documented takt cases did not include trade wrecks, there was no waiting**

Why takt production has gained momentum so fast?

- In pilot projects, by only implementing better planning process, ~30% duration reduction has been achieved
- When control processes and supporting activities are included, duration reduction of ~50% is normal
- Takt is not only about time reduction! Other benefits include

Improvement of work flow		Decrease of waste	
Increase of productivity	Decrease of Work-in-Progress (WIP)	Cost savings of projects	Decrease of quality errors
Crews know when and where to work	Prevention of overproduction	Stabilizing work processes	Less inventory / waiting times between work steps
Opportunity to discuss with other crews about problems	Optimization of logistics through continuous flow	Shorter cycle time	

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

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Level iii) example – Case Folks Hotel

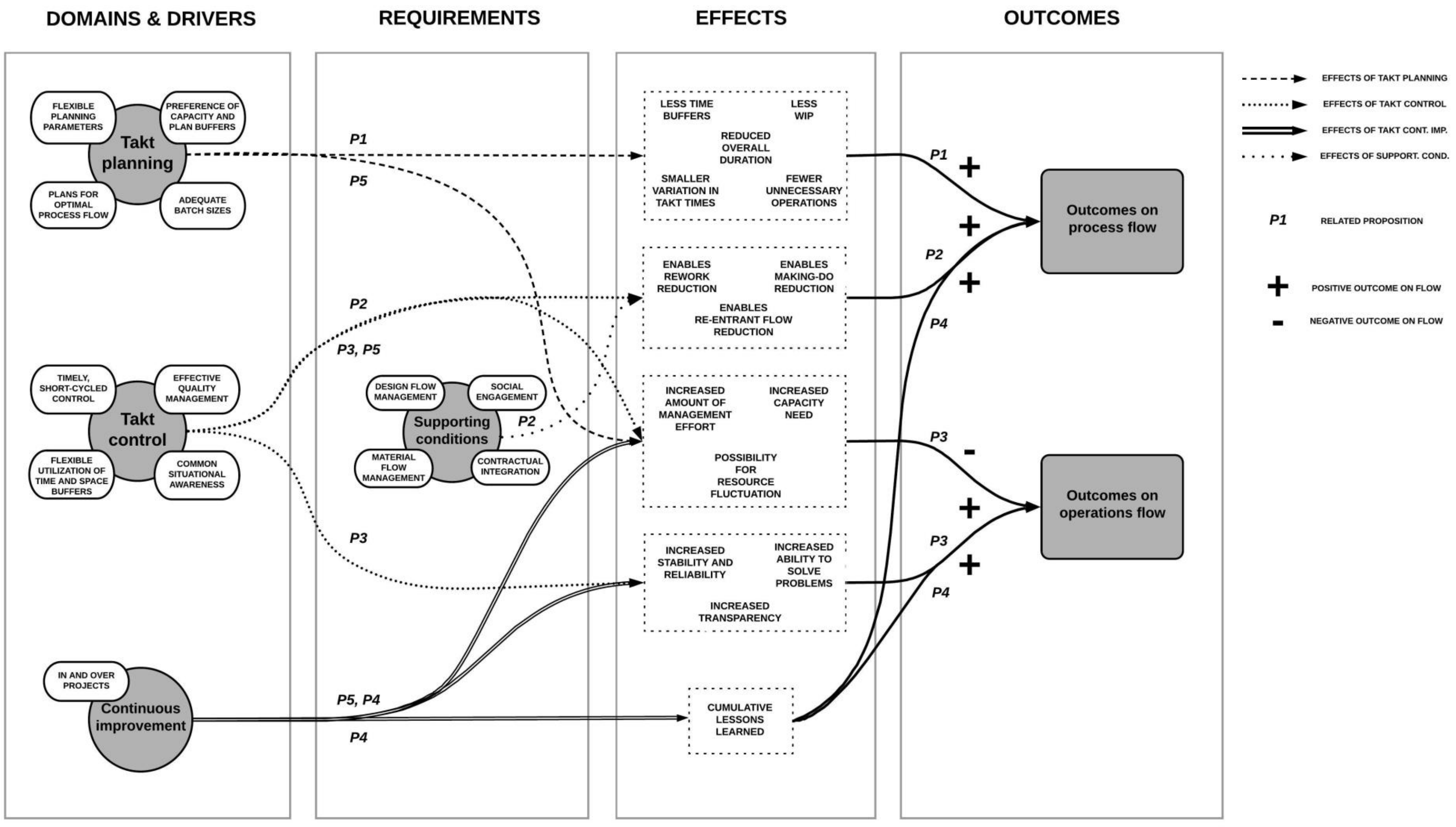
- **NCC hotel renovation project**
  - 75 hotel rooms with high repetition
- **Intensive takt planning and control**
  - 50% duration reduction
- **However, continuous observation revealed high amount of waste**
  - The plan was achieved with 37% room utilization rate
  - ~80 entries to a room per day 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)

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.*

Thank you
Questions & Comments