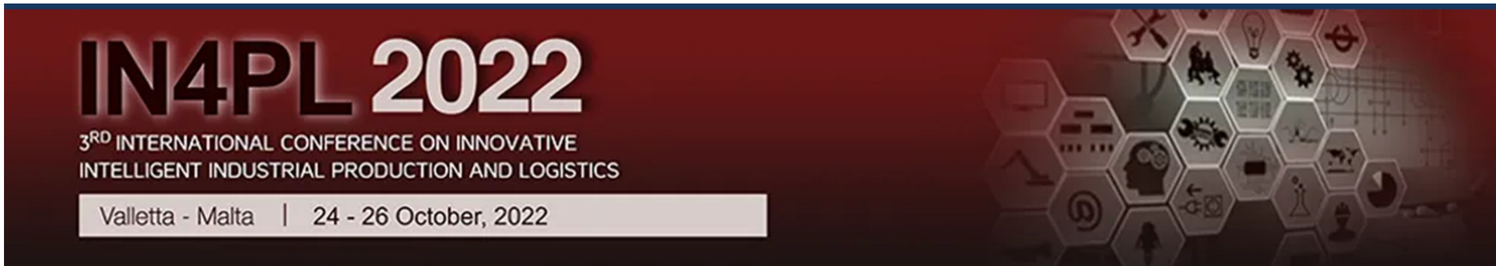

Digital Twin for Assembly Line Fitness Analytics

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FORD ANALYTICS
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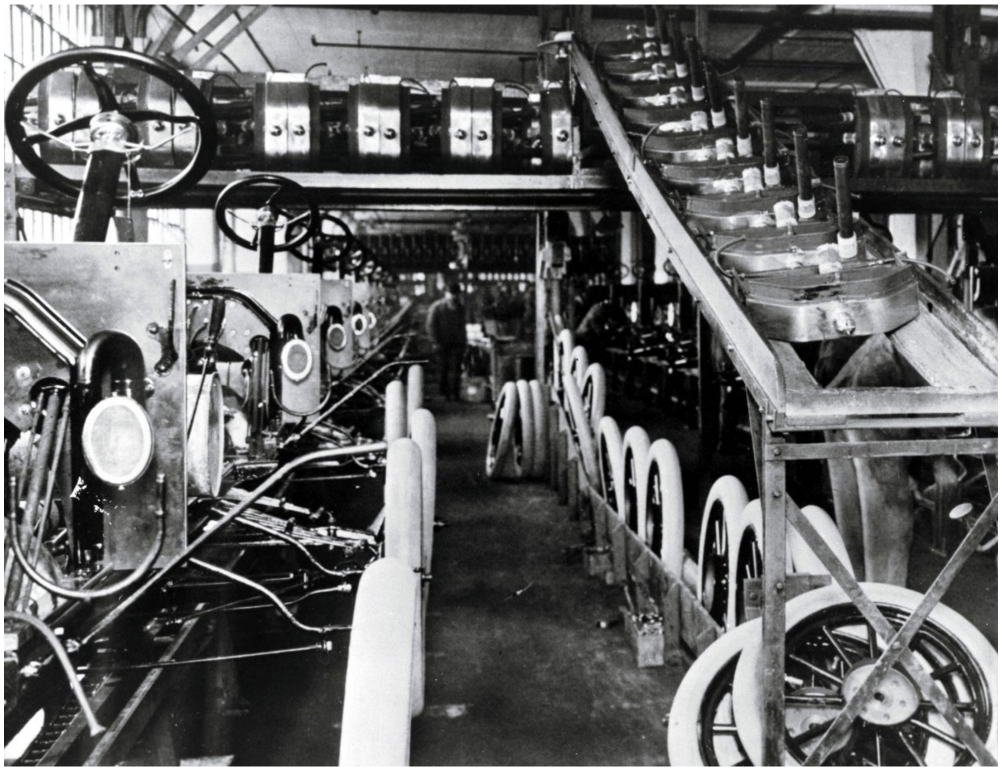
Presentation Outline

- Introduction
- 109 years of assembly line evolution
- Assembly Line Planning
- Assembly Line Digital Twin
- Workcell Layout and Operator Walk Pattern Analysis
- Precedence Constraints Generation
- Assembly Line Balancing
- Predicting Operator Overload and Interference
- Summary

Assembly Line

an arrangement of machines, tools, and workers in which a product is assembled by having each perform a specific, successive operation on an incomplete unit as it passes by in a series of stages organized in a direct line.

Ford Model T Assembly Line at Highland Park

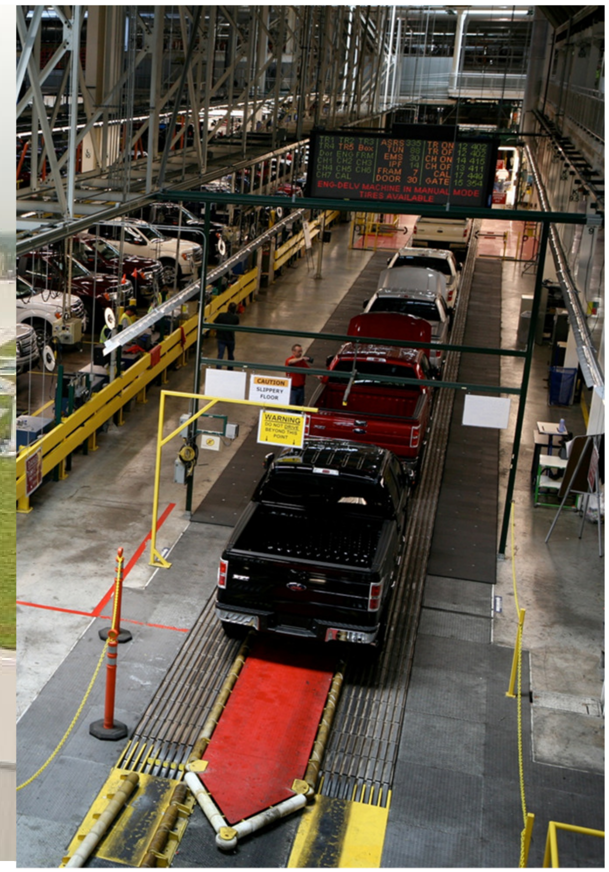


Assembly Line 1940th

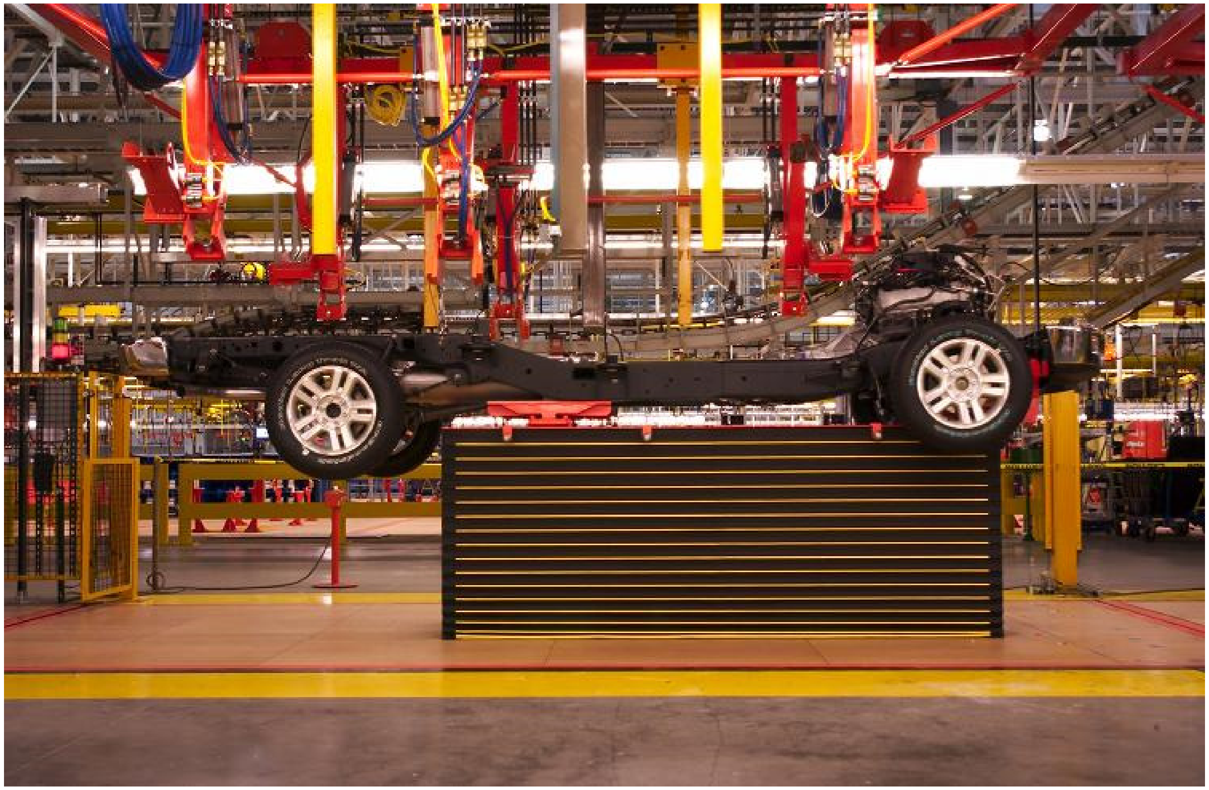
Dearborn Assembly Plant 1954

F-Series Production

Dearborn Truck Plant 2000



Dearborn Truck Plant 2000



Dearborn Truck Plant 2000

e-Workcell for workstation layout

VRML-based interactive 3D tool for assembly workcell layout

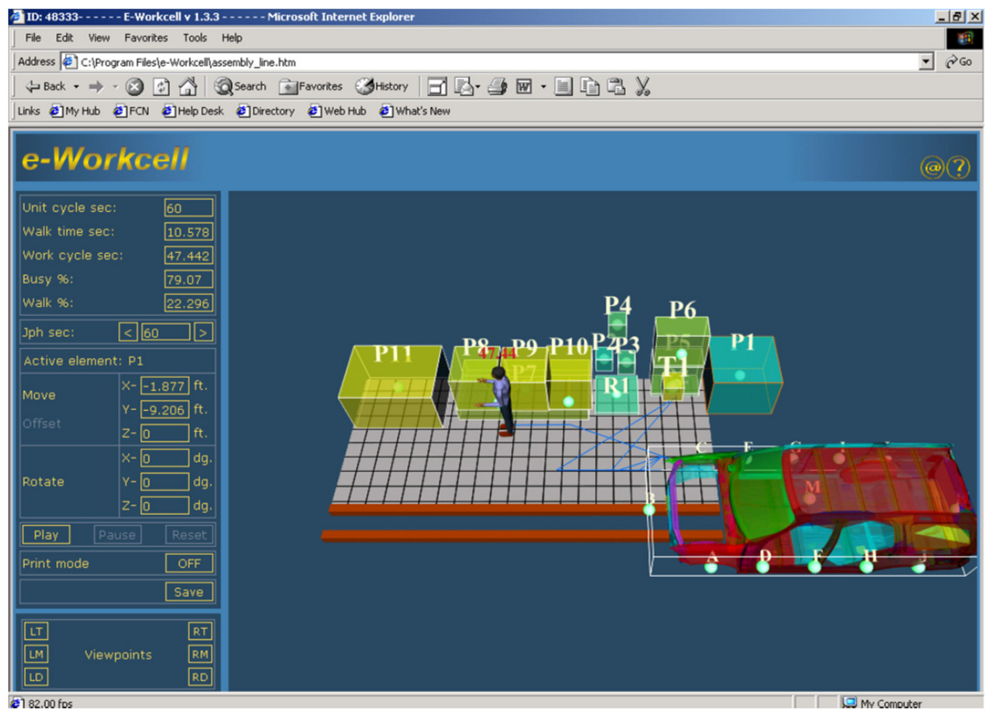
Lean Manufacturing tool developed to support the launch of Dearborn Truck Assembly

Provides direct interface to existing database systems

Universally accessible and intuitive. Used by engineers and assembly line operators

Detailed Modeling

- Pitch, vehicle size
- Workstation dimension
- Line speed
- Part/tool location
- Vehicle zone
- Operator Synchronization

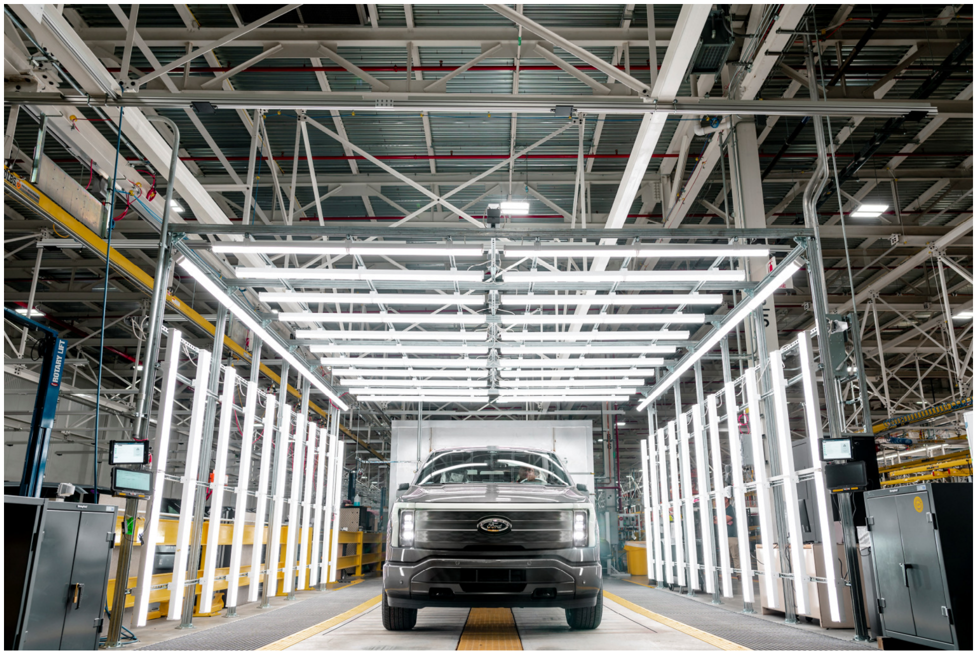


F150 Lightning Production

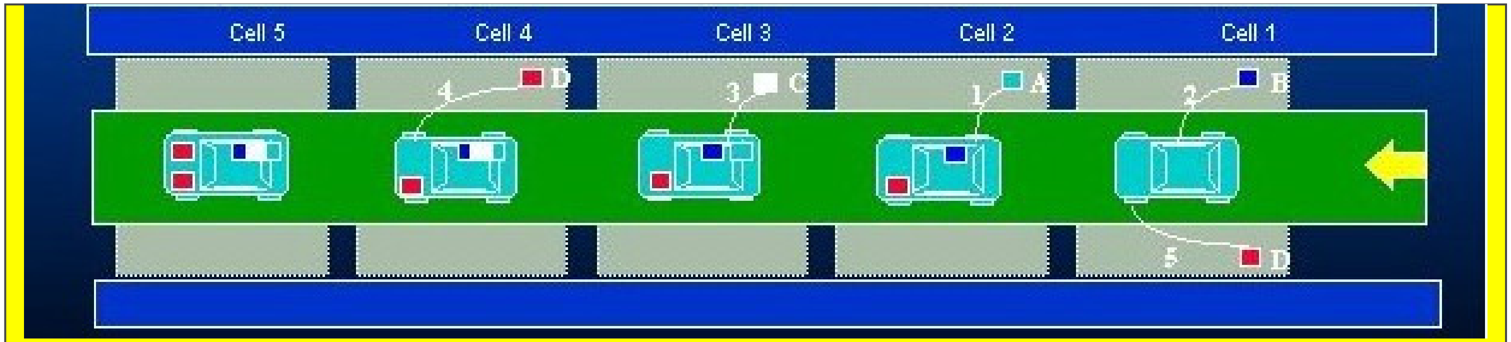
F150 Lightning Production

F150 Lightning Production

F150 Lightning Advanced Manufacturing



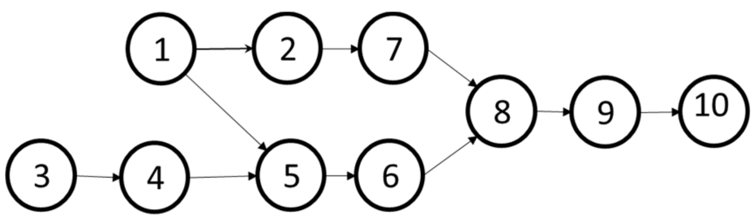
Automotive Assembly Line Planning

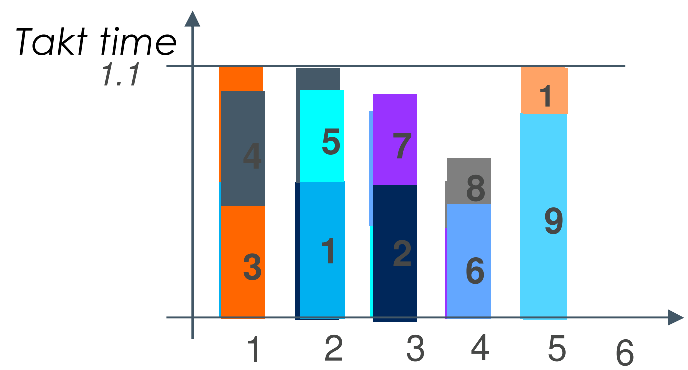


- Line Balancing: distribute work required to assemble the vehicle among a set of workstations
- Workstation design: arrange elements in workstations (bins, tools, etc)

Line Balancing Problem

Task	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Time (Min)	0.6	0.6	0.5	0.5	0.4	0.5	0.4	0.2	0.9	0.2

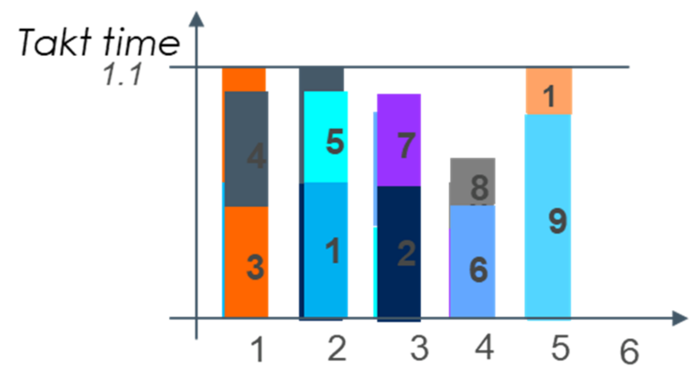


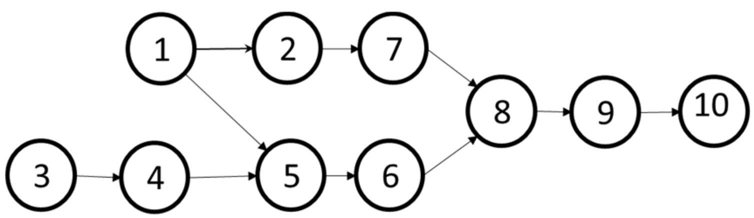


Precedence graph for assembly process

Line Balancing Problem

Task	1	2	3	4	5	6	7	8	9	10
M1 (60%)	0.40	0.20	0.40	0.30	0.40	0.40	0.00	0.20	0.70	0.15
M2 (40%)	0.80	1.20	0.60	0.80	0.40	0.65	1.00	0.20	1.20	0.28
Time (Min)	0.6	0.6	0.5	0.5	0.4	0.5	0.4	0.2	0.9	0.2





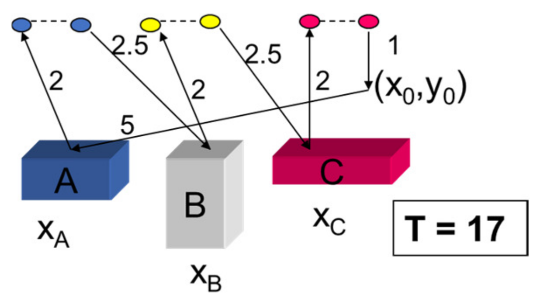
Precedence graph for assembly process

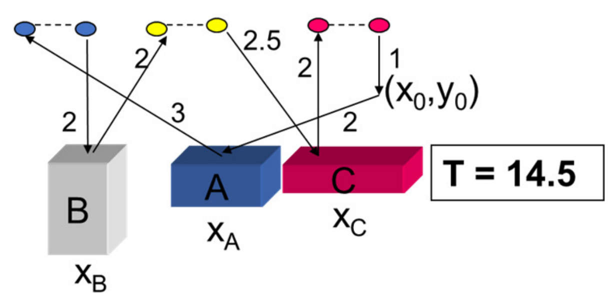
Workstation Layout Problem

- Each operator has their own workcell
- Each workcell contains part bins necessary for the operator's work.
- Each operator has a set of tasks that must be performed
- Each operator must determine how to arrange the part bins in the workcell

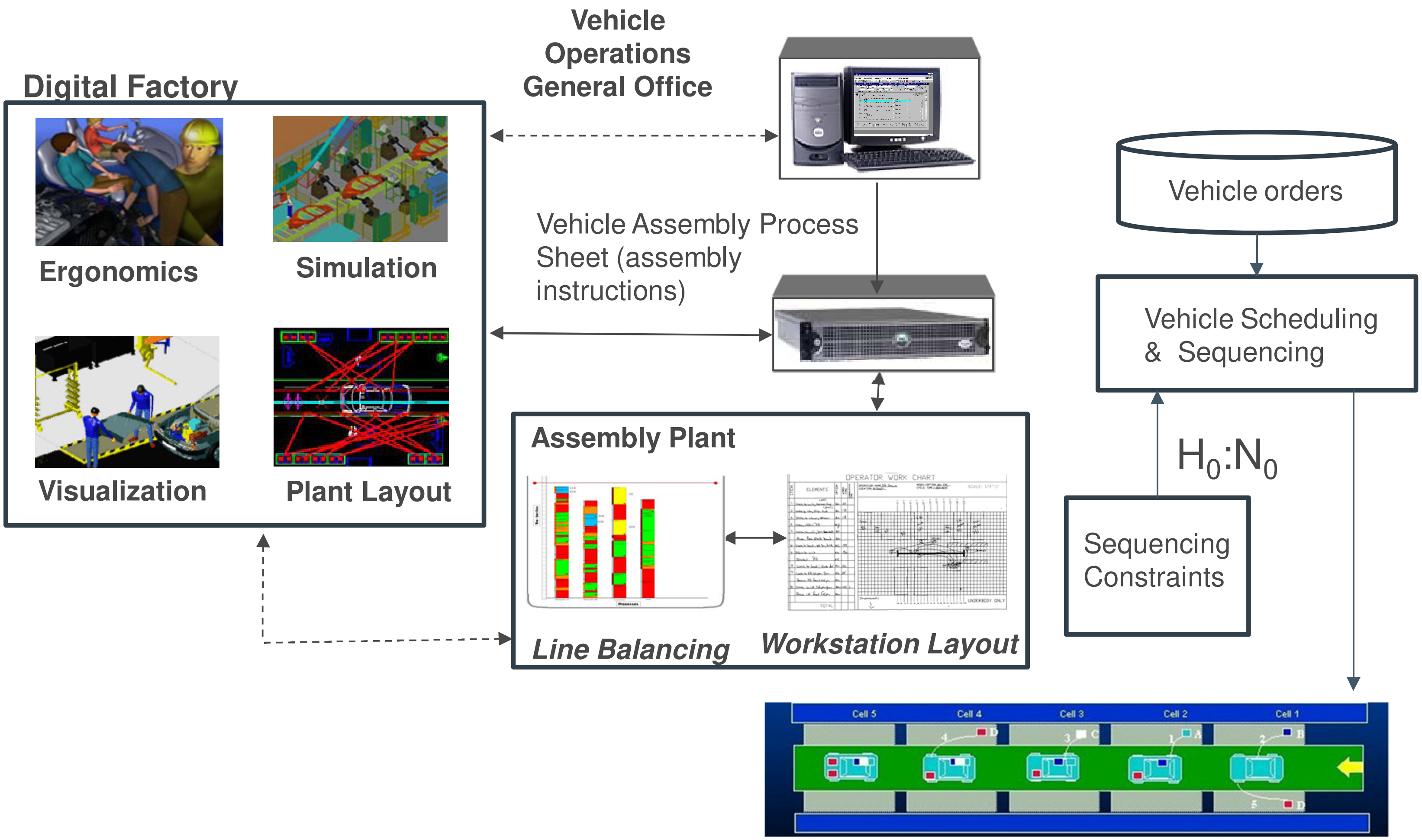
Sequence:

- Pick up part A
- Install part A
- Pick up part B
- Install part B
- Pick up part C
- Install part C
- Return to initial starting point





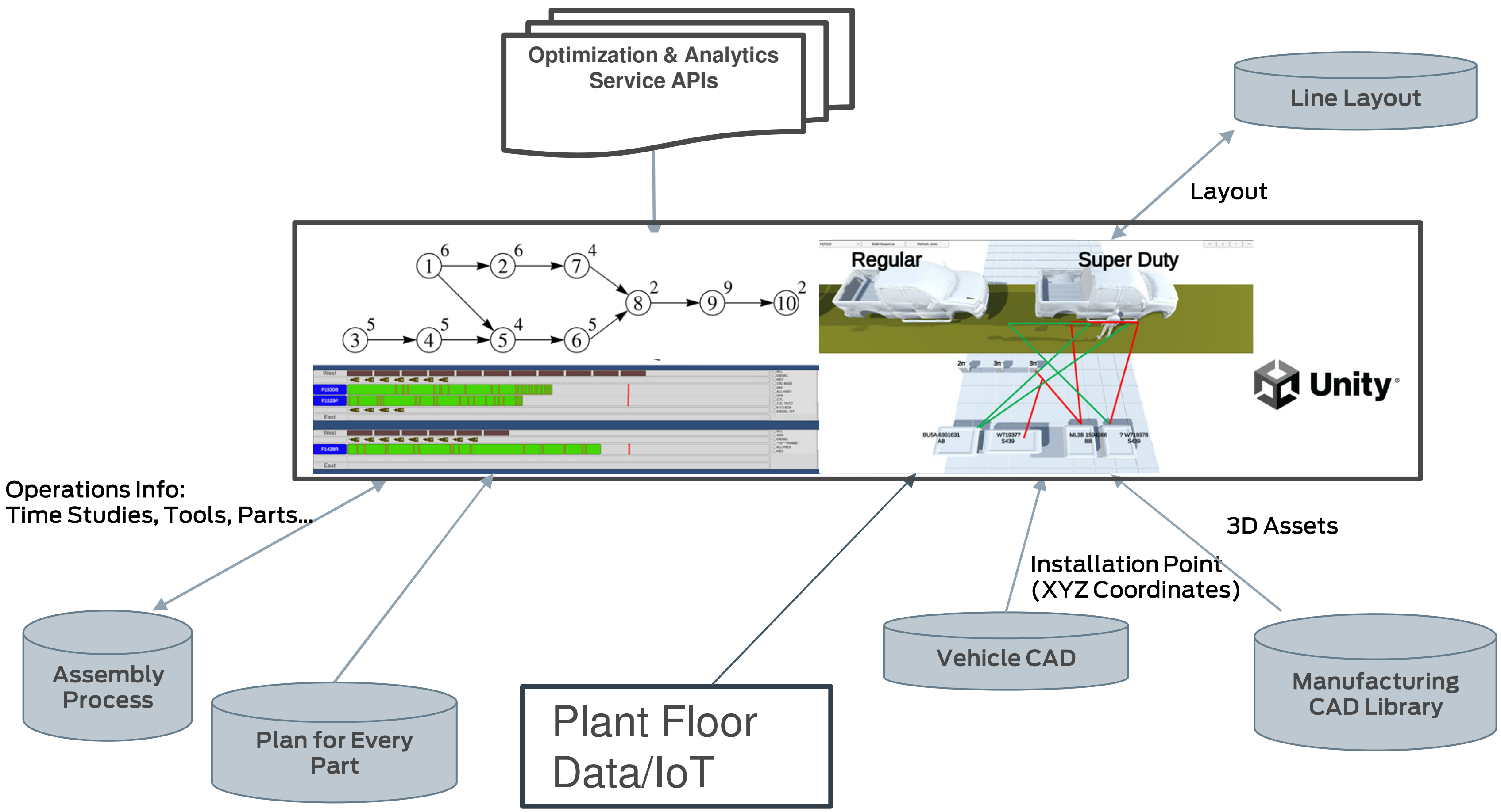
Vehicle Assembly Planning



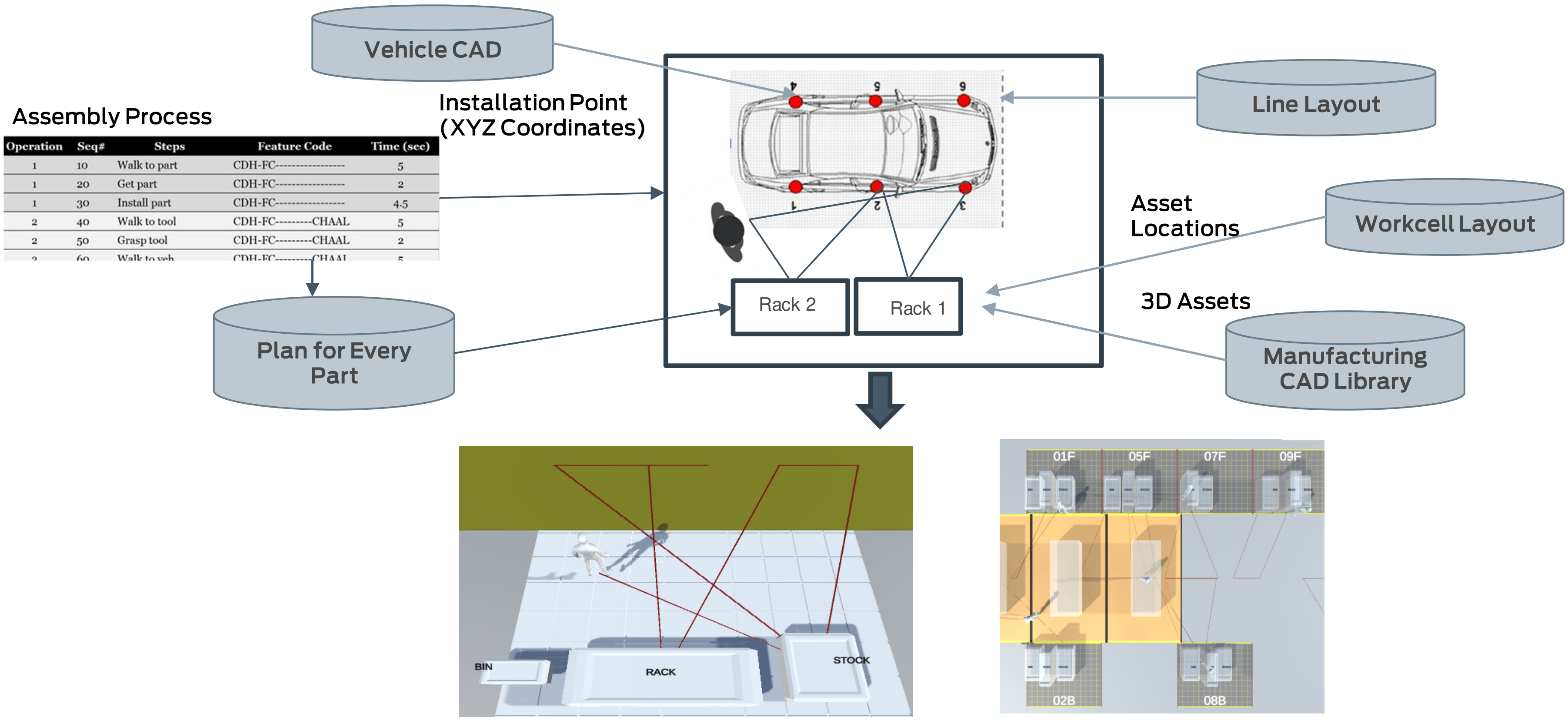
Automotive Assembly Line Planning Challenges

- No formalized precedence constraints
- Operation Times dependent on the work cell layout
- Operation's time estimation accuracy
- Loose interface with vehicle sequencing
- Input requires multiple heterogenous data sources
- Problem complexity

Assembly Line Digital Twin

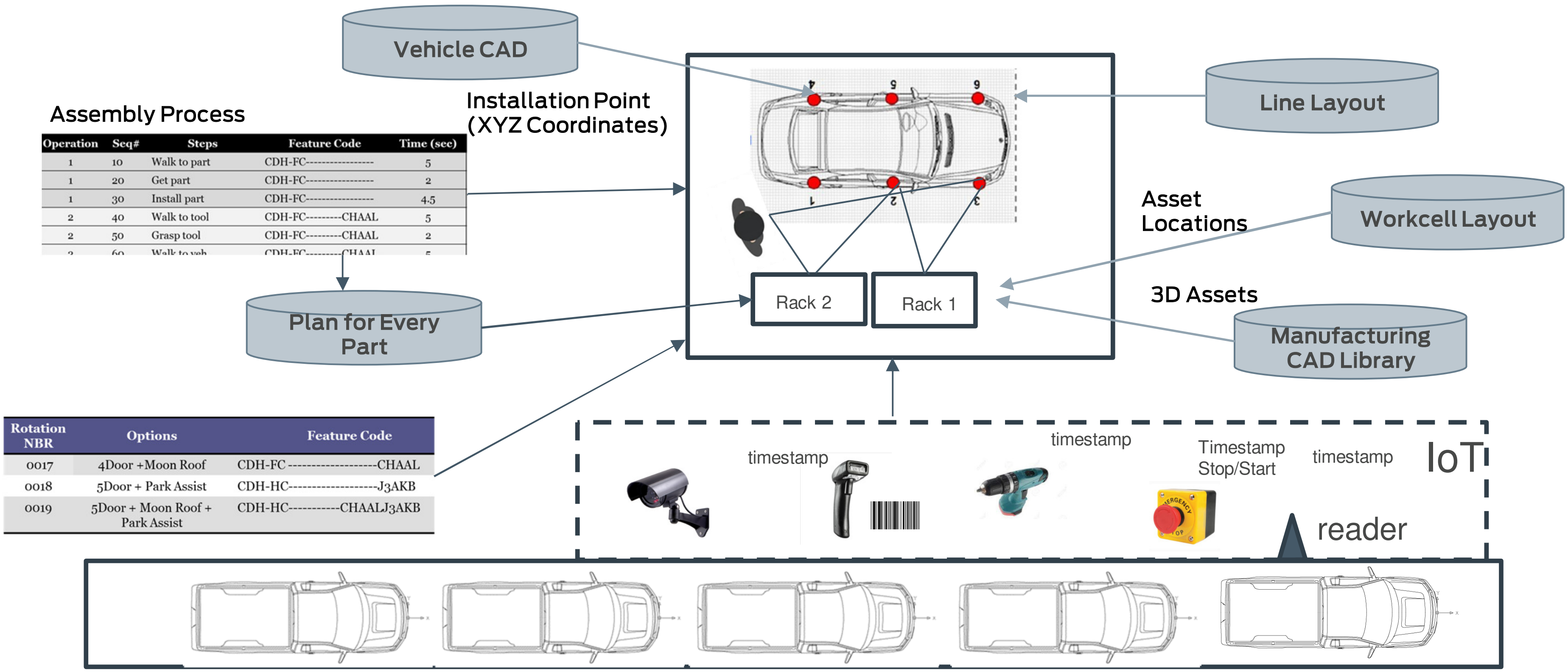


Model Generation



Operation	Seq#	Steps	Feature Code	Time (sec)
1	10	Walk to part	CDH-FC----------------	5
1	20	Get part	CDH-FC----------------	2
1	30	Install part	CDH-FC----------------	4.5
2	40	Walk to tool	CDH-FC---------CHAAL	5
2	50	Grasp tool	CDH-FC---------CHAAL	2
2	60	Walk to veh	CDH-FC---------CHAAL	5

Synchronization with Plant Floor Data



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2	40	Walk to tool	CDH-FC---------CHAAL	5
2	50	Grasp tool	CDH-FC---------CHAAL	2
2	60	Walk to veh	CDH-FC---------CHAAL	5

Rotation NBR	Options	Feature Code
0017	4Door +Moon Roof	CDH-FC -------------------CHAAL
0018	5Door + Park Assist	CDH-HC-------------------J3AKB
0019	5Door + Moon Roof + Park Assist	CDH-HC-----------CHAALJ3AKB

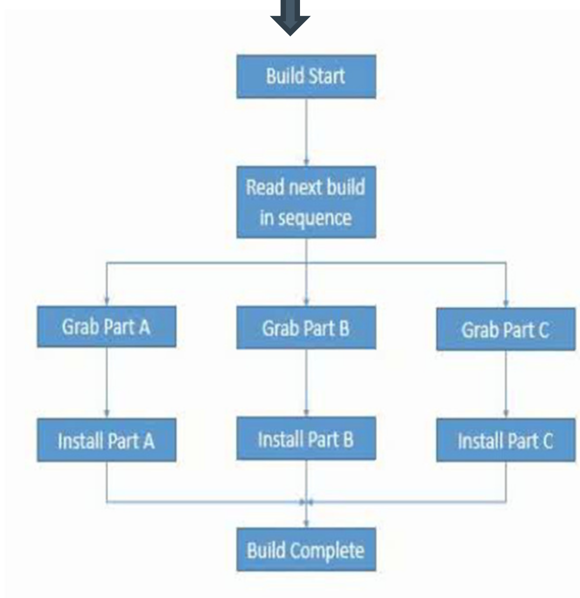
Vision-Based Synchronization

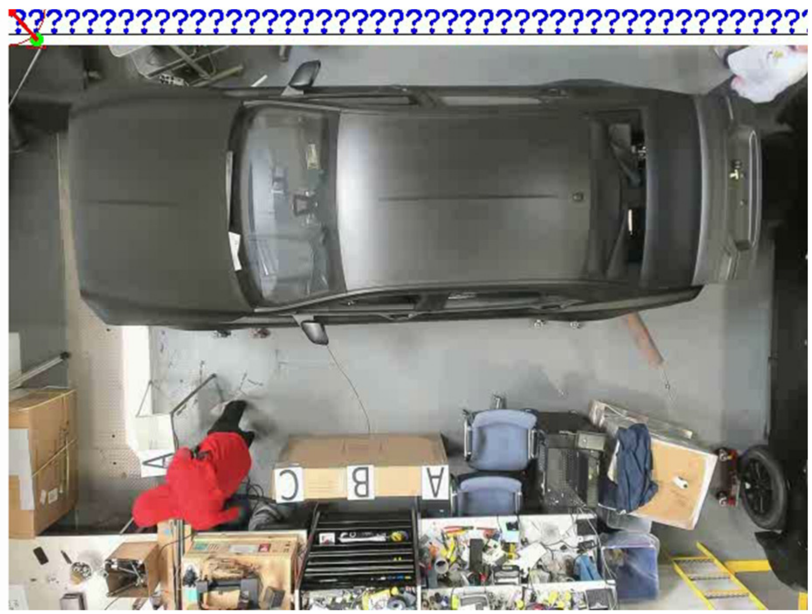
Work Instructions

	Operation	Seq#	Steps	Feature Code	Time (sec)
veh.1	1	10	Walk to part	CDH-FC----------------	5
	1	20	Get part	CDH-FC----------------	2
	1	30	Install part	CDH-FC----------------	4.5
veh.2	2	40	Walk to tool	CDH-FC---------CHAAL	5
	2	50	Grasp tool	CDH-FC---------CHAAL	2
	2	60	Walk to veh.	CDH-FC---------CHAAL	5
	2	70	Tighten the screw	CDH-FC---------CHAAL	3.5

Vehicle Sequence

Rotation NBR	Options	Feature Code
0017	4Door +Moon Roof	CDH-FC ------------------CHAAL
0018	5Door + Park Assist	CDH-HC------------------J3AKB
0019	5Door + Moon Roof + Park Assist	CDH-HC----------CHAALJ3AKB





Sensor-Based Synchronization

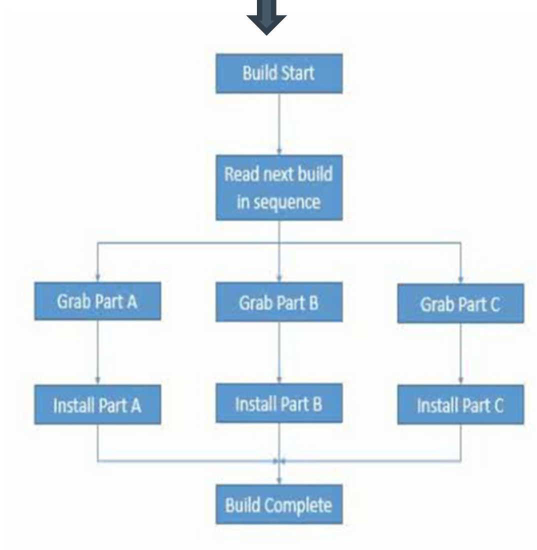
- Model Verification
- Conformance Checking
- Variance Analytics

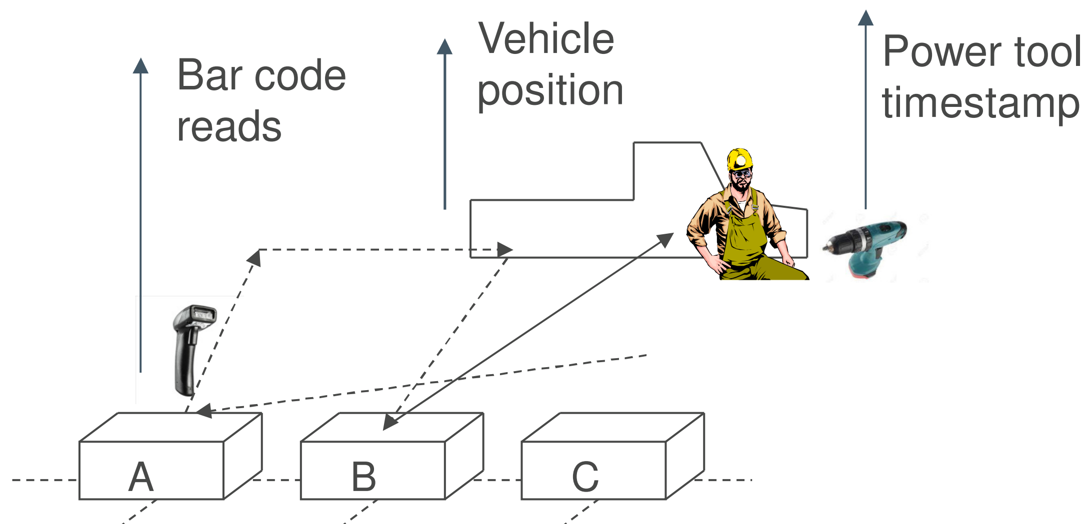
Work Instructions

	Operation	Seq#	Steps	Feature Code	Time (sec)
	1	10	Walk to part	CDH-FC----------------	5
veh.1	1	20	Get part	CDH-FC----------------	2
	1	30	Install part	CDH-FC----------------	4.5
	2	40	Walk to tool	CDH-FC---------CHAAL	5
	2	50	Grasp tool	CDH-FC---------CHAAL	2
veh.2	2	60	Walk to veh.	CDH-FC---------CHAAL	5
	2	70	Tighten the screw	CDH-FC---------CHAAL	3.5

Vehicle Sequence

Rotation NBR	Options	Feature Code
0017	4Door +Moon Roof	CDH-FC -------------------CHAAL
0018	5Door + Park Assist	CDH-HC------------------J3AKB
0019	5Door + Moon Roof + Park Assist	CDH-HC----------CHAALJ3AKB

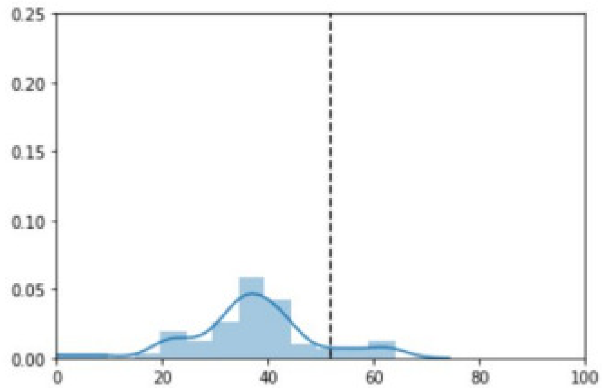




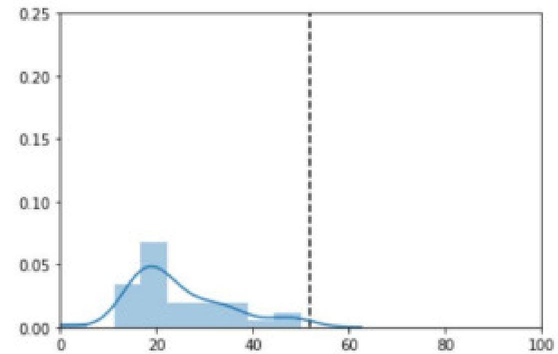
Task Time Distribution

Station: C5W04R   Date: June-12-2019

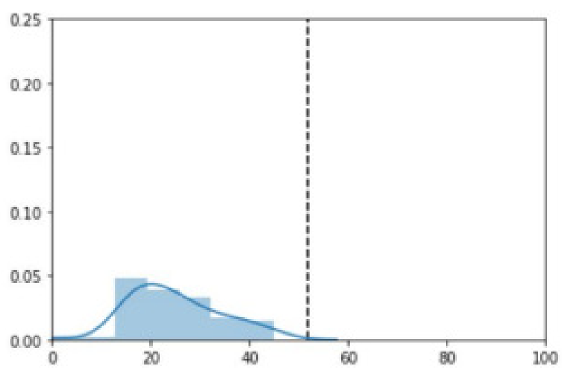
X-axis: Delta time(sec)   **Y-axis**: Percentage



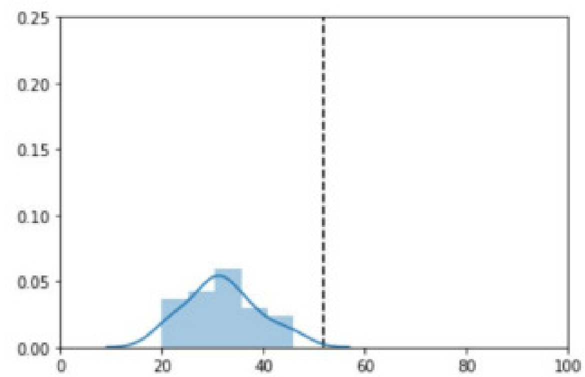
12:00-1:00 a.m.



7:00-8:00 a.m.

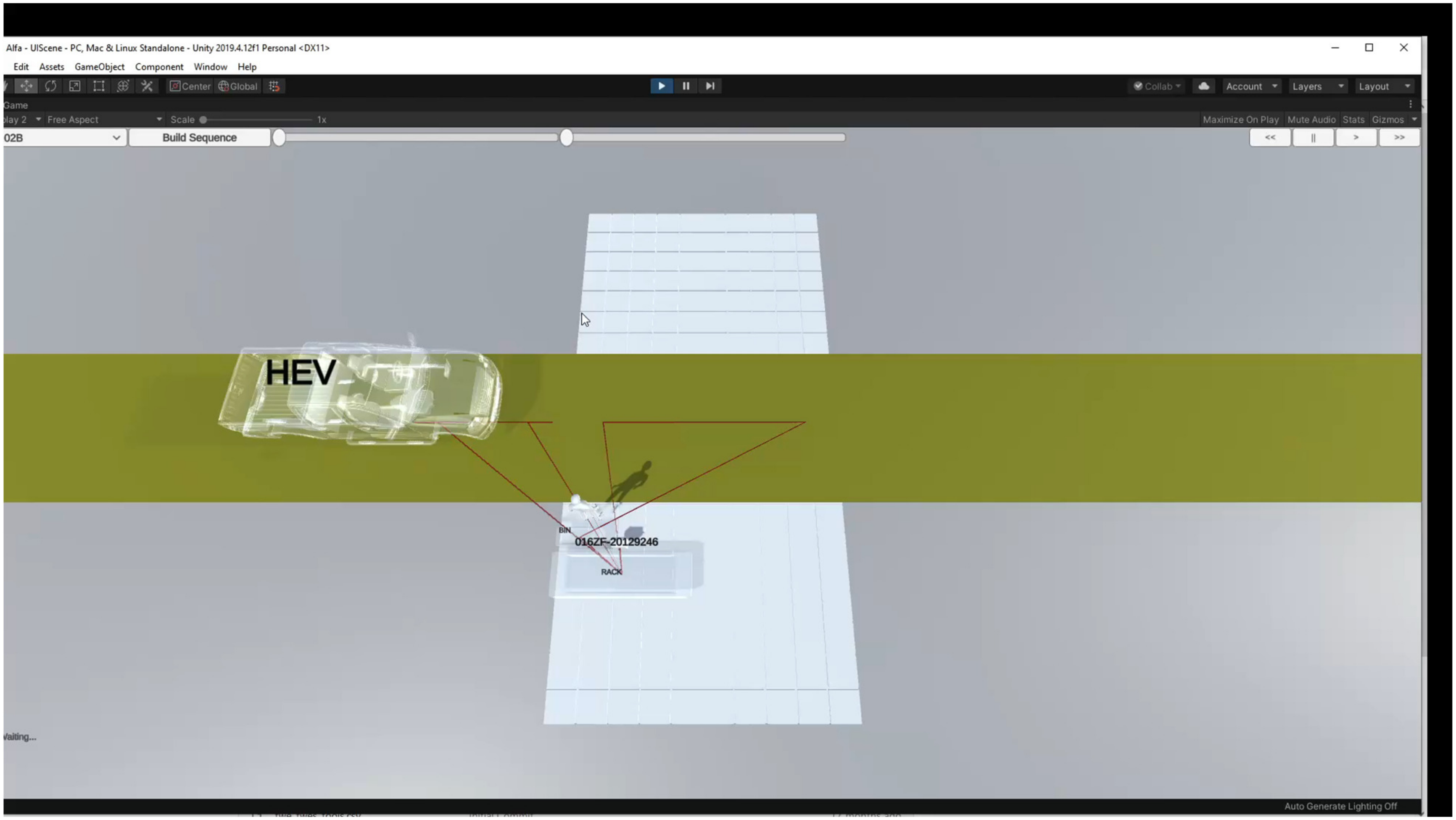


12:30-1:30 p.m.

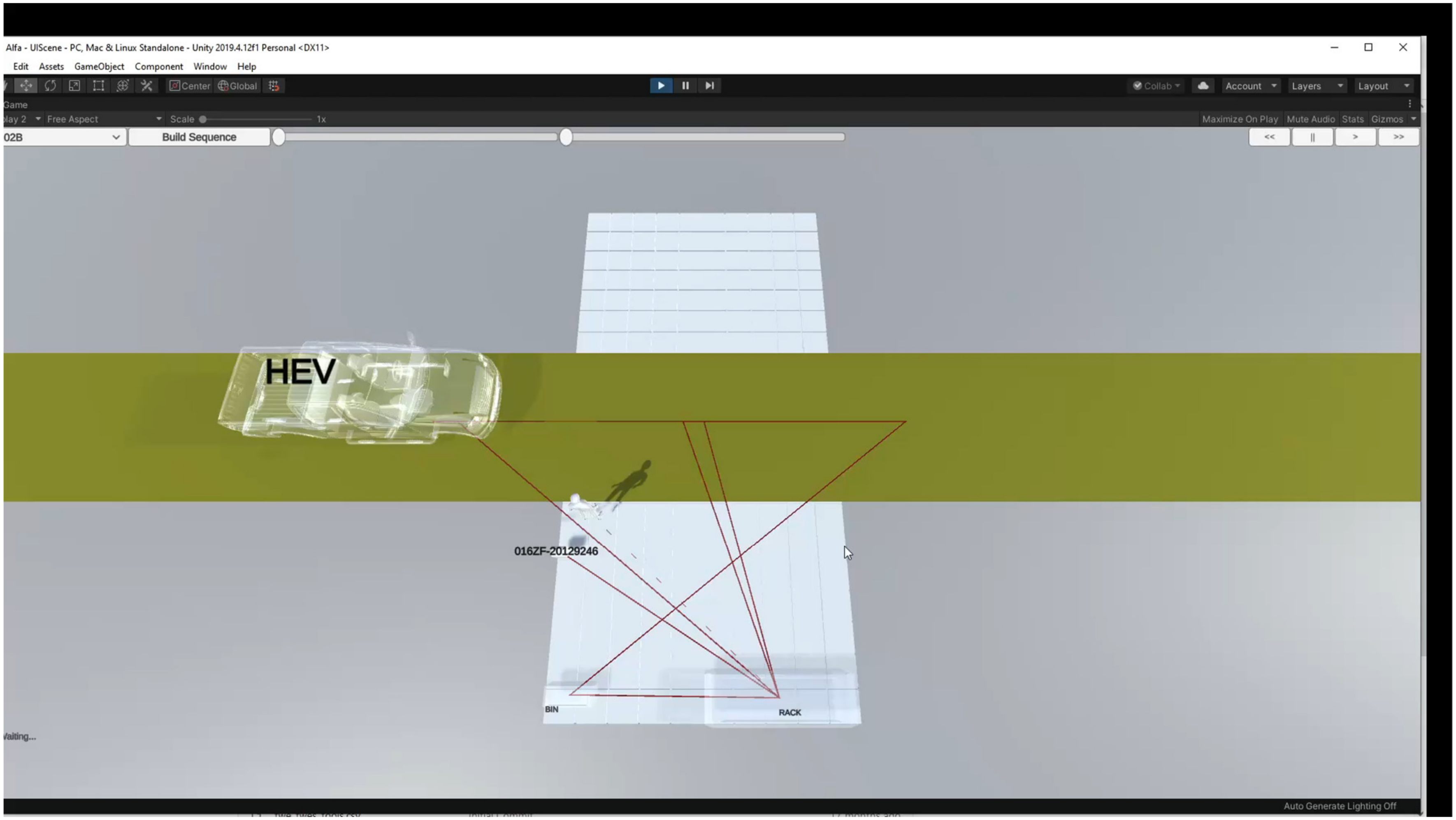


11:00-11:59 p.m.

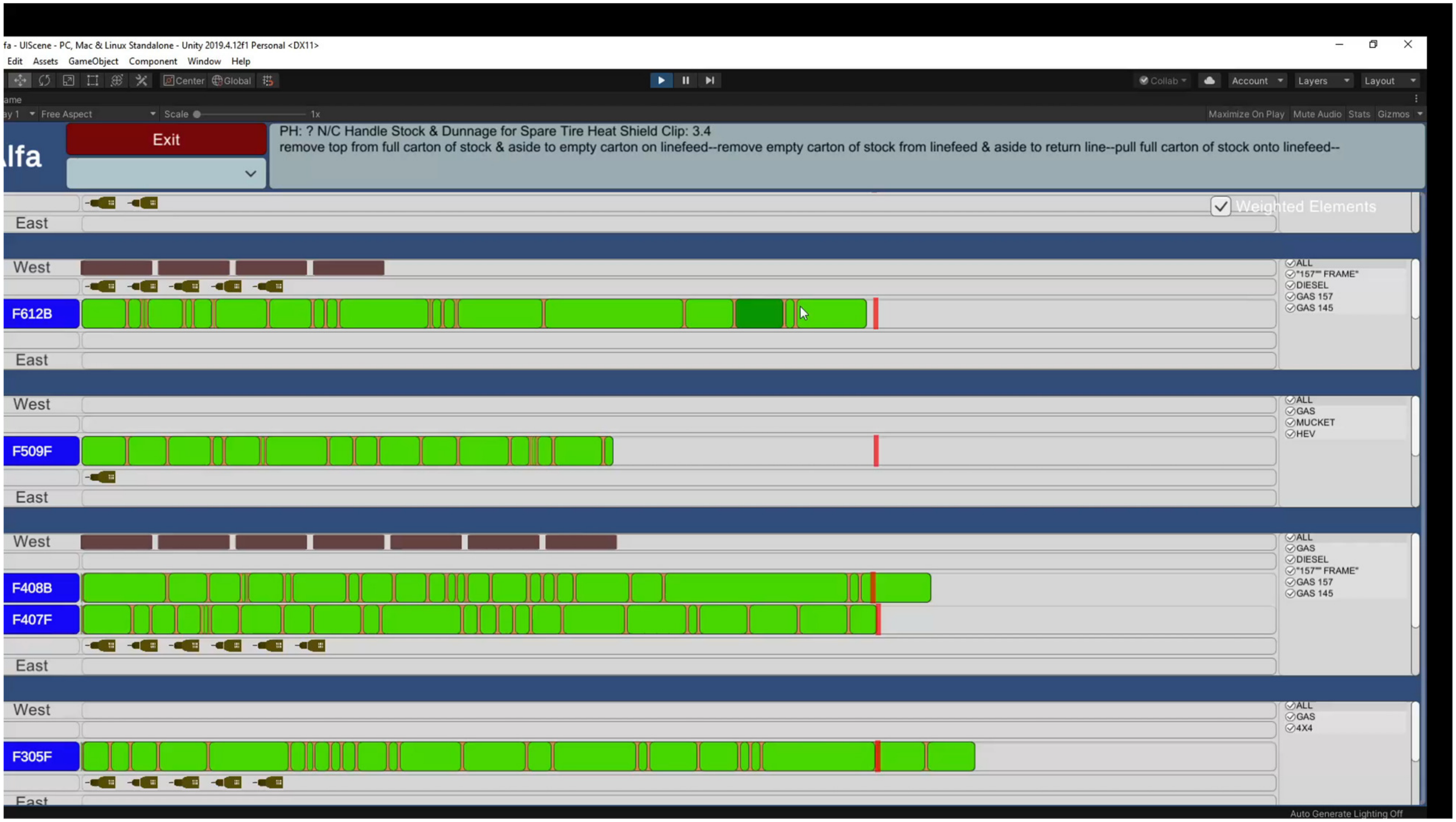
Operator Walk Pattern Animation



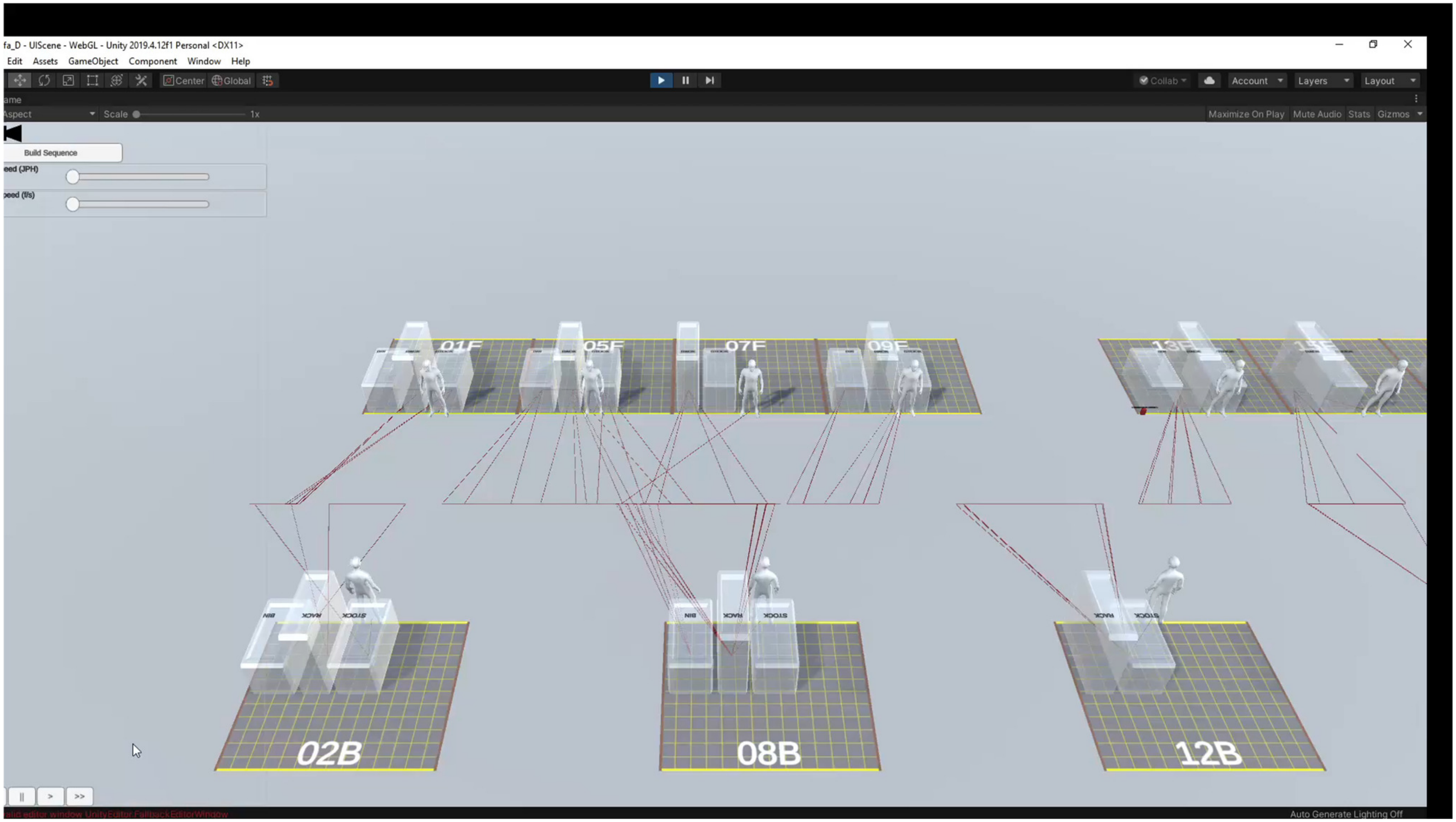
Cell Layout Analysis



Interactive Balance Board



Line Animation and Analysis



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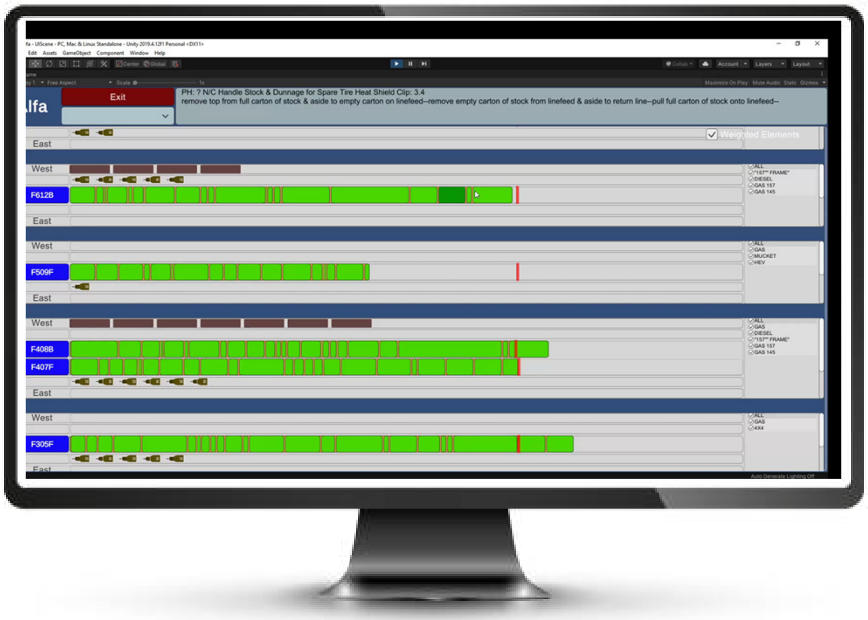
Simultaneous line balancing and layout



Practical Precedence Constraints Graph Generation

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Discrete Optimization

On a learning precedence graph concept for the automotive industry

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ABSTRACT

Assembly line balancing problems (ALBP) consist in assigning the total workload for manufacturing a product to stations of an assembly line as typically applied in automotive industry. The assignment of tasks to stations is due to restrictions which can be expressed in a precedence graph. However, (automotive) manufacturers usually do not have sufficient information on their precedence graphs. As a consequence, the elaborate solution procedures for different versions of ALBP developed by more than 50 years of intensive research are often not applicable in practice.

Unfortunately, the known approaches for precedence graph generation are not suitable for the conditions in the automotive industry. Therefore, we describe a new graph generation approach that is based on learning from past feasible production sequences and forms a sufficient precedence graph that guarantees feasible line balances. Computational experiments indicate that the proposed procedure is able to approximate the real precedence graph sufficiently well to detect optimal or nearly optimal solutions for a well-known benchmark data set. Even for additional large instances with up to 1,000 tasks, considerable improvements of line balances are possible. Thus, the new approach seems to be a major step to close the gap between theoretical line balancing research and practice of assembly line planning.

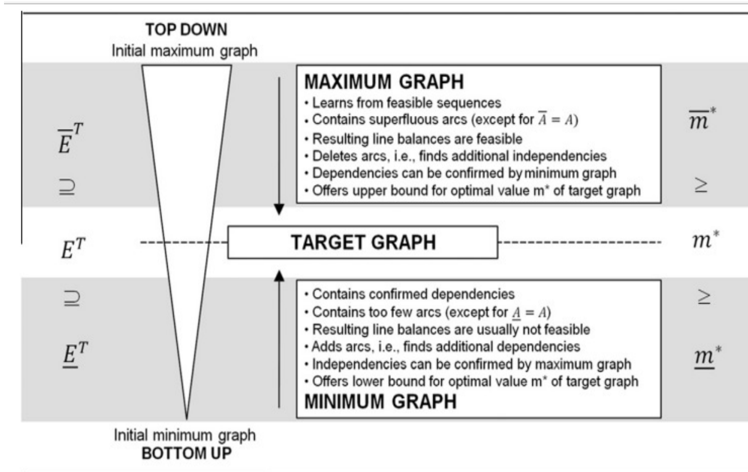

Fig. 4. Relationships and contributions of different graph types.

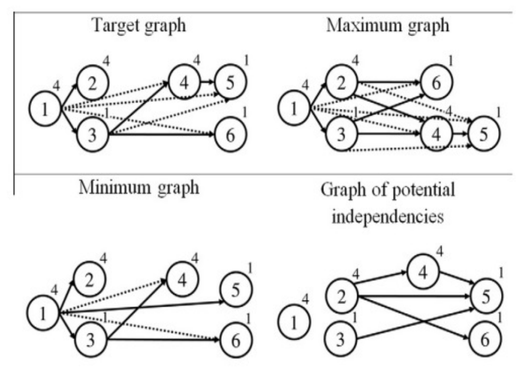

Fig. 5. Example for precedence graph types and transitive closures.

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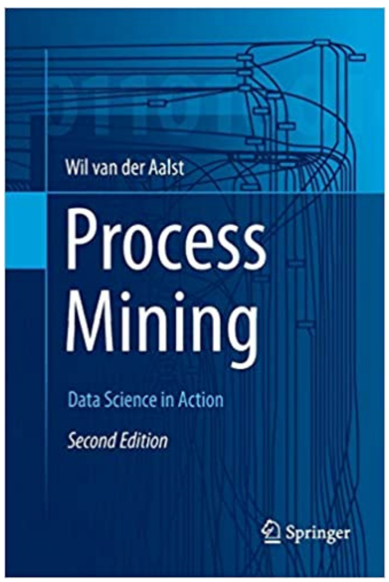
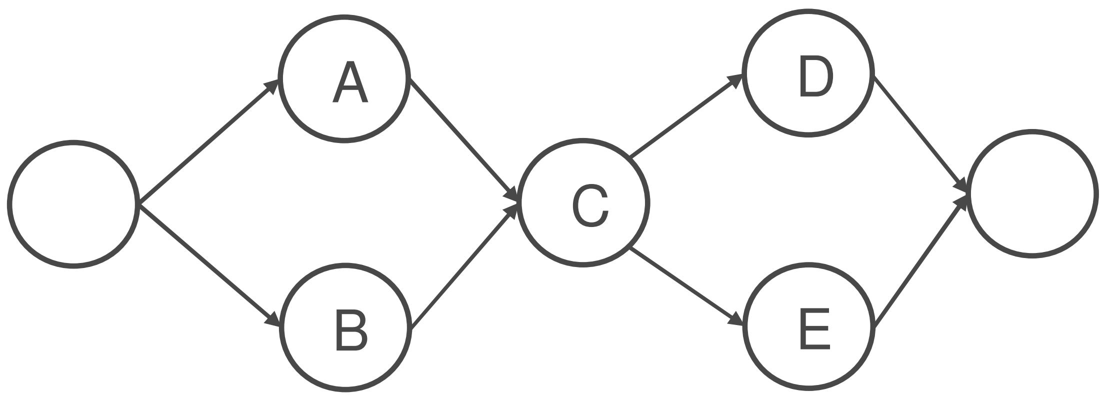
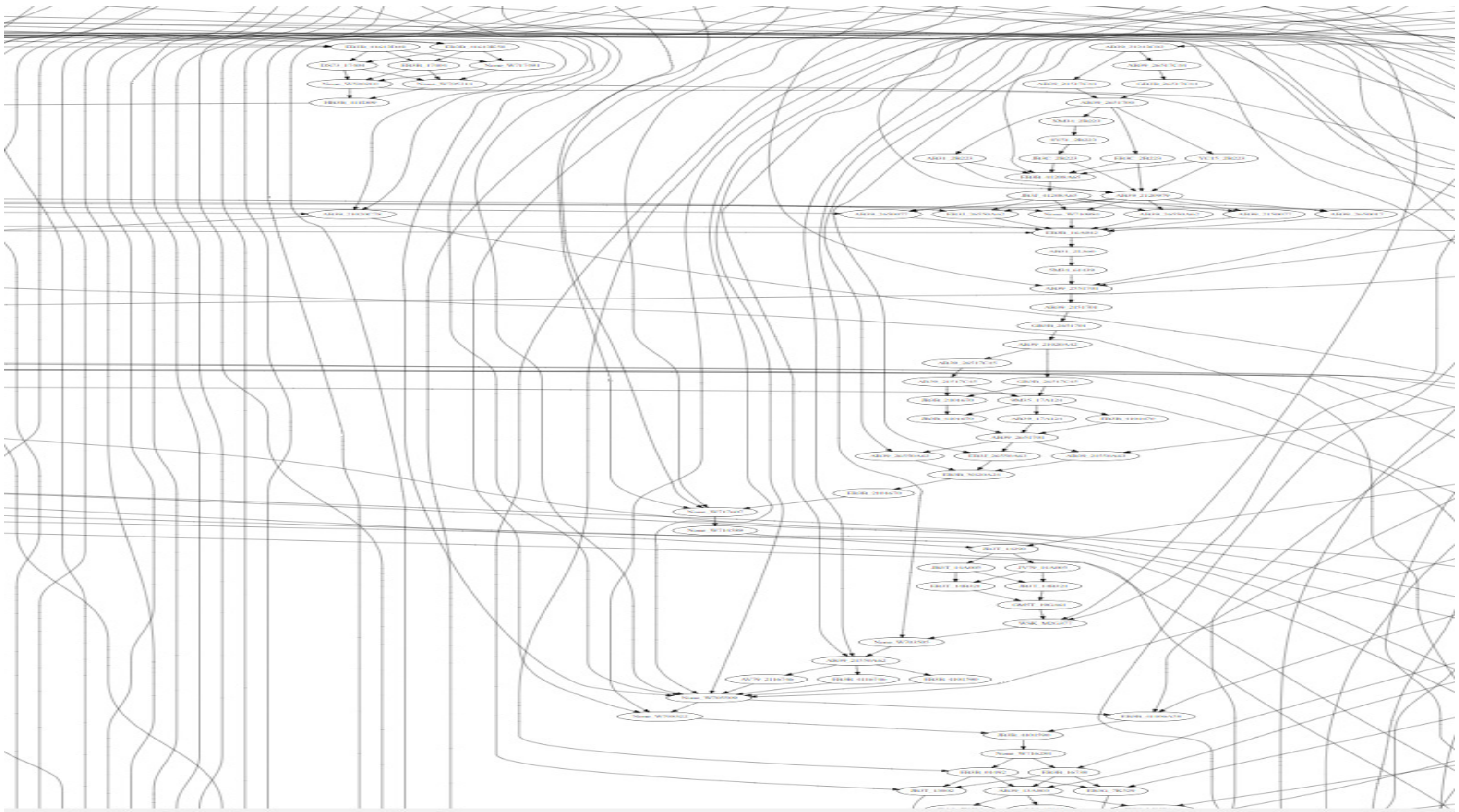
Mining of Precedence Constraints

Process 1	A	B	C	D	E
Process 2	B	A	C	E	D

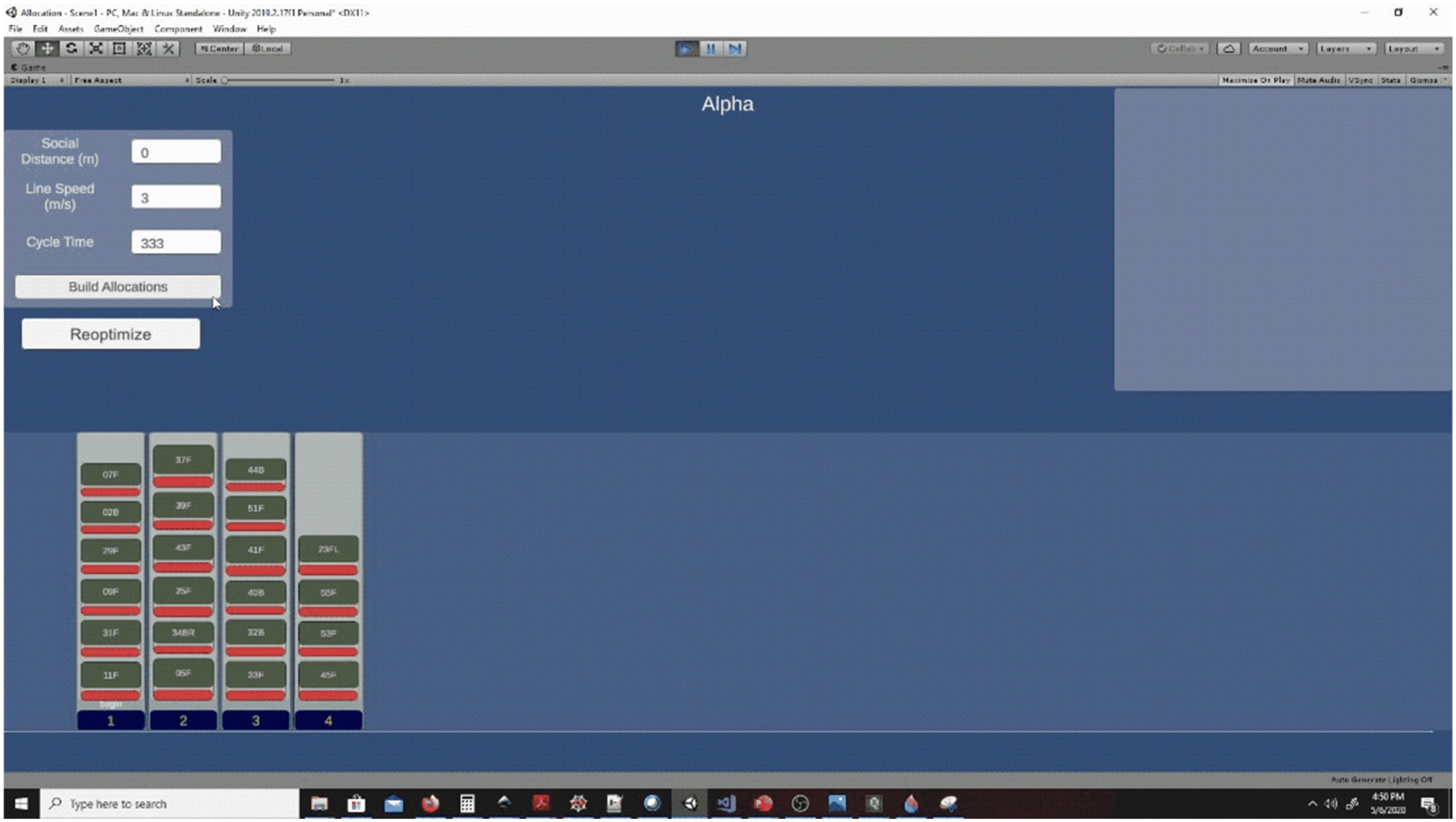




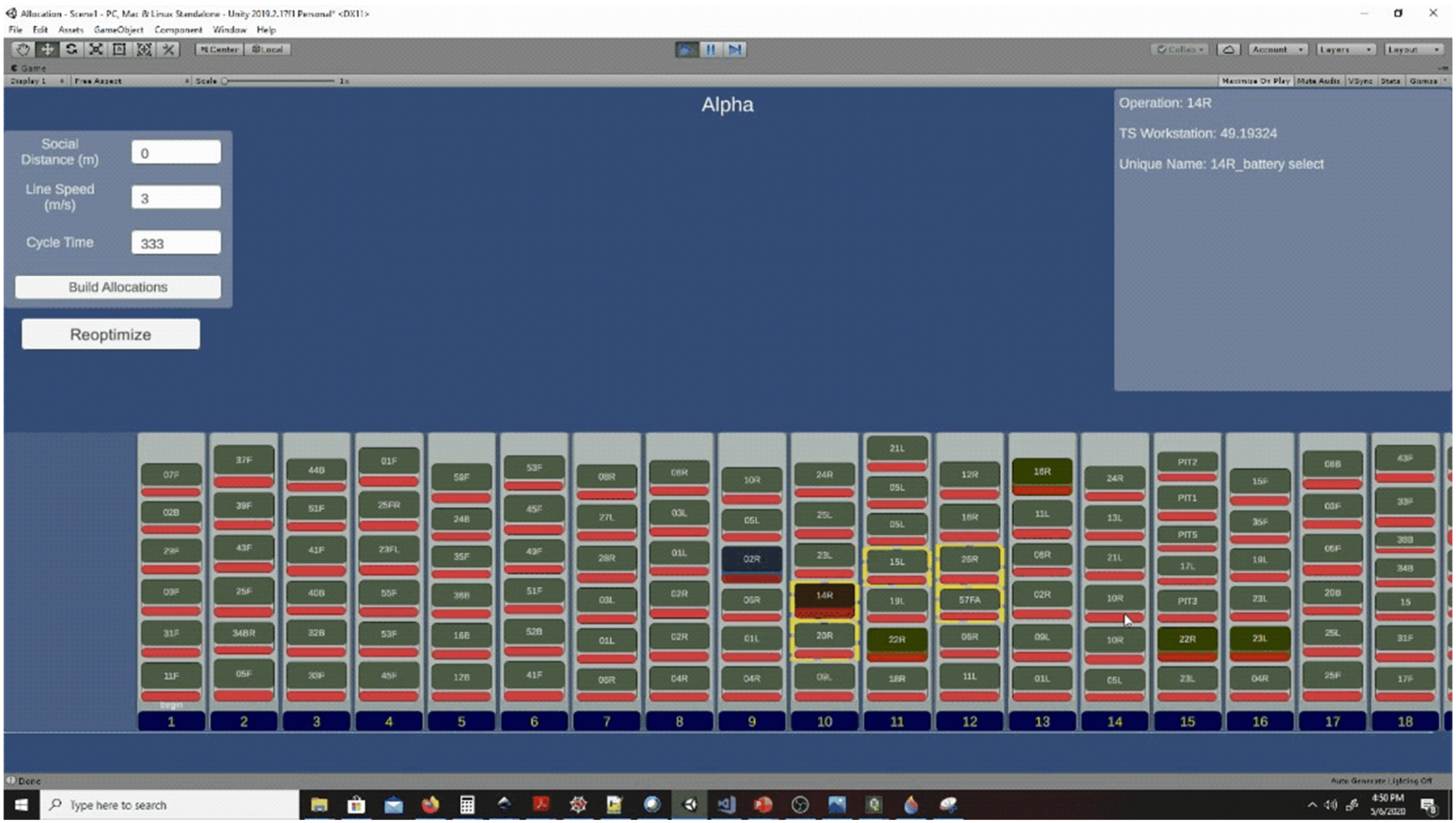
Fragment of F150 Precedence Constraints



Automatic and Interactive Line Balancing



Automatic Line Balancing with Fixed Operations



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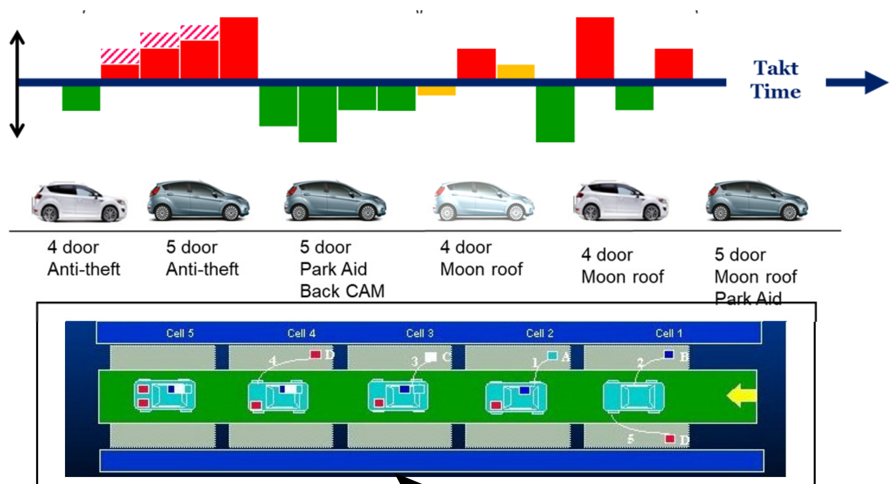
Predicting Operator Overload and Interference

Car sequencing to minimize sequencing rules violations

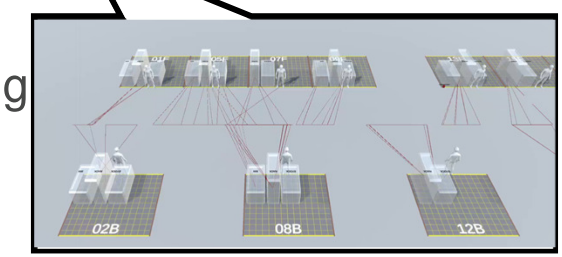
Vehicle sequence

H_0:N_0

Sequencing Constraints



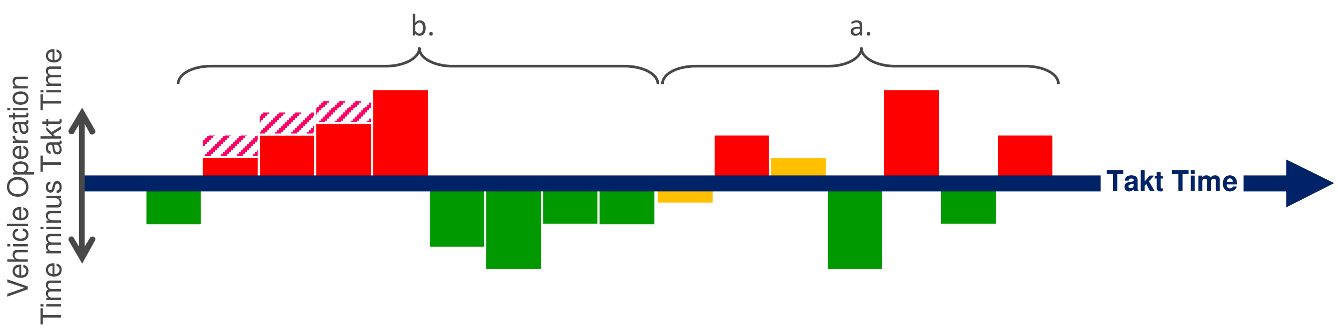
Line Balancing & Workcell Layout



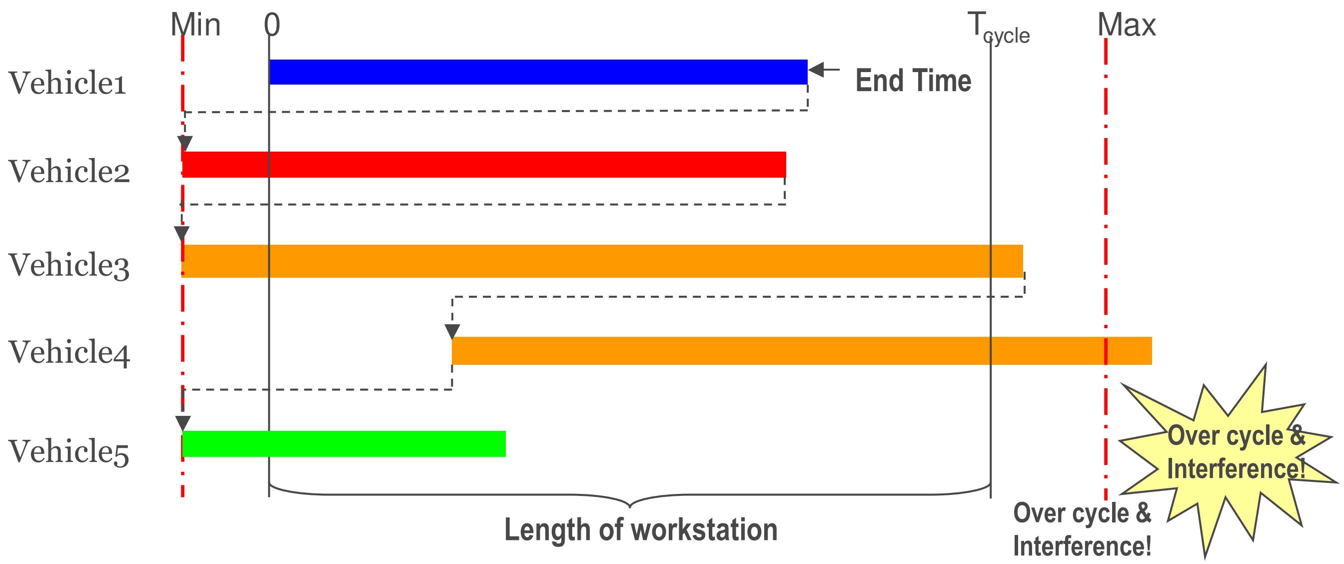
Vehicle Sequence Impact on Operator Workload

a. An operator will often be able to handle Red high-content units (going over *takt* time) followed by a Green low-content (under *takt* time) without ever needing to stop the line.

b. There are only two choices when high-content units are together, no matter how many low-content units came before: stop the production line, or do not complete the operation.

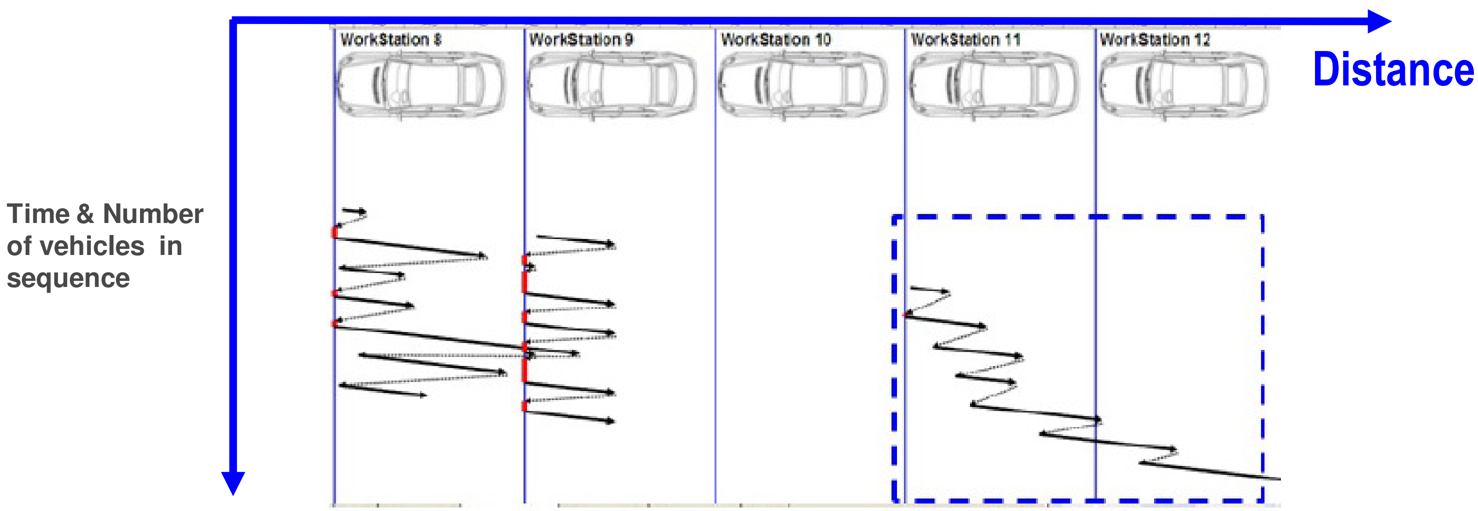


Movements of an Operator



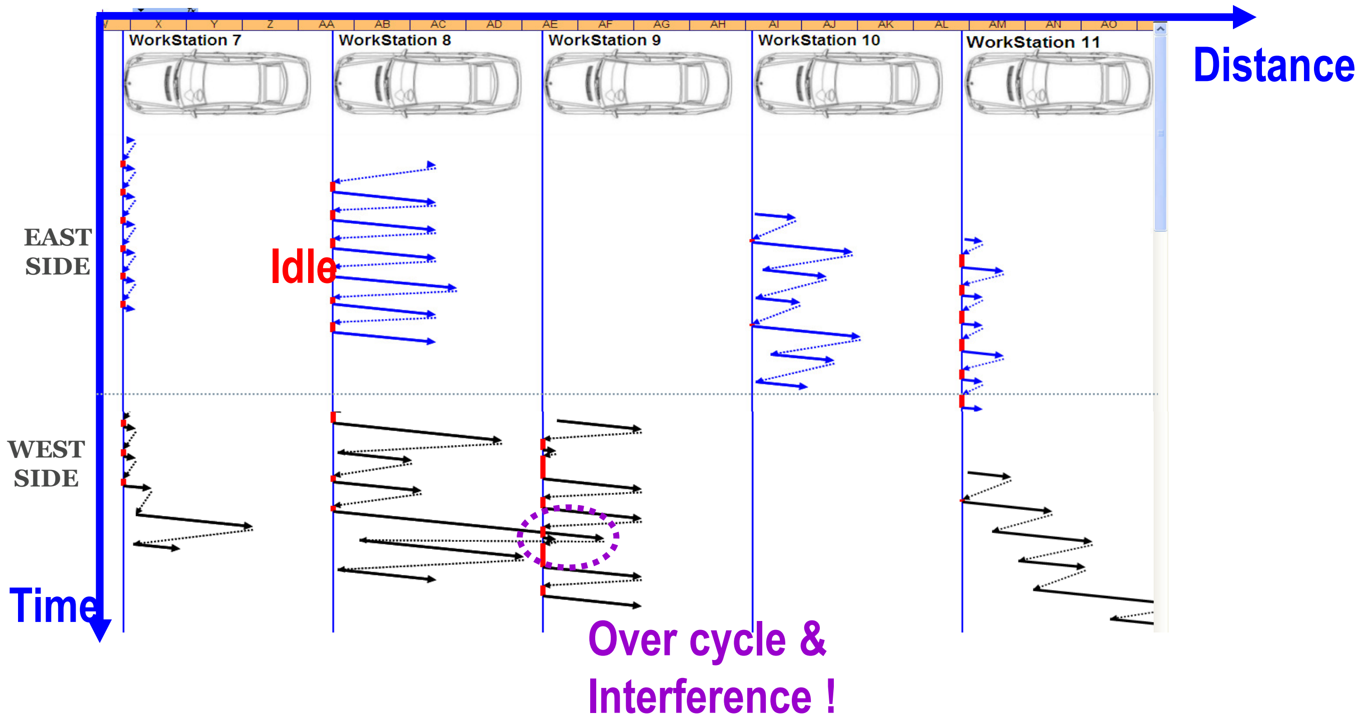
Workload at any particular workstation must not exceed some allotted time to prevent conveyor stoppages.

Case I: Overcycle and Propagation of Delays



Several vehicles with high content options are consecutive in the sequence leading to overcycle problems and propagation of delays.

Case II: Overcycle and Interference



- The operator walkover to the next workcell and may interfere with the another operator.

Operator Interference Conditions

Walkover Distance: $\Delta x = x(i) - L_x = v_c t_I(i) + z_x(j) - L_x$

Algorithm for identifying interference conditions:

If $\Delta x > 0$ **(Walkover or Overcycle)**

If $z_x(i,n) = z_x(i+1,1)$

then

{there is *operator interference*} "Type I"

else if $z_x(i,n) < z_x(i+1,1)$

then

{over-cycle but *no interference*} "Type II"

Elseif $\Delta x \leq 0$(No Overcycle)

If $T_{finish} + t_{return} < T_{cycle}$

then

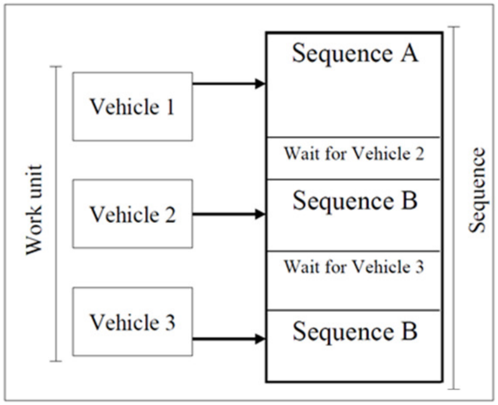
{Idle > 0}

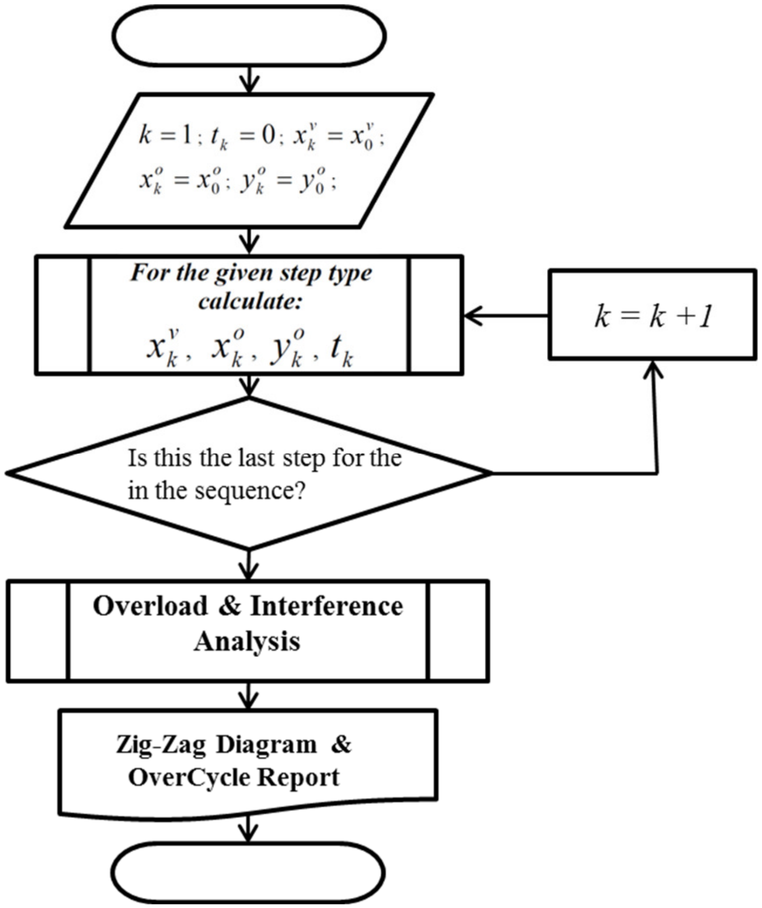
Else

then

{Idle =0 (there is overcycle)}

Operator Walk Pattern Calculations





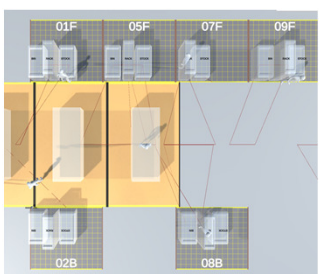
Dynamic Modeling of Operator Overload

Plant Floor System

Rotation NBR	Options	Feature Code
0017	4Door +Moon Roof	CDH-FC -------------------CHAAL
0018	5Door + Park Assist	CDH-HC-------------------J3AKB
0019	5Door + Moon Roof + Park Assist	CDH-HC-----------CHAALJ3AKB

Allocation Planning Tool

	Operation	Seq#	Steps	Feature Code	Time (sec)
veh.1	1	10	Walk to part	CDH-FC-----------------	5
	1	20	Get part	CDH-FC-----------------	2
	1	30	Install part	CDH-FC-----------------	4.5
veh.2	2	40	Walk to tool	CDH-FC---------CHAAL	5
	2	50	Grasp tool	CDH-FC---------CHAAL	2
	2	60	Walk to veh.	CDH-FC---------CHAAL	5
	2	70	Tighten the screw	CDH-FC---------CHAAL	3.5



Sequence Modeling & Operator Work Pattern Analysis

Zig-Zag Diagram & Over Cycle Report

Over Cycle & Interference Report

Workstation	VIN	Rotation #	Work Over Time	% Work Over Time	Work Over Distance	% Interference Distance	Type of Interference *
408W	CL194686	0005	0.6259091 mins	76.46%	5.26283 ft	29.24%	2
411W	CL194686	0005	0.5810264 mins	70.98%	0.77605 ft	4.31%	1
411W	CL196746	0006	0.9897427 mins	120.91%	7.90446 ft	43.91%	1
411W	CL196860	0007	1.943457 mins	237.41%	27.09179 ft	150.51%	1
...	...	...	...	...	...	...	...

*Type=1: Operator works over cycle time but there is no interference with the work in the downstream workstation.

Type=2: Operator works over cycle time and also interfere with operator in the next station because they work on the same point on the vehicle.

Assembly Line Fitness Analytics

Descriptive

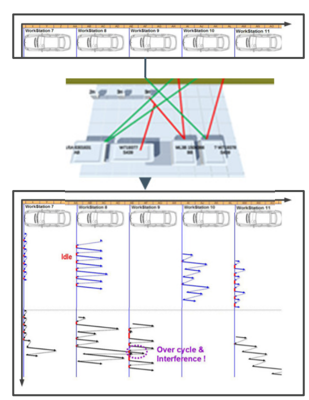
- Eliminate as much manual tasks as possible.
- Full representation of the floor operations
- Slice and dice the data for quick insights
- Combine data from other manufacturing systems for real time analytics.
- Modify time studies

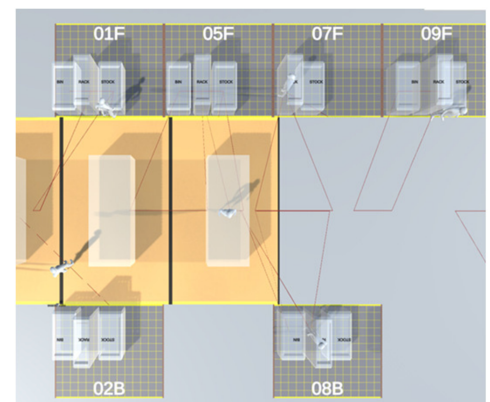
Predictive

- Highlight existing problematic operations
- Predict problematic operations
- View the effect of decisions

Prescriptive

- Optimize cell layout and line layout in rebalance
- Create what-if scenarios
- Automatically generate sequencing constraints
- Suggest better ways to rebalance cells





Summary

- Data-Driven Assembly Line Model Synchronized with Plant Floor
- Incorporates historical and real time data and provides descriptive, predictive and prescriptive analytics capabilities
- Empowers multiple stakeholders to analyze, visualize and interact with the data and facilitates collaboration
- Standardizes interfaces for different optimization models


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
спасибо
Баярлалаа
рахмат
merci
obrigado
bedankt
dziękuję
sukriya
kop khun krap
go raibh maith agat
mochchakkeram
tapadh leat
terima kasih
감사합니다
ありがとう
arigatô
dakujem
мерси
grazie
takk
dank je
mauruuru
hvala
merci
mersi
barka
tack
spas
dankie
kiitos
dhanyavad
faafetai lava
vinaka
blagodaram
misaotra
matondo
paldies
grazzi
хвала
asante
manana
obrigada
mamnun
trugarez
shukriya
dhanyavadagalu
diolch
rahmet
tanemirt
xiexie
ευχαριστώ
najis tuke
kam-sah hamnida
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chnorakaloutioun
gracies
sulpay
taiku
djiere dieuf
дякую
sagolun