



LEAN

Understanding Performance in Construction

Presented by
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OAC Services, Inc.

September 2017

Statement Of Purpose

- Assembling 1,000 square feet per shift
- Contextual framework of the origin and history of industrial engineering
- LEAN principles and the Toyota Production System applied to construction performance



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**ASSEMBLING
1,000-SQUARE
FEET PER
SHIFT**



Hour 0



Design of Assembly



Hour 100



LEAN Performance

(1,800 pieces erected)

The Metrics

Structural Steel											
				\$ 0.03	12	12	1,812	1,812	-	Piece Rate	2' -59"
		Cost per minute on the glasses		Remaining Zones	22	Remaining Pieces of Steel	318	Remaining Zones of Decking			
Building	Days since first load	Date	Day of the Week	# of Zones	Running Total	# Pieces of Steel installed	Running Total	# of Zones of Decking	Start Time	End Time	Pieces Per Minute
OB	1	13-Apr	Mon	4	4	190	190		6:00	16:00	2' -51"
OB	2	14-Apr	Tue	4	8	191	381		6:00	16:30	2' -59"
OB	3	15-Apr	Wed	3.5	12	213	594		6:00	16:00	2' -32"
OB	4	16-Apr	Thr		12	196	790		6:00	16:00	2' -45"
OB	5	17-Apr	Fri		12	169	959		6:00	16:00	3' -12"
OB	6	18-Apr	Sat		12	198	1,157		6:00	16:00	2' -44"
OB		19-Apr	Sun		12		1,157		6:00		
OB	7	20-Apr	Mon		12	204	1,361		6:00	16:00	2' -39"
OB	8	21-Apr	Tue		12	166	1,527		6:00	16:00	3' -15"
OB	9	22-Apr	Wed		12	138	1,665		6:00	16:00	3' -55"
OB	10	23-Apr	Thr		12	147	1,812		6:00	15:30	3' -28"



Sept. 6

Continuous Improvement



Oct. 4

- 2,986 pieces erected
- 10 floors decked
- Stairs to 11th
- 2 floors poured
- 1 floor fireproofed
- 300 major deliveries

LEAN Performance



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ORIGINS AND HISTORY OF INDUSTRIAL ENGINEERING

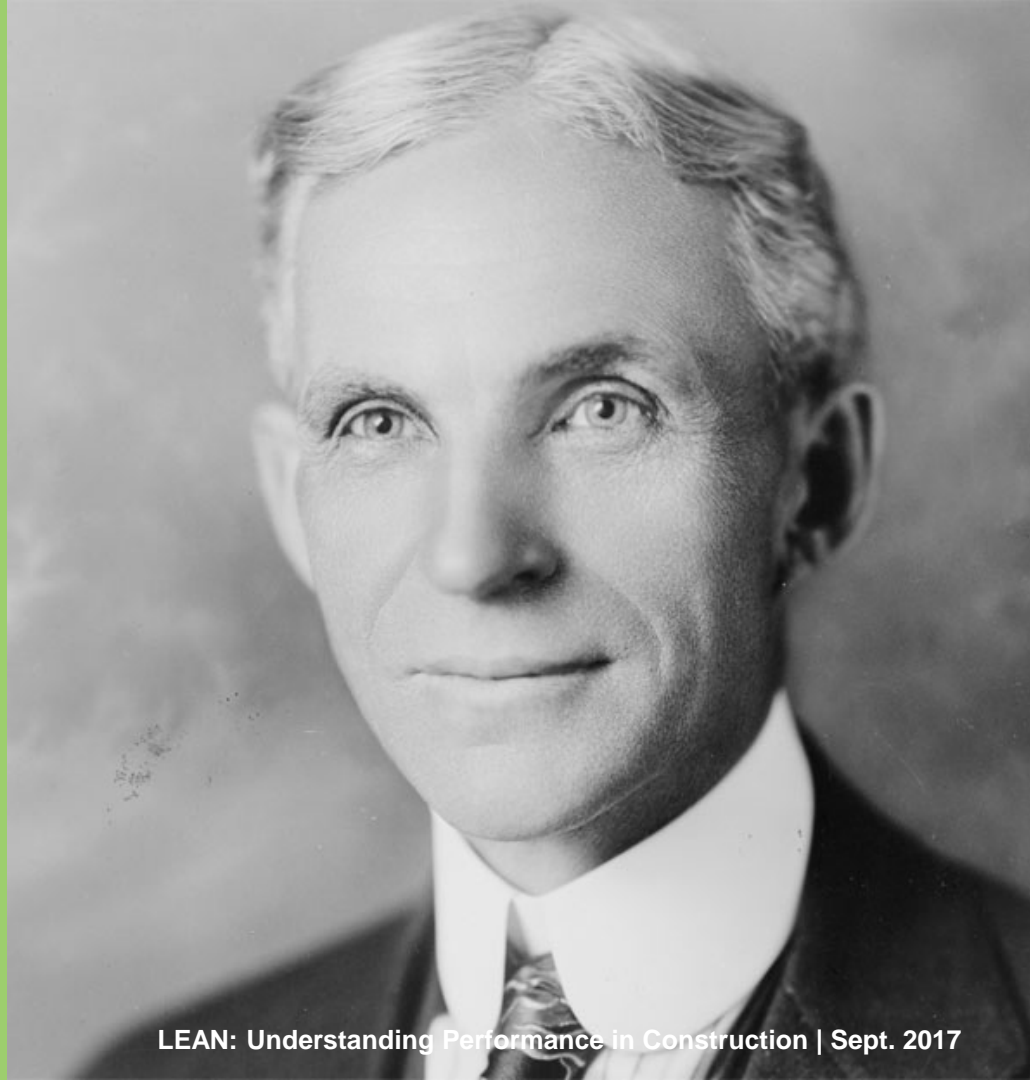


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Henry Ford

Henry Ford River
Rouge Complex

Assembly Line



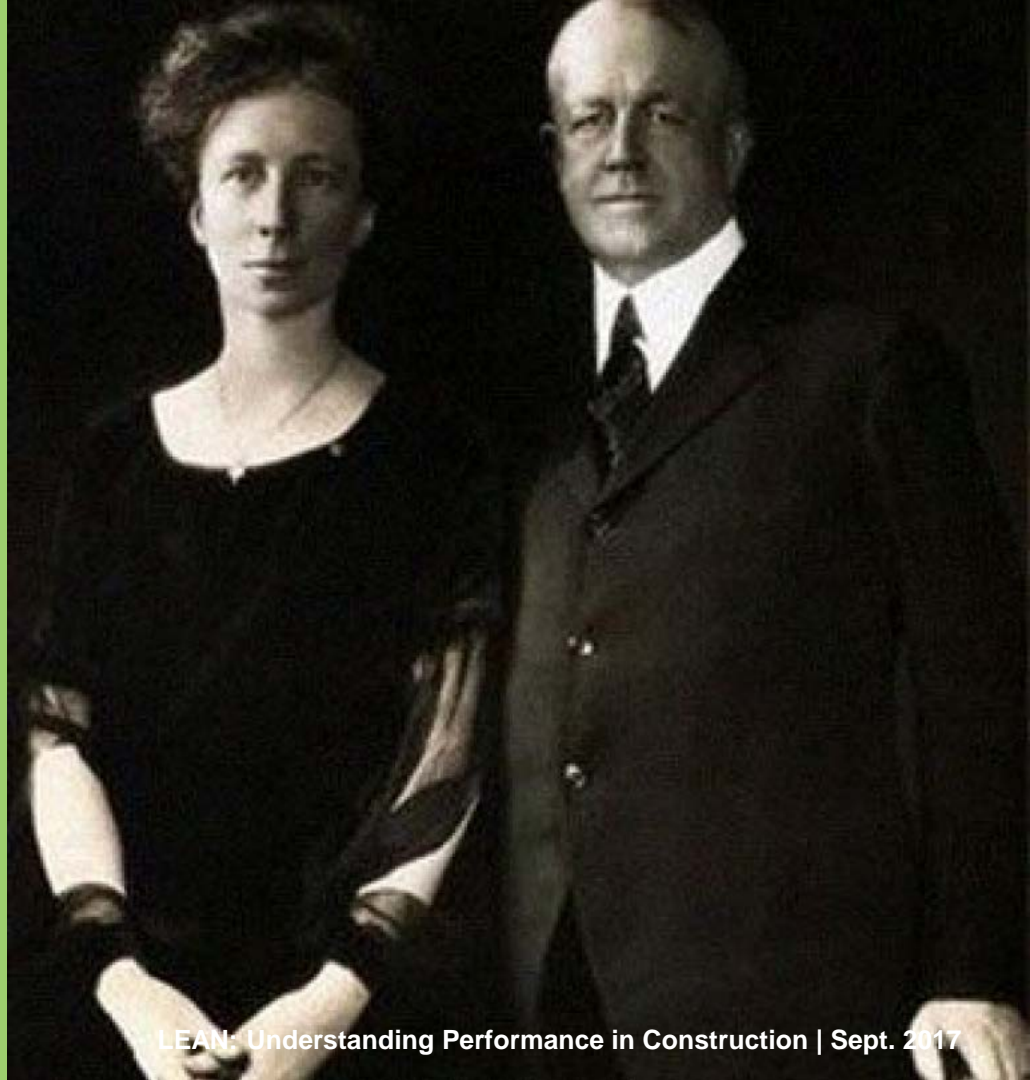


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Frank & Lillian Gilbreth

“The One Best Way”

- Reducing brick laying steps from 18 to 5
- Increased bricks installation from 125 to 300 / hr
- Increased production 240%





OAC:::

Frank & Lillian Gilbreth

“The One Best Way”

- Interchangeable parts with all construction
- Create uniform and tighter tolerances



6,000 years of interchangeable parts

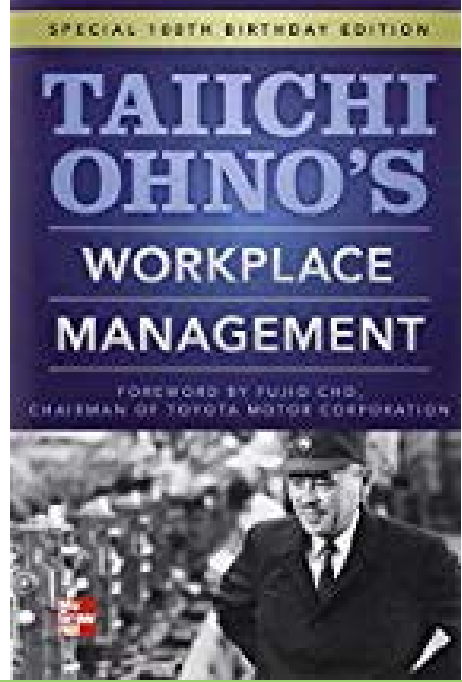
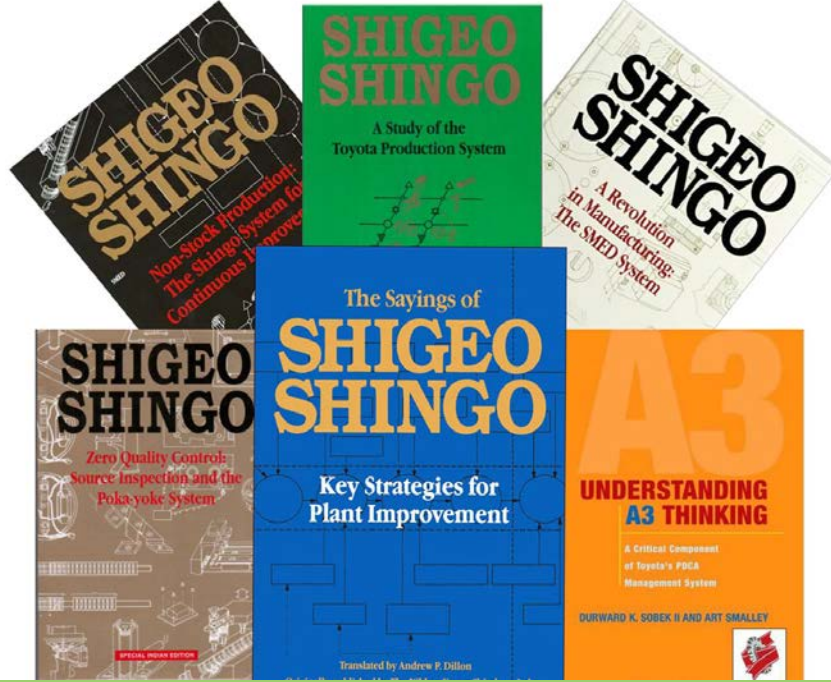


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Allan Mogensen

Work Simplification (1932)

- Work smarter not harder
- A common sense approach to motion studies



Continuous Improvement Pioneers



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Eliyahu Goldratt

The Theory of
Constraints





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TOYOTA PRODUCTION SYSTEM



The Word, “LEAN”



WHO'S AHEAD IN THE GLOBAL AUTO WARS AND WHY:
JAPAN'S REVOLUTIONARY LEAP FROM MASS PRODUCTION
TO LEAN PRODUCTION—AND WHAT INDUSTRY
EVERYWHERE CAN LEARN FROM IT

THE MACHINE THAT CHANGED THE WORLD

*Based On
The Massachusetts Institute of Technology
5-Million-Dollar 5-Year Study On The
Future Of The Automobile*

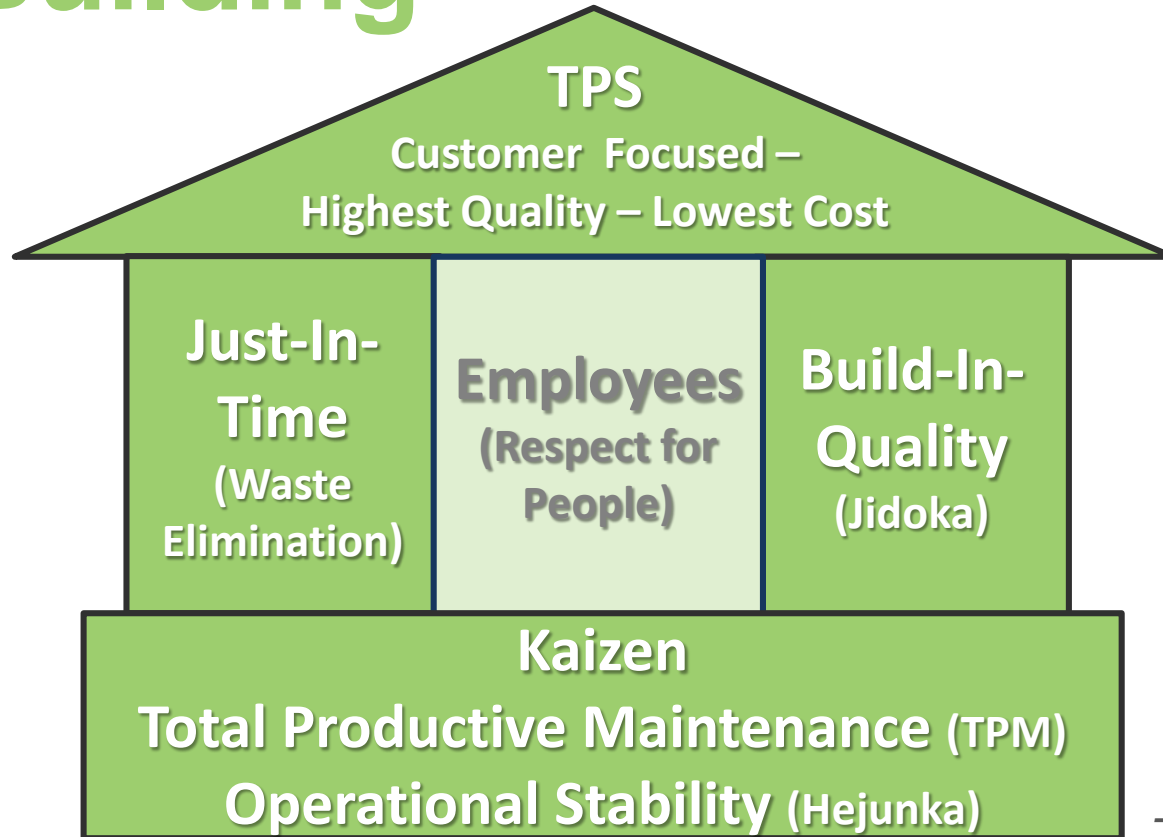


“It provides a way to do more with less – less human effort, less equipment, less time and less space – while coming closer and closer to providing customers with exactly what they want.”

- James Womack, Lean Thinking, 1996

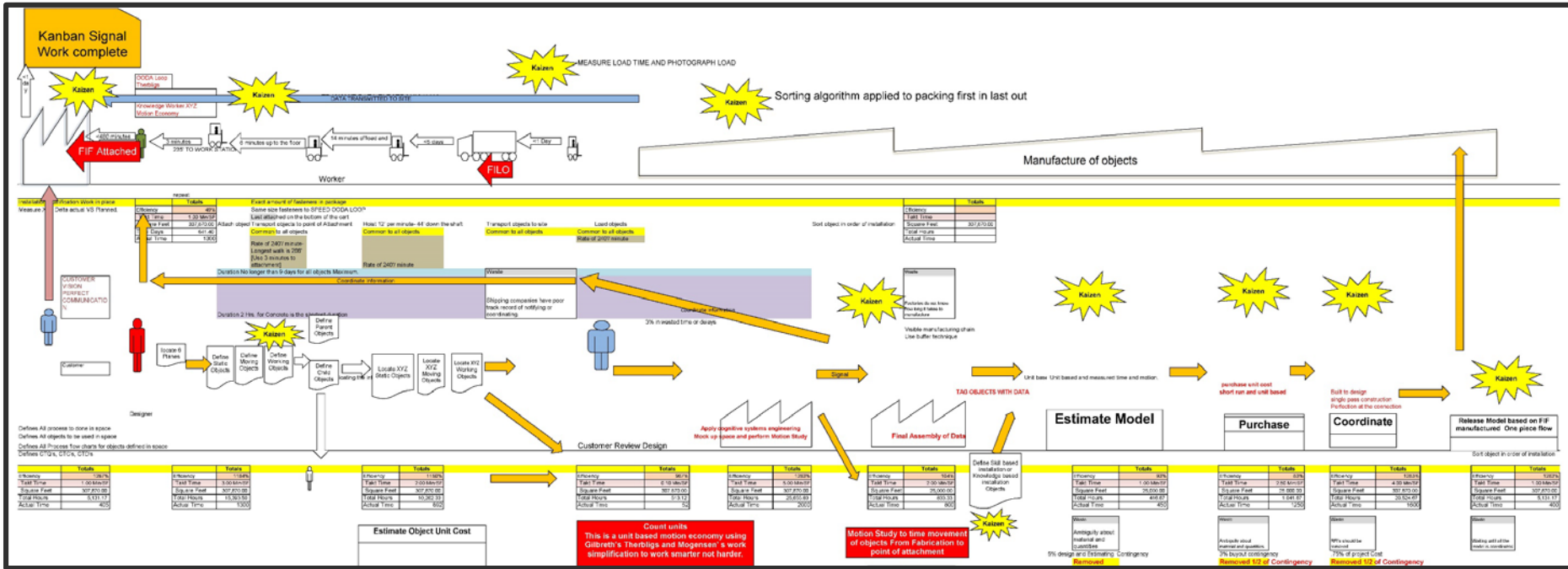
Why LEAN?

TPS Building



- Fujio Cho

Building is a "Process"



Work Simplification

Install drywall Wednesday, February 06, 2013		PRESENT		PROPOSED		DIFFERENCE		ANALYSIS					WHY	QUESTION EACH DETAIL
		NO.	TIME	NO.	TIME	NO.	TIME	WHAT?	WHERE?	WHEN?	WHO?	HOW?		
Operations														
Transportation								x	MAN	OR		MATERIAL		1. MAKE READY
Inspection														2. DO
Delays														3. PUT AWAY
Storage														
Distance Traveled			500 FT.		250 FT.		250 FT.							

DETAILS OF (PRESENT-PROPOSED) METHOD																	
	Constant / Variable	Operations	Transportation	Inspection	Delays	Storage	Distance in feet	Quantity	Mass	Number of People	Takt Time in minutes	Eliminate	Combine	Separate	Plan	Improve	Standardize
Uncover truck	Variable	●	→	■	■	▼	312	400	448	14	3760	0	0	0			
Unstrap units	Variable	●	→	■	■	▼	50	400	32	2	480						
Hoist into building	Variable	●	→	■	■	▼	50	800	32	2	480						
Load onto cart	Variable	●	→	■	■	▼	50	400	64	2	480						
transport to room	Variable	●	→	■	■	▼	100	400	32	2	480						
set on ground	Constant	●	→	■	■	▼	1	400	64	1	400						
pick up	Variable	●	→	■	■	▼	5	400	64	1	400						
lift to wall	Variable	●	→	■	■	▼	5	400	64	1	400						
screw off to wall 8 + 8 + 8	Variable	●	→	■	■	▼	1	400	64	1	400						



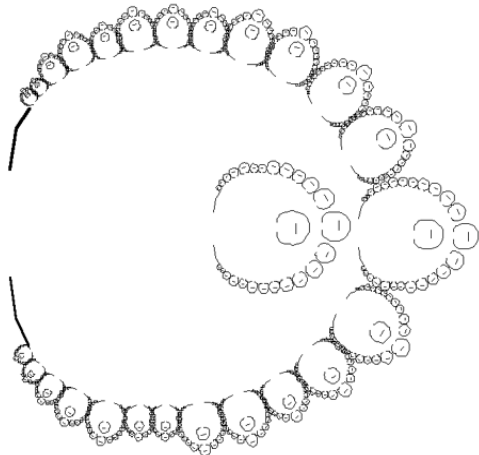
Like a pawl in a ratchet wheel, it permits forward motion, but prevents retracing of steps already taken

Where	What	What	What	What	Where			3,615 Items	What	Who attaches it	When is it attached	What is it attached to	How is it attached
Level	Category	Family	Type	Workset	Room	Zone	Space	Edited by	Id				Step 1
LEVEL 3	Walls	Basic Wall	interior - (FA) 4" Stud	Everything Else	<room unassigned>	<zone unassigned>	<space unassigned>	<nobody>	678264				
LEVEL 3	Rooms	Room	<Placed>	Everything Else	PHARMACY J0345	<zone unassigned>	<space unassigned>	<nobody>	1381014				
LEVEL 3	Rooms	Room	<Placed>	Everything Else	SURG PREP BAY B J0380B	<zone unassigned>	<space unassigned>	<nobody>	2040440				
LEVEL 3	Walls	Basic Wall	interior - (FA) 4" Stud	Everything Else	<room unassigned>	<zone unassigned>	<space unassigned>	<nobody>	2290063				
LEVEL 3	Electrical Fixtures	elec-Outlet	E Power - Duplex	Everything Else	PREP/PACU FLEX 2 J0370B	<zone unassigned>	<space unassigned>	<nobody>	2891749				
LEVEL 3	Specialty Equipment	Medical Equipment Library	Cabinet - Storage - Clinical - Stainless Steel	Medical Equipment	DR 31 J0331	<zone unassigned>	<space unassigned>	<nobody>	3867878				
LEVEL 3	Parts	Floors: Floor	Resilient RBS-3 (dark)	Interior Finishes	<room unassigned>	<zone unassigned>	<space unassigned>	<nobody>	4534151				

Modeling Utilization

Extracting Other Forms of Data from the Model

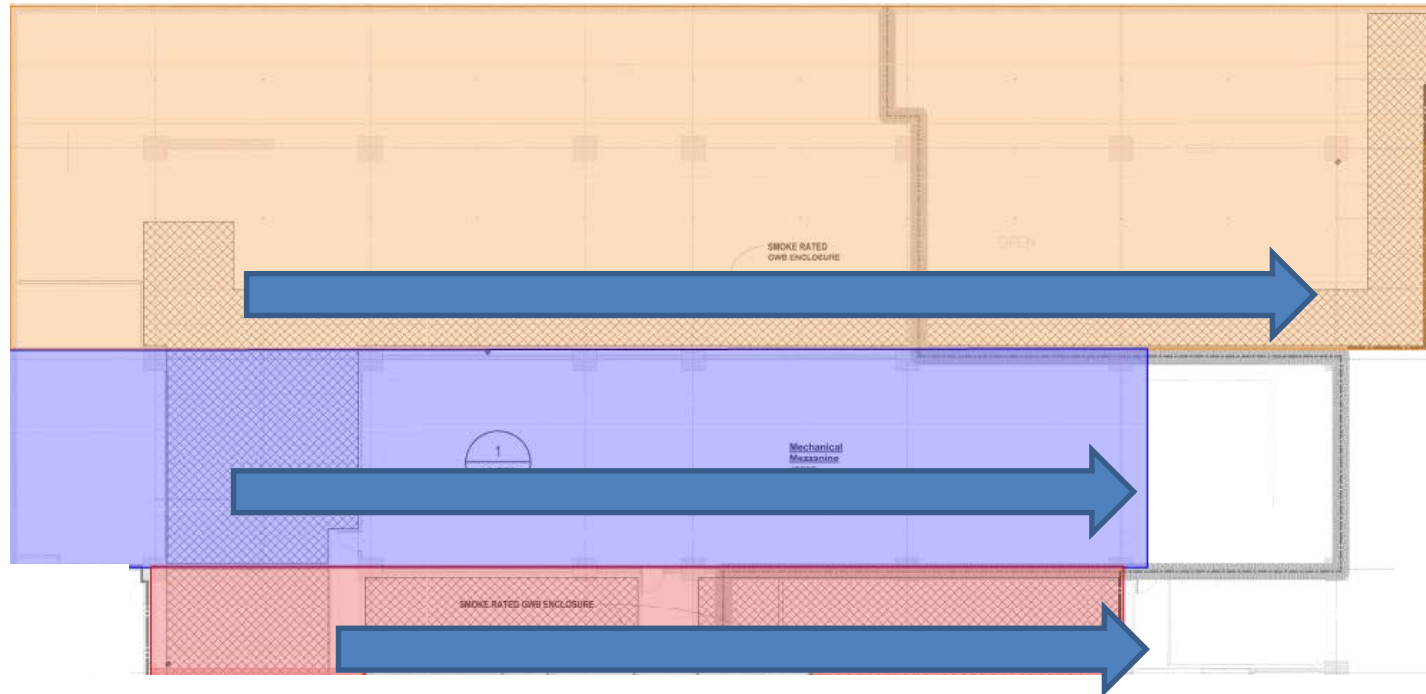
Look For Repeating Patterns



Man		Process		CHART	
OF <u>Carpenters</u>					
DATE <u>9-8-68</u>		LOCATION <u>Interstate 70</u>			
CONTRACTOR <u>Jones, J.</u>		BY <u>J.A.H.</u>		FILM NO. <u>B-40</u>	
DIST	SYMBOL	DESCRIPTION	TIME (SEC)		
50'	○	GO TO STOCKPILE	25		
	○	GET PLYWOOD	5		
50'	⊖	RETURN TO WORKPLACE	29		
	○	CHECK FIT AND MODIFY	35		
	○	NAIL	51		
	▽	IDLE	35		
50'	○	GO TO STOCKPILE	27		
	○	GET PLYWOOD	7		
50'	⊖	RETURN TO WORKPLACE	28		
	▽	PERSONAL BREAK	120		
	○	CHECK FIT AND MODIFY	40		
	○	NAIL	57		
50'	○	GO TO STOCKPILE	31		
	○	GET PLYWOOD	10		
50'	⊖	RETURN TO WORKPLACE	28		
	○	CHECK FIT AND MODIFY	15		
	○	NAIL	50		

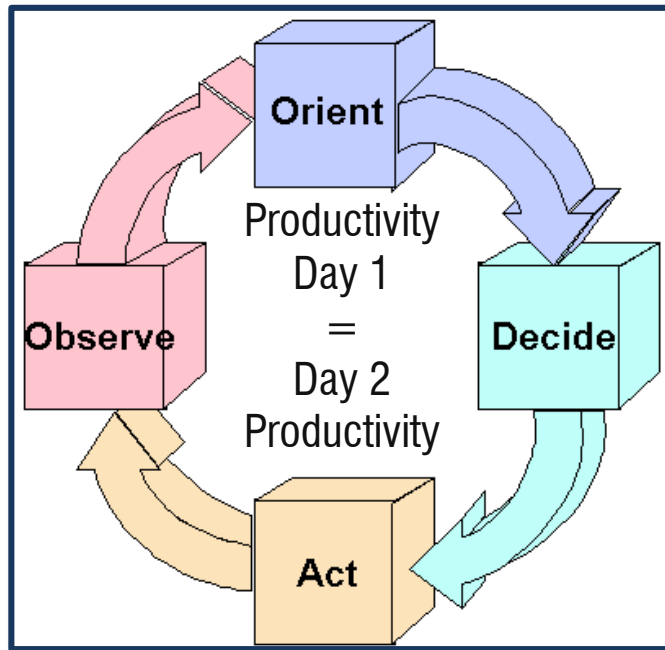


Building as a Process Chart





Situational Awareness = Tempo



Originated
by Col. John
Boyd (USAF)



Visual Work System

Visual Flows

Flows of Construction

Customer	Management	Workers	Equipment	Supplies	Material To be attached	Information	Waste	Food-Water-Sanitation	Cost Center
YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO

Construction Flow Types

	Attach	Detach	Self Attaching	Fastener	Self Organizing	Tool	Layout	Visual Control	Long Lead time
Trade	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO	YES / NO
Utilities	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined
Demolition	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined	Undetermined



Visual Workplace of the Future

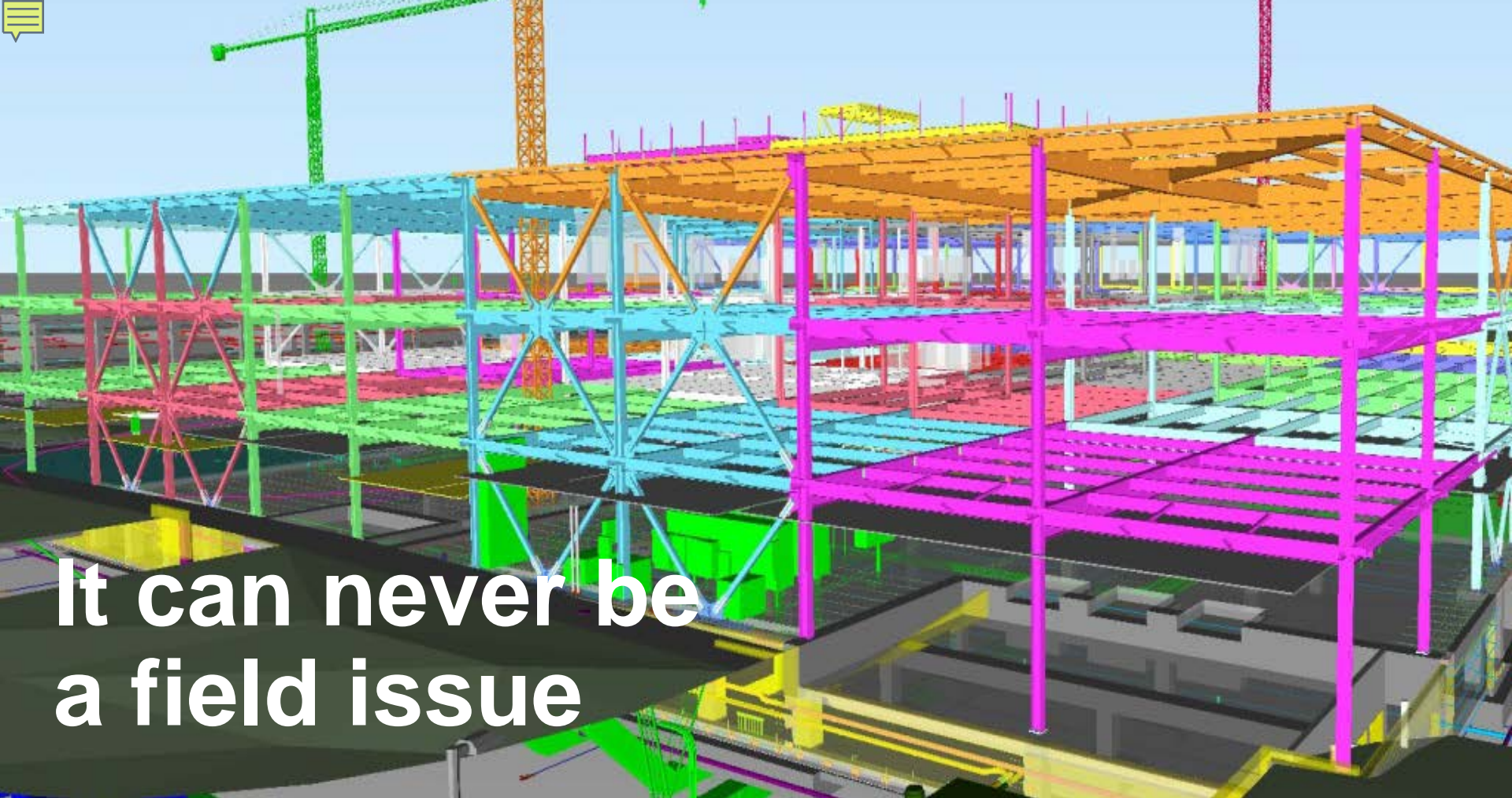


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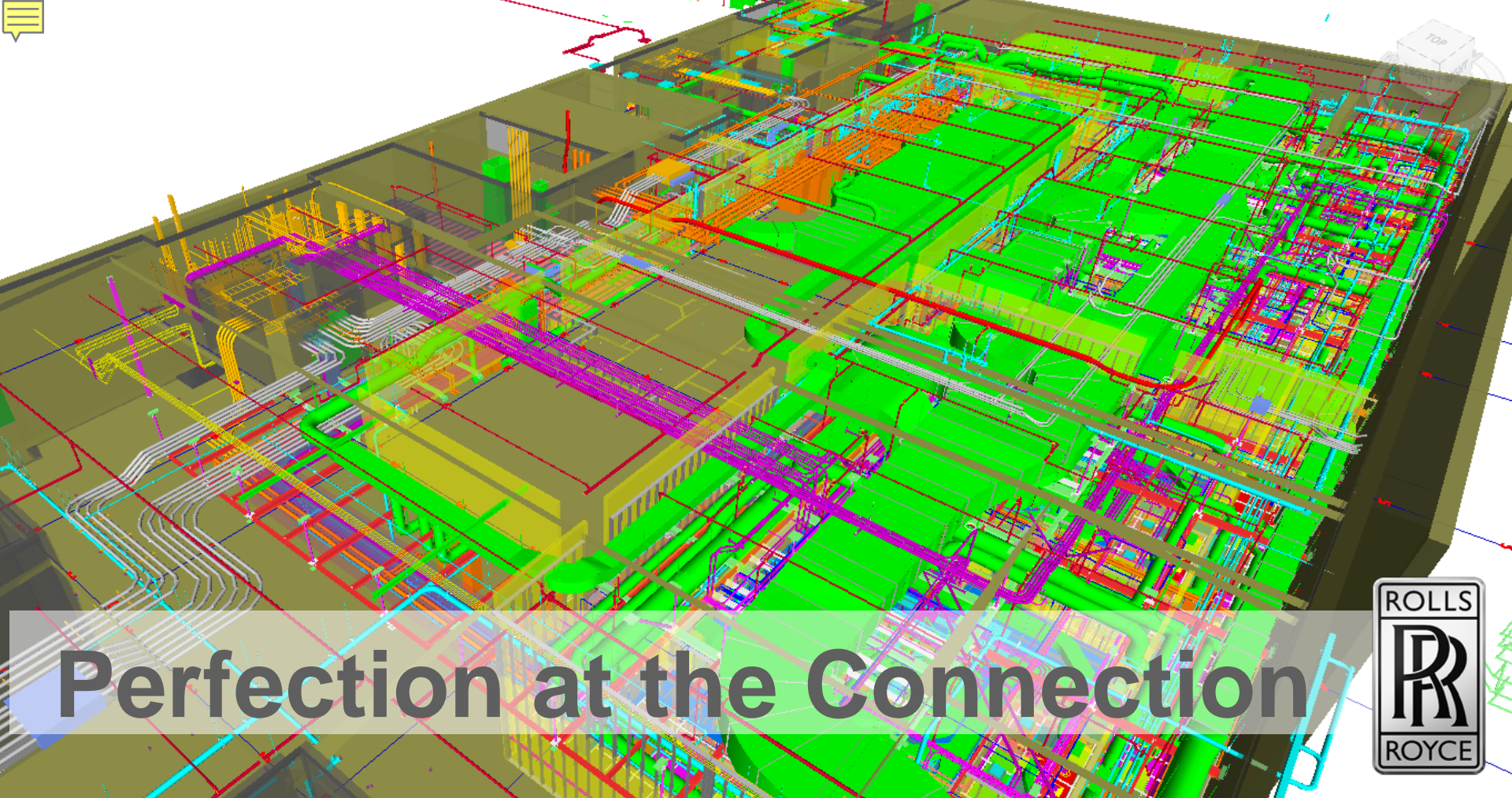
Construction Quality

- Unitized System from California
- Steel and Rain Screen Panels from Oregon
- Attached in Seattle





**It can never be
a field issue**



Perfection at the Connection



Single Minute Exchange of Die (SMED)

1. Separate internal to external setup
2. Standardize functionality
3. Promote clamps over fasteners
4. Utilize intermediate jigs
5. Adopt parallel operations
6. Eliminate adjustments by using positive stops
7. Mechanize technology to reduce time





SMED Structural Steel Erection





External Setup = Improved Working Conditions

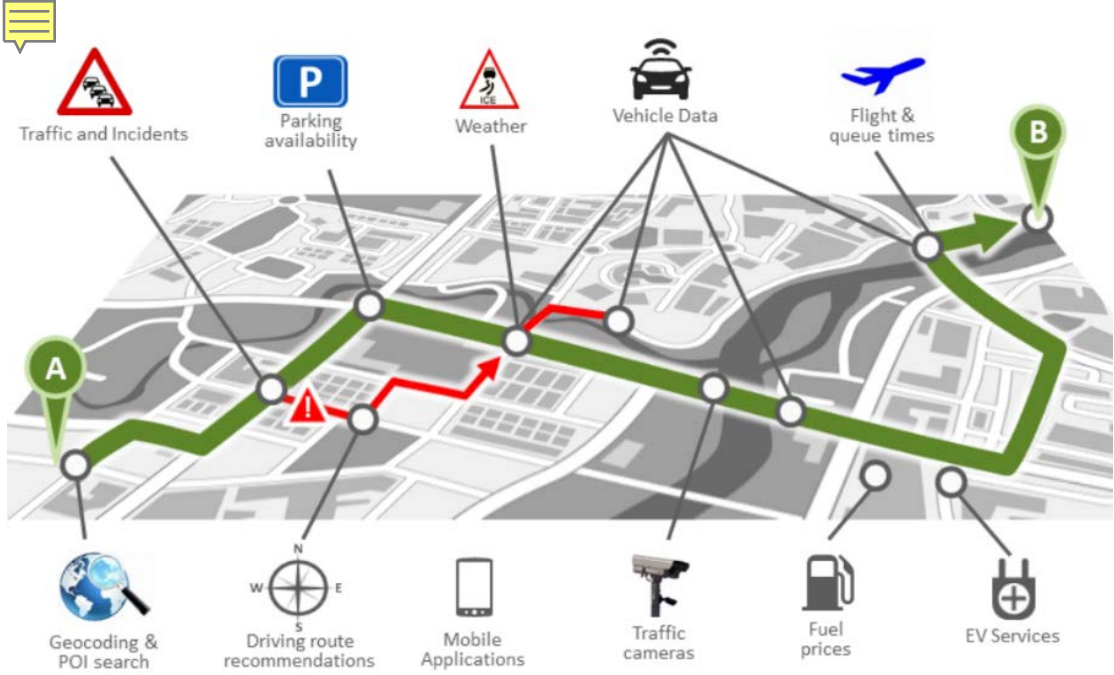


Global Site

Factory and site synchronization

Supply Chain

Building	Delivery DATE	START TIME	END TIME	Coming IN or going OUT	Contractor	ITEM Description	Detailed Description- Including Barcode # and area needed for laydown	HOISTING METHOD- All units must be on wheels	# Trucks	#Units	Location on site of Offload	Location of installation	Supplier and Location	Trucking Company	Contact Person on site	Phone TXT Message
B45	Thursday, October 09, 2014	7:00	7:45	IN	Apex	Stair # 3 and Stair # 6		North Towercrane	1	8	Crimson Gate	Stair # 3 and Stair # 6	Pacific Stair Salem Dr.	Unknown	Dave Chase	425-635-8757
B45	Thursday, October 09, 2014	7:00	15:00	Pump	Ralph's	Level 8	SOMD, Mix- 3169, 24,110sf	Pump	1	306 CuYds	Crimson Gate	LVL 8 Zone 2			Chris Lang	(206) 423-5108
B45	Thursday, October 09, 2014	7:00	7:05	Service	Clean Scapes	Pick up and Tip and Return Mixed use Dumpster	Dumpster to Be marked with Red Card	Self	1	1	9th Ave N				Torsten North	206-730-4265
B45	Thursday, October 09, 2014	7:30	15:00	IN	Calportland	Level 8	SOMD, Mix- 3169, 24,110sf	Pump	31	306 CuYds	Green Gate	Level 8	Calportland	Calportland	Chris Lang	(206) 423-5108
B45	Thursday, October 09, 2014	8:00	12:00	Pump	Ralph's	Level 1 Zone 2 Central-Curbs-Pour 2	Curbs, Mix- 3210	Pump	1	45 CuYds	Green Gate	LVL 1 Zone 2			Chris Lang	(206) 423-5108
B45	Thursday, October 09, 2014	8:30	12:00	IN	Calportland	Level 1 Zone 2 Central-Curbs-Pour 2	Curbs and Walls, Mix- 3210	Pump	5	60 CuYds	Green Gate	LVL 1 Zone 2	Calportland	Calportland	Chris Lang	(206) 423-5108
B45	Thursday, October 09, 2014	8:30	9:00	IN	MMFS	HARDWARE AND HANGERS	SET ON ROLLING CARTS	HAND	1	10 CuYds	Yellow Gate	LEVEL 1	ACME	ACME	PAT SCOTT	206-510-3104
B45	Thursday, October 09, 2014	11:00	11:30	IN	MMFS	HOUSEKEEPING PAD FRAMES	FRAMES	HAND	1	3 CuYds	Crimson Gate	ROOF LEVEL	MMFS	MMFS	PAT SCOTT	206-510-3104



Block 45 Truck Route

Movement Analytics



Supply Chain & Crane Schedule Synchronized

Upper Table: Tower Crane Schedule

Lower Table: Site Delivery Schedule

Crane 2 North					Monday, October 20, 2014		Crane 1 South				
Time	Contract or	Towercrane		From	To	Time	Contractor	Towercrane		From	To
7:00	TCCO	SAFETY MEETING	SANICANS/CAMLEVE RS			7:00	TCCO	SAFETY MEETING			
7:10	TCCO	SANICANS/CAMLEVE RS				7:10	TCCO	SAFETY MEETING	SANICANS/CAMLEVE RS		
7:30	APEX	Erect Steel		Shake out		7:30	Gerdau	LVL 1 Stem Walls, Curbs and Architectural Walls		Green Gate	
8:00	MMFS	LVL 4&5 Risers		Crimson Gate		8:00	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof
8:15	MMFS	LVL 4&5 Risers		Crimson Gate		8:15	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof
8:30	MMFS	LVL 4&5 Risers		Crimson Gate		8:30	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof
8:45	MMFS	LVL 4&5 Risers		Crimson Gate		8:45	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof
9:00	MMFS	LVL 4&5 Risers		Crimson Gate		9:00	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof
9:30	MMFS	LVL 4&5 Risers		Crimson Gate		9:30	APEX	Structural Steel Delivery		Truck in Purple Gate	Roof

Delivery DATE	START TIME	END TIME	Coming IN or going OUT	Contractor	ITEM Description	Detailed Description - Including Barcode # and area needed for laydown	HOISTING METHOD - All units must be on wheels	# Trucks	#Units	Location on site of Offroad	Location of installation
10/20/2014	7:00	7:30	OUT	MMFS	Scissor Lift Call Off	Ramp	N/A	1.0	0:00	Alley on Republica n	N/A
10/20/2014	8:30		In	Clearscapes	Dumpster Switch out			1.0	1@ 40 Yards	Crimson Gate	
10/20/2014	9:30		In	Clearscapes	Dumpster Switch out			1.0	1@ 40 Yards	Purple Gate	
10/20/2014	7:30	8:00	IN	ANG	Gang boxes and clips	Level 5	Reach Forklift / menut	1.0	0:00	Purple Gate	Level 5
10/20/2014	7:30	8:00	IN	Gerdau	LVL 1 Stem Walls Curbs and Architectura l walls		South Towercrane	0.0	0:00	Green Gate	Level 1



Assembly Line



Crimson Gate

Green Gate

Purple Gate



Predicting the Entire Process

ZONES: 123 & 124		Weight: 52,278	Total Time		Date	Begin	Finish
Unload	2 Trucks @	40.0 Minutes / Each	1.33	1.33	09/16/2014	2:03 PM	3:23 PM
123		Piece Count: 29					
Erect	5 Columns @	8.0 Minutes / Each	0.67				
Erect	5 Headers @	4.0 Minutes / Each	0.33				
Erect	19 Beams @	2.5 Minutes / Each	0.79				
Erect	0 Braces @	5.0 Minutes / Each	0.00				
Spot	3 Deck Bundles @	5.0 Minutes / Each	0.25				
Stair	0 Flights	15.0 Minutes / Each	0.00	2.04	09/17/2014	3:23 PM	5:00 PM



Value Added vs. Wasteful Activities



OVERPRODUCTION



WAITING



INVENTORY



MOVEMENT



EFFORT

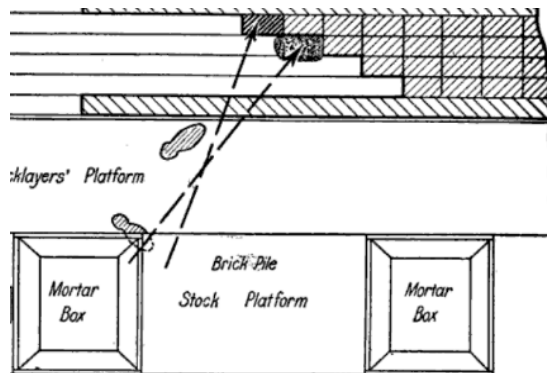


REWORK OF
ERRORS



PROCESSING

Motion Study & Engineering Science



1911 - Foot placement for Masons

Therblig	Color	Symbol/Icon	Therblig	Color	Symbol/Icon
Search	Black	⊖	Use	Purple	U
Find	Gray	⊗	Disassemble	Violet, Light	#
Select	Light Gray	↑	Inspect	Burnt Orange	o
Grasp	Lake Red	∩	Pre-Position	Sky Blue	⊗
*Hold	Gold Ochre	⊖	Release Load	Carmine Red	6
Transport Loaded	Green	∩	Unavoidable Delay	Yellow Ochre	∩
Transport Empty	Olive Green	∪	Avoidable Delay	Lemon Yellow	∩
Position	Blue	9	Plan	Brown	⊖
Assemble	Violet, Heavy	#	Rest for overcoming fatigue	Orange	∩



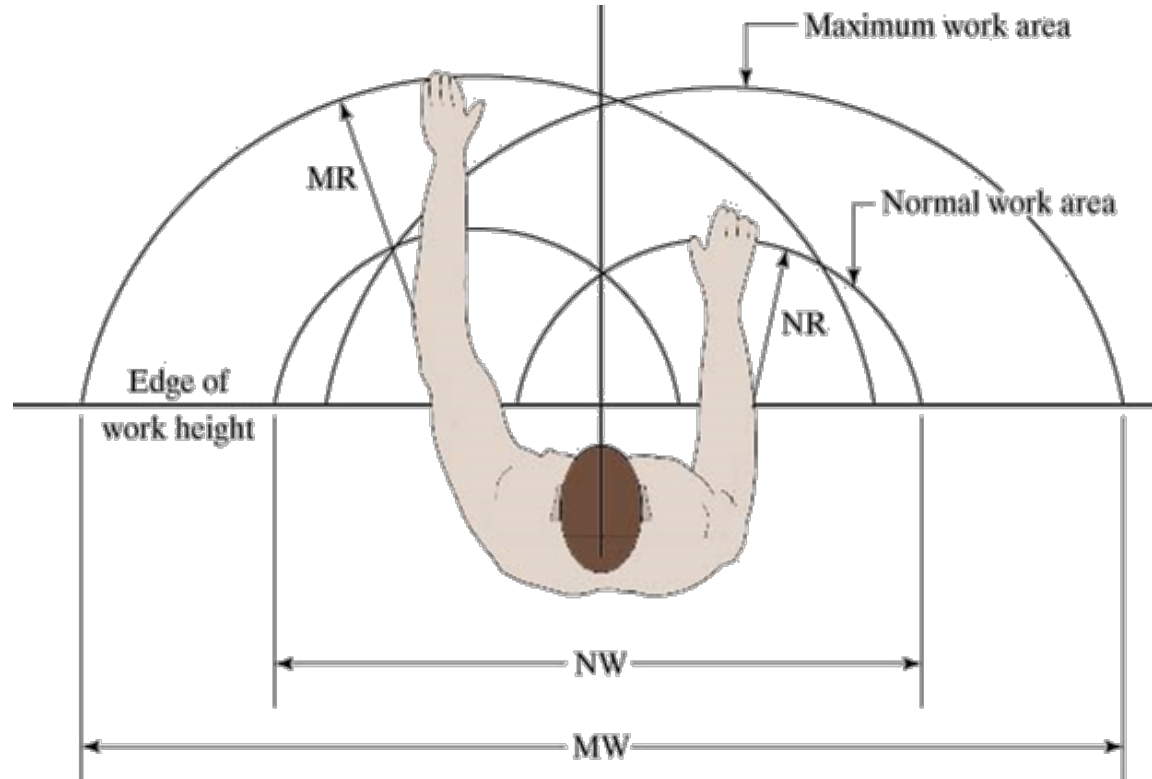
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Motion Study & Engineering Science





Motion Study



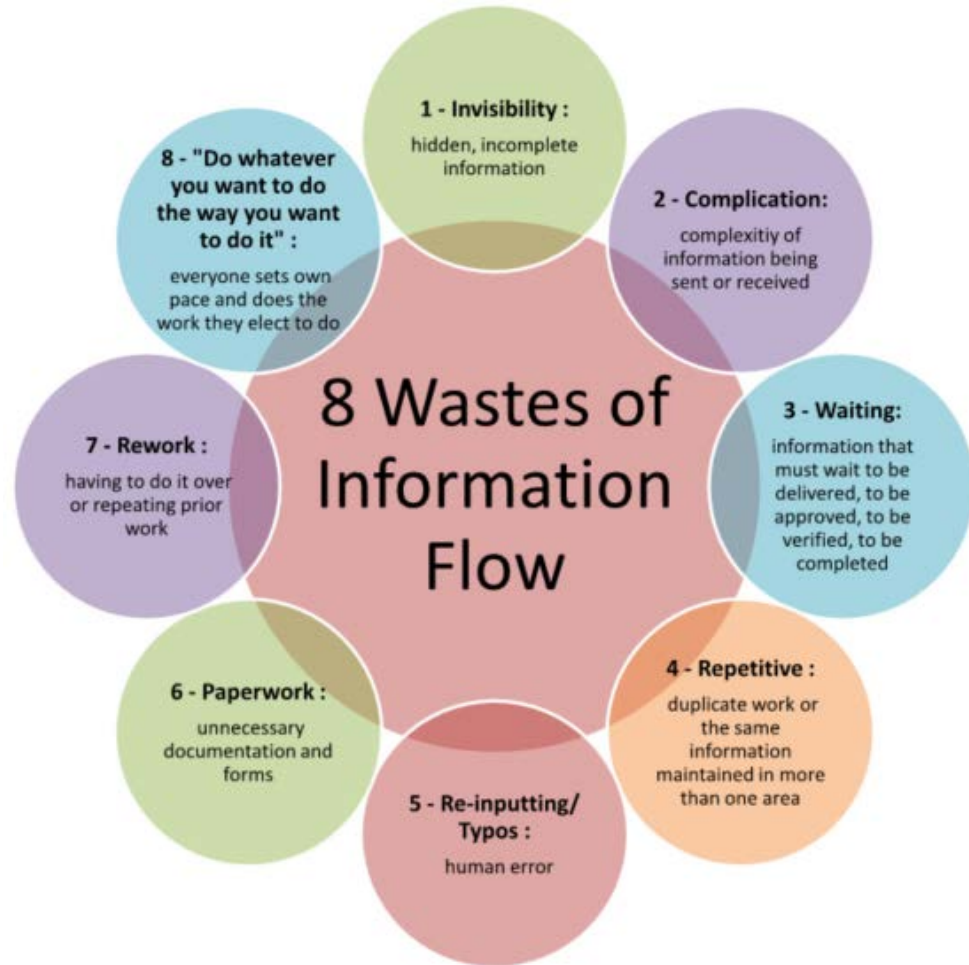
1. 3 motions x 2 seconds ea. =
6 seconds
2. 500 times daily x 6 seconds
= 50 minutes / day
3. 5 work days x 50 minutes =
4.16 hours/week
4. 5 workers a week x 4.16 hours
= 20.8 hours a week
5. \$10 /hour x 20.8 hours =
\$208 a week



10% Savings From a
Two Second Change

- Gilbreth

Sato's Eight Wastes





1. Design
2. Estimating
3. Master Schedule
4. Purchasing
5. Submittals
6. BIM
7. Detailing
8. Task based
process chart
9. Last Planner
10. Fabrication
11. Receiving
12. Installation
Qualification
13. Billing
14. AHJ Inspections
15. Special Inspections
16. Start up
17. Commissioning
18. Punch list
19. Owner Training
20. Maintenance
21. End User

The “I” in BIM



OAC:::

Quality of Information

- What is it?
- Where should it be?
- When did it get here?
- Who is installing it?
- Does it meet specification?



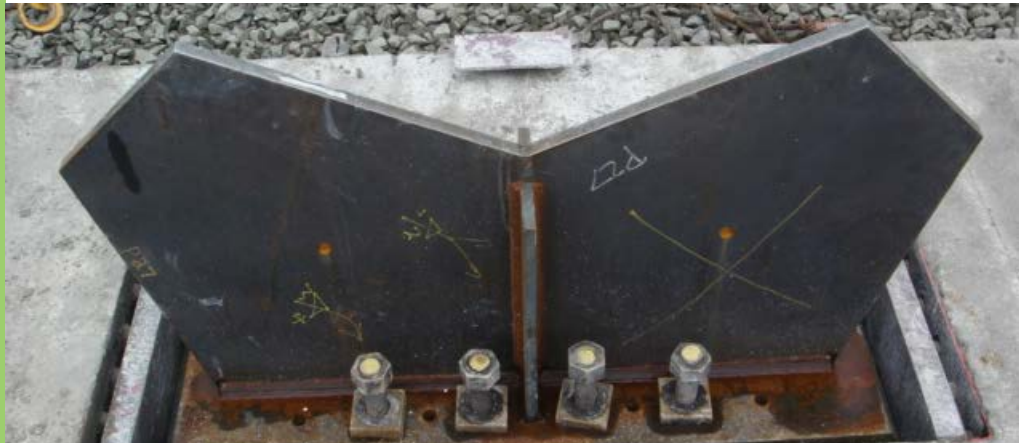
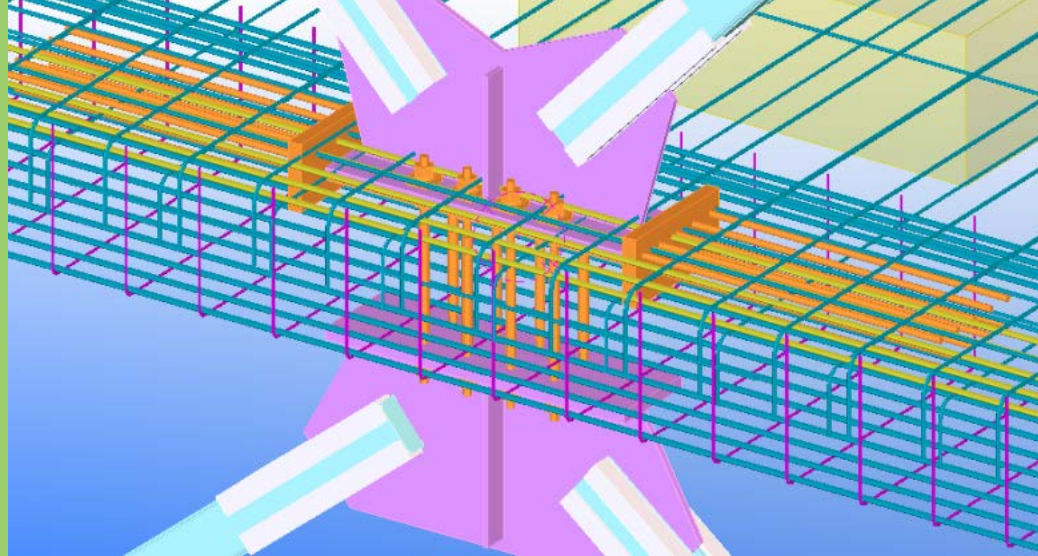


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Built in Quality

Problem: lack of time and congestion

Solution: model of brace frame, bolts, rebar, and embeds





Positioning to Design

1,800 targets
+/- 3/16 in.

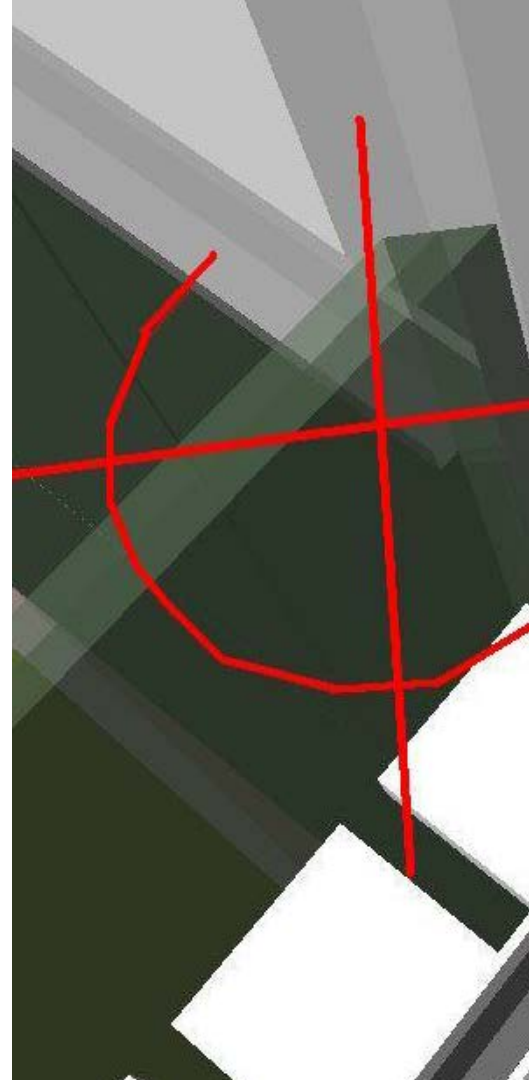


OAC:::

Virtual = Reality

Installation Qualification
Work in Place Report

- Quality
- Schedule
- Cost
- Billing validation





Electrons to Atoms

1. General Contractor
2. HVAC
3. Pipe fitters
4. Plumbing
5. Electrical
6. GWB
7. Fire Protection
8. Glaziers
9. Underground Utilities
10. Shoring
11. Structural Excavation



Cost of Quality

RFI's 0.8%-1.5%
 Punch List ?%
 Contingency 1%-5%
 Wrong information ?%
 No information ?%

Tasks	Average Hours/ Task	Hourly Rate	Cost of Task	Cost of Materials	Other Failure Costs	Total Cost of Non-Conformance	
Find the problem	1.5	\$85	\$127.50		\$0.00	\$127.50	
Research background information	1.3	\$75	\$93.75		\$0.00	\$93.75	
Write RFI	0.5	\$75	\$37.50		\$0.00	\$37.50	
Read and research answer	2.0	\$75	\$150.00		\$0.00	\$150.00	
Review RFI in OAC Meeting	0.8	\$75	\$62.50		\$0.00	\$62.50	
Respond and distribute RFI	1.0	\$65	\$65.00		\$0.00	\$65.00	
Review and distribute RFI	1.0	\$65	\$65.00		\$0.00	\$65.00	
Review and install New work	2.0	85	\$170.00		\$0.00	\$170.00	
			\$0.00		\$0.00	\$0.00	
Total Cost Per Failure						\$771.25	
Outages/Project						80	
1. Lost Opportunity Costs					\$5,430.00	\$5,430.00	
2. Lost Assets Costs					\$0.00	\$0.00	
3. Lost Business Costs					\$0.00	\$0.00	
Additional Failure Costs						\$5,430.00	
Project Field Failure Cost						\$67,130.00	
Basic tasks to fix the problem		Average min/60	Loaded rate	Calculated cost	Expenses	Customer or Employee founc	Total
Return on Investment and Payback							
Target Reduction				50%	\$33,565.00		
Prevention Costs					\$10,000.00		
ROI					\$3:\$1		







Presenter Contact Information

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