Visible Knowledge

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Designing the Future Summit 2019

lppd Lean Product & Process Development

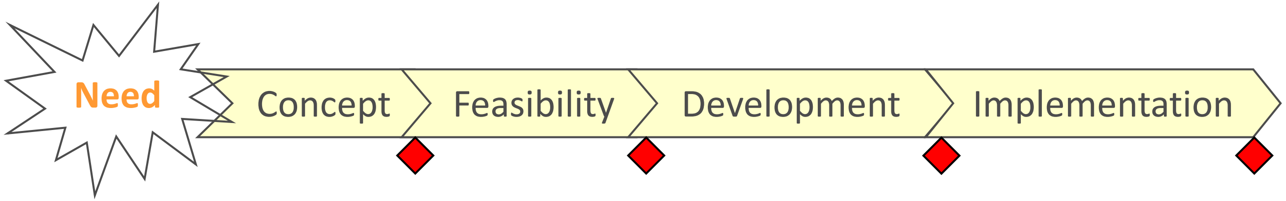
Introductions

Professor of Industrial & Management Systems Engineering, Montana State University

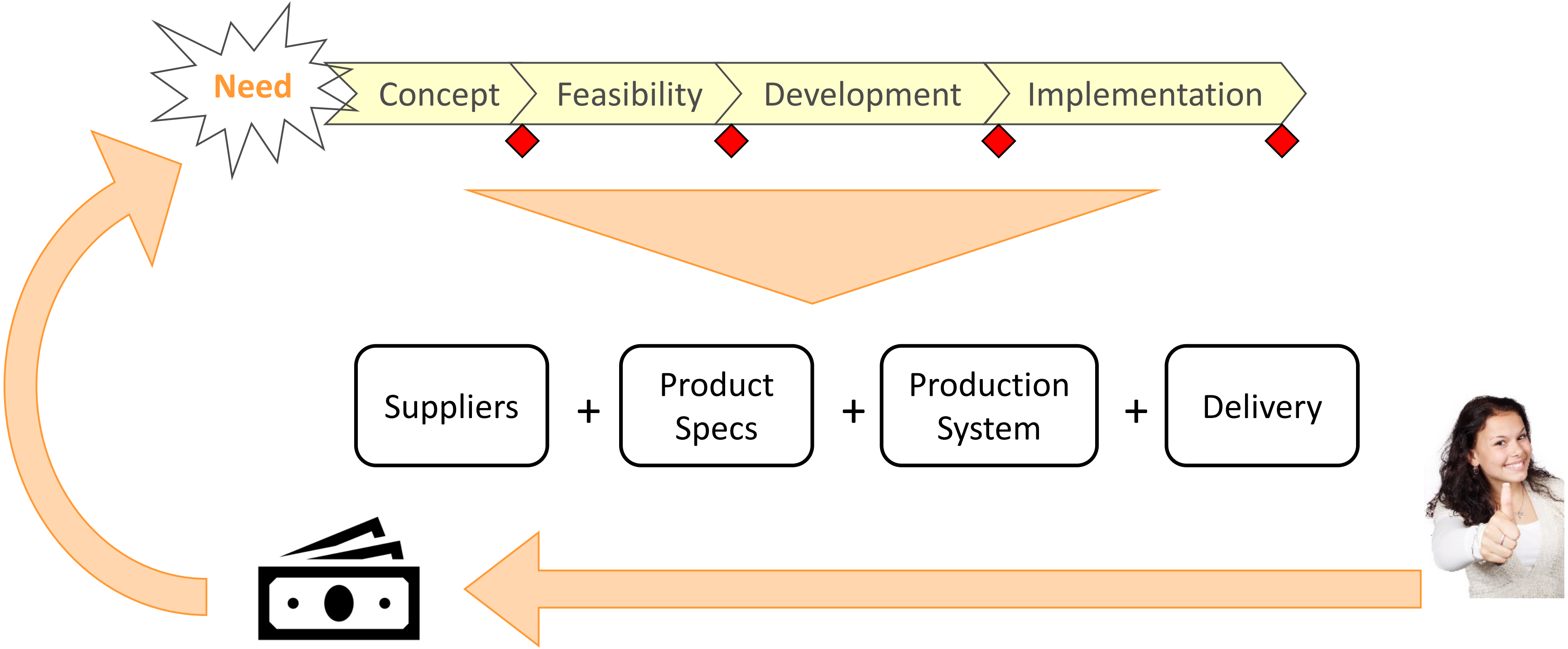
Ph.D. in Industrial and Operations Engineering from The University of Michigan

Researcher in Lean PD for two decades

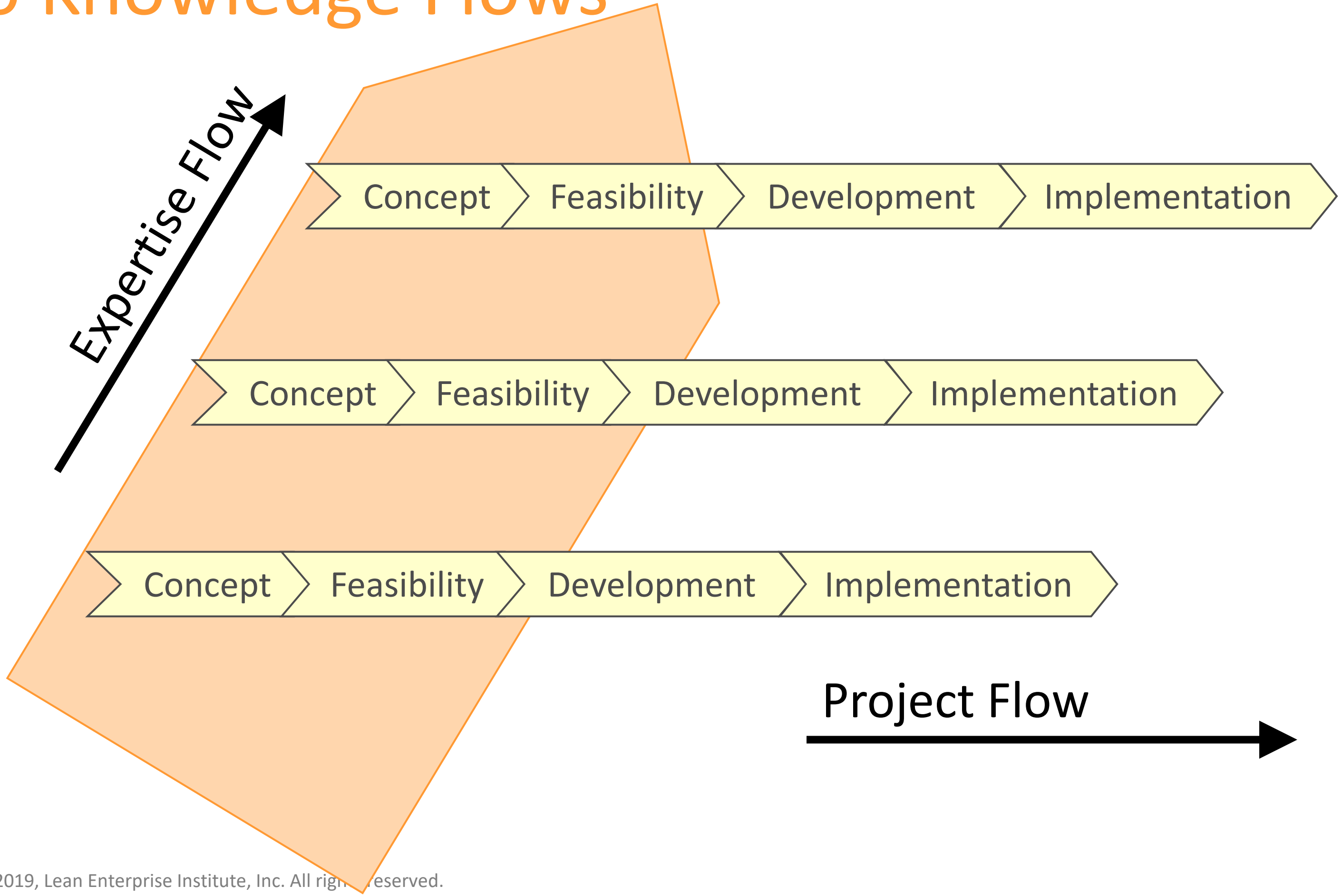
Often we see PD this way...



When it’s really more like this.



Two Knowledge Flows



“Value added” in product development is creating **(re)useable** knowledge and hardware/software.

Four LPPD Principles

1. Deeply understand what your product needs to be.
2. Create flow and eliminate waste for speed to market.
3. Learning is what creates new value.
4. LPPD is all about people.

Source: https://www.lean.org/leanpd/

Deeply Understand What Your Product Needs to Be

Providing customer value = first principle of Lean.

LPPD focuses on:

- Going to the source to deeply understand
- Studying users/products within specific contexts
- Set-based experimentation to look broadly at potential solutions
- Aligning the organization around a vision for the new product

Create Flow, Eliminate Waste for Speed to Market

Deliver product to your customer with speed and precision.

Manage the development process with simple, visual tools and an effective cadence.

Understand, manage, and continually improve capacity and capability.

Synchronize activities across teams and organizations.

Focus on compatibility before completion of individual elements.

Underpin these activities with a powerful system of standards.

Learning is What Creates New Value

Learn effectively and apply it to the creation of new value.

LPPD learning tools and methods include:

- Rapid learning cycles
- Scientific method/experimentation
- Structured, built-in reflection
- Design reviews by going to the source

Recognize and capture knowledge that is created with each product.

LPPD is All About People

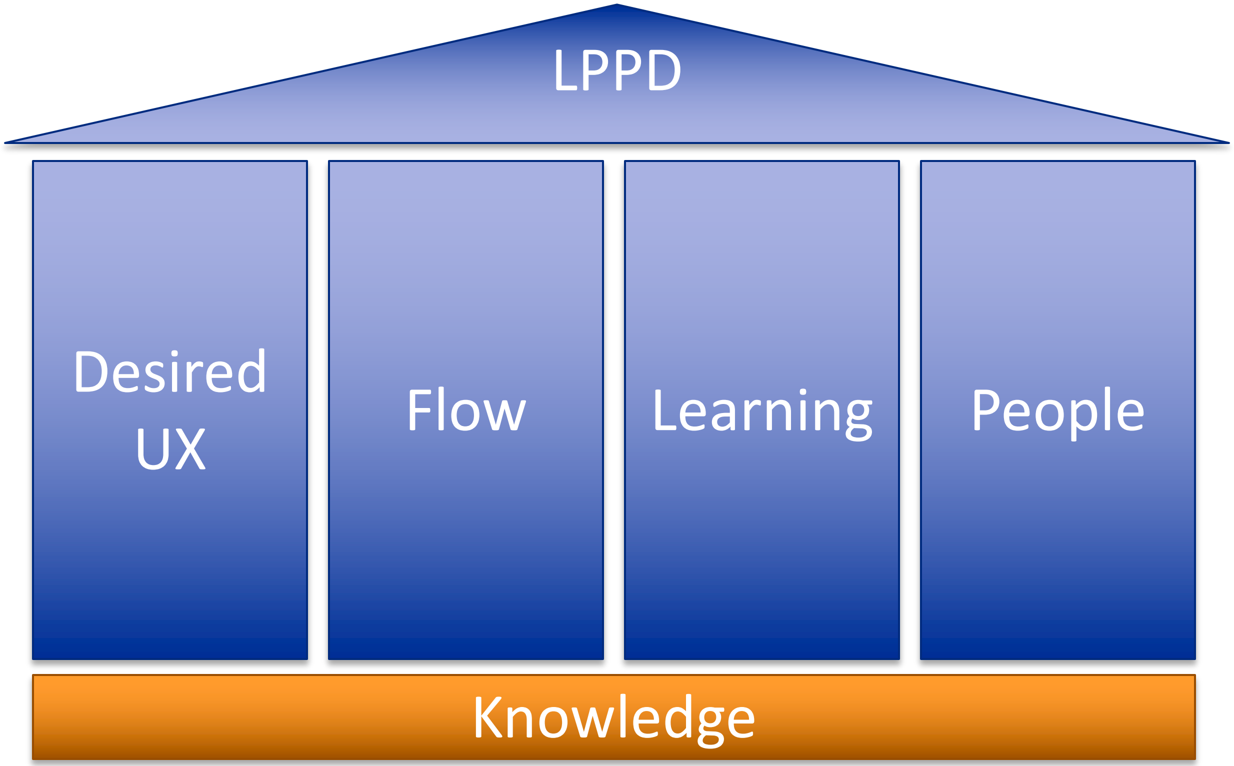
People supply the energy, imagination, and creative potential.

Encompass the extended enterprise – all internal organizations + key suppliers and other outside stakeholders.

Understand the role and power of the "entrepreneurial system designer" who works across highly skilled functions to deliver product excellence.

Strive to create a culture in pursuit of perfection.

Develop leaders who embody these principles.


LPPD
Desired UX
Flow
Learning
People
Knowledge

A lesson from history

Designing the Future Summit 2019

lppd Lean Product & Process Development

How to Design the First Airplane

(and live to tell about it)

Would-be Inventors of Flight

Otto Lilienthal (Germany)

- 18 gliders over 10 years, 2000 test flights
- Perished in test flight crash in 1896

Clement Ader (France)

- $120K spent over 1872-1897 without success

Hiram Maxim (England)

- $200K invested in 1890’s without success

Samuel Langley (US)

- $70K spend over 16 years; no manned flight achieved for longer than a few seconds

How about the Wrights?

Never attended university.

Spent about $1000.

22 months of development work, 3 people, spread over 3-4 years

First full prototype flew.

How did they do it?

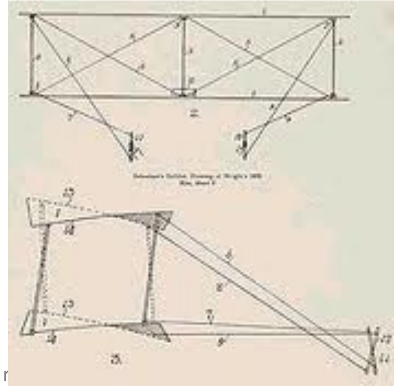
They Innovated an Entirely New Approach

Three knowledge gaps identified:

- In-flight control
- Wing design
- Propulsion

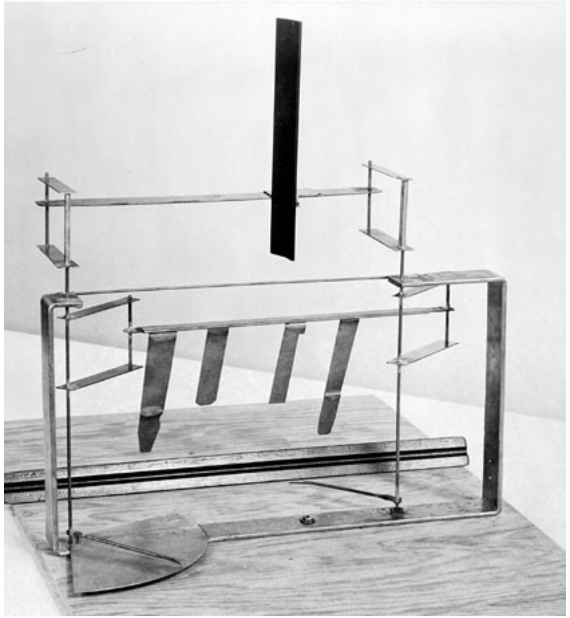
Attacked first.

- Systemic testing of control ideas in kites, gliders.
- Discovered need to control yaw.
- Discovered that existing lift tables were wrong…

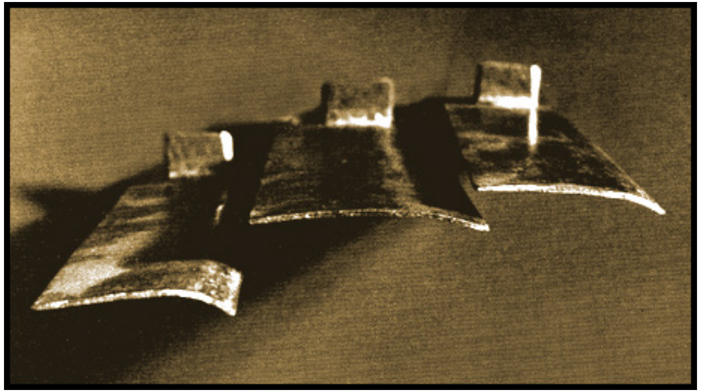


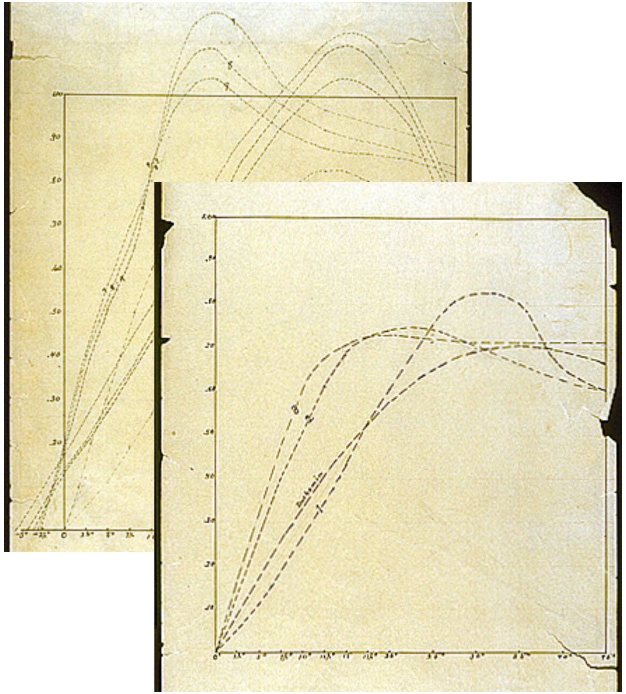
Closing the wing design gap

Wind Tunnel



Lift Balance





Wind tunnel data confirmed in a subsystem test

Closing the Propulsion Gap

<u>**Breakthrough Realization:**</u>

"It was apparent that a propeller was simply an aeroplane (wing) travelling in a spiral course. As we could calculate the effect of a wing traveling in a straight course, why should we not be able to calculate the effect of a wing travelling in a spiral course?"

Reusable Knowledge!

Reused Knowledge

Airfoil knowledge curves used to design novel propeller.

Highly efficient propeller allowed a small motor.

They closed the propulsion gap!

“Success assured.”

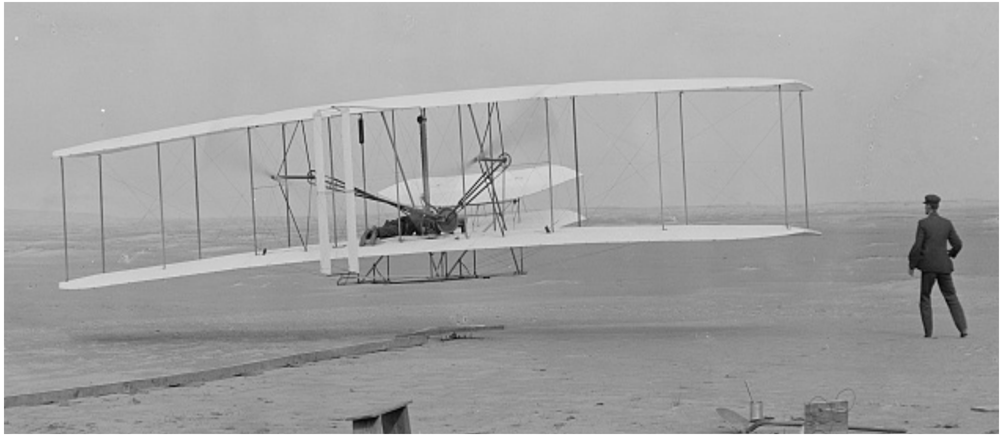
With the knowledge gaps now closed…

A full system prototype was built…

Transported to Kitty Hawk…

And flew,

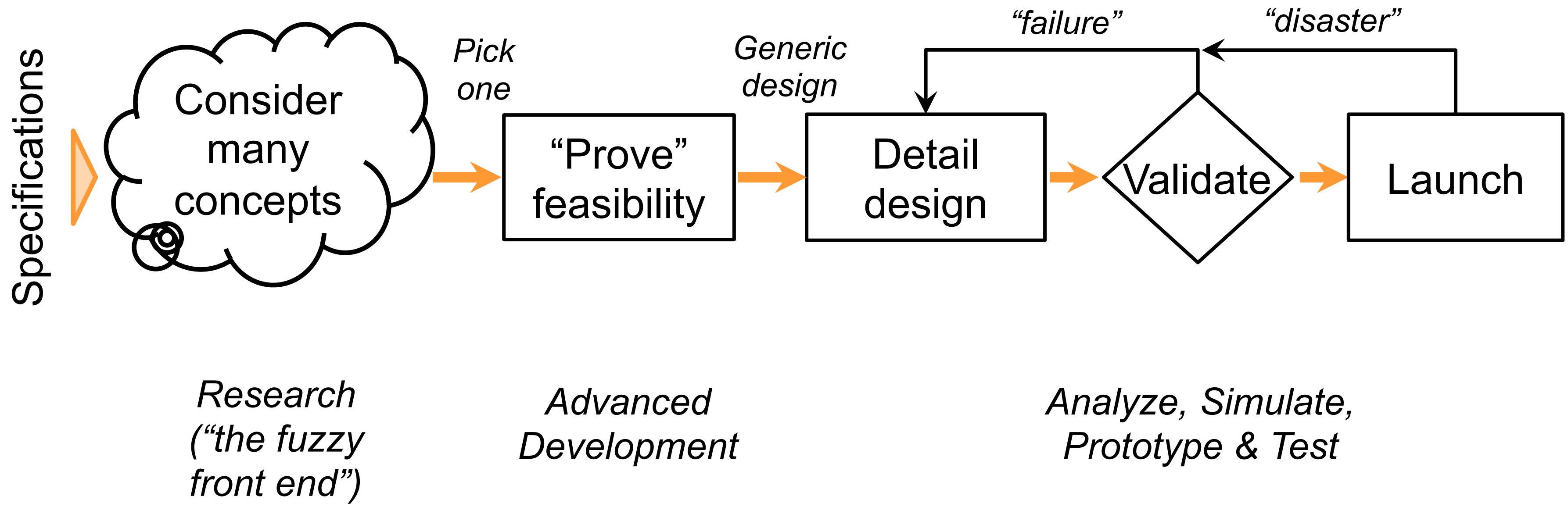
with no design changes!



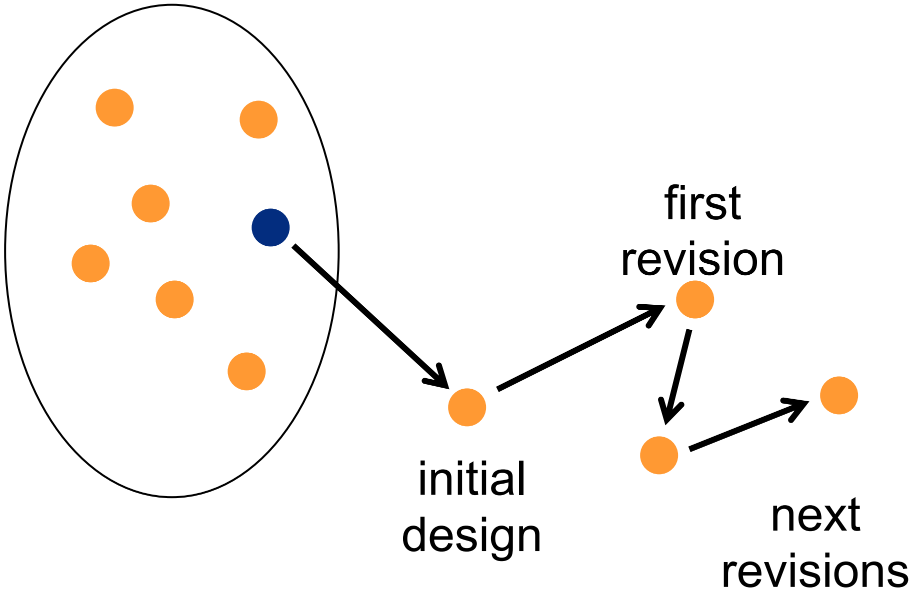
Take-aways

1. Design-build-test vs. learning first

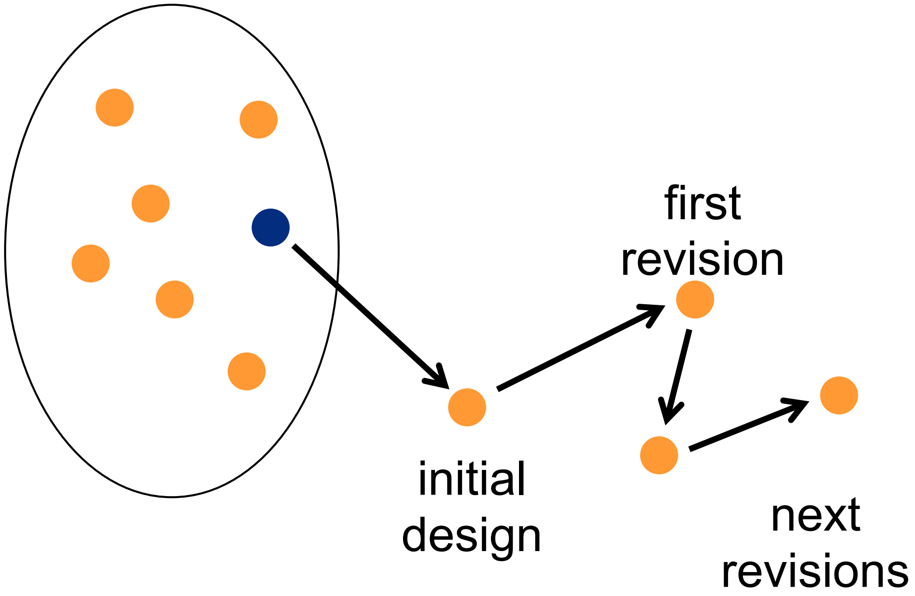
Conventional Development



Iteration on a "Point" Solution



Iteration on a "Point" Solution



Problems

When will you find a design that works?

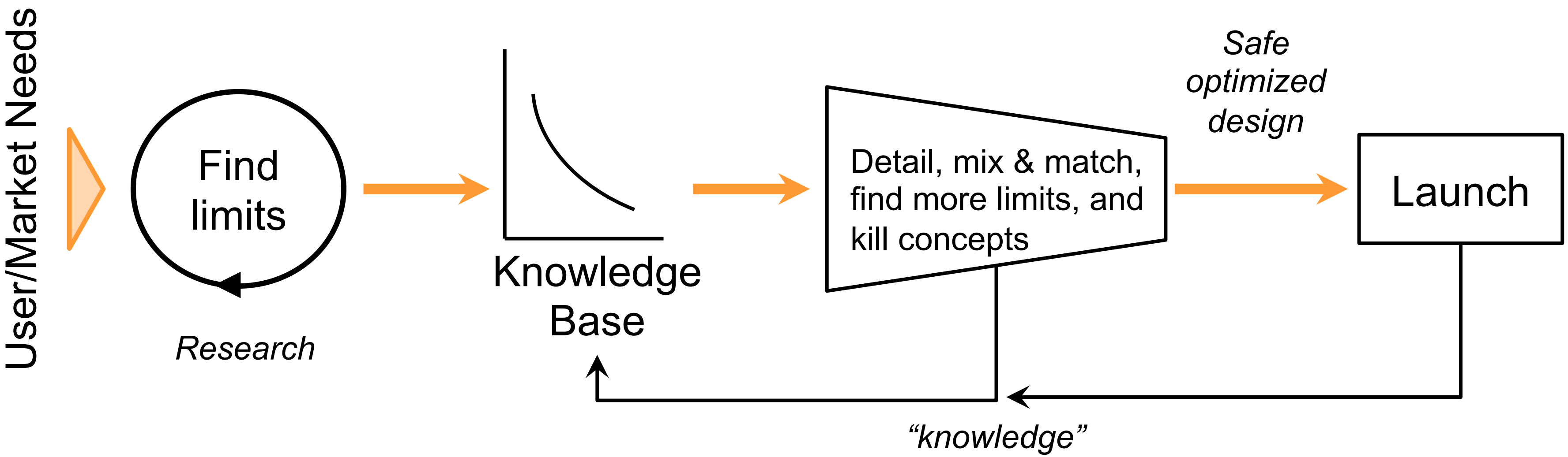
Where to go next?

How far are you from a "cliff"?

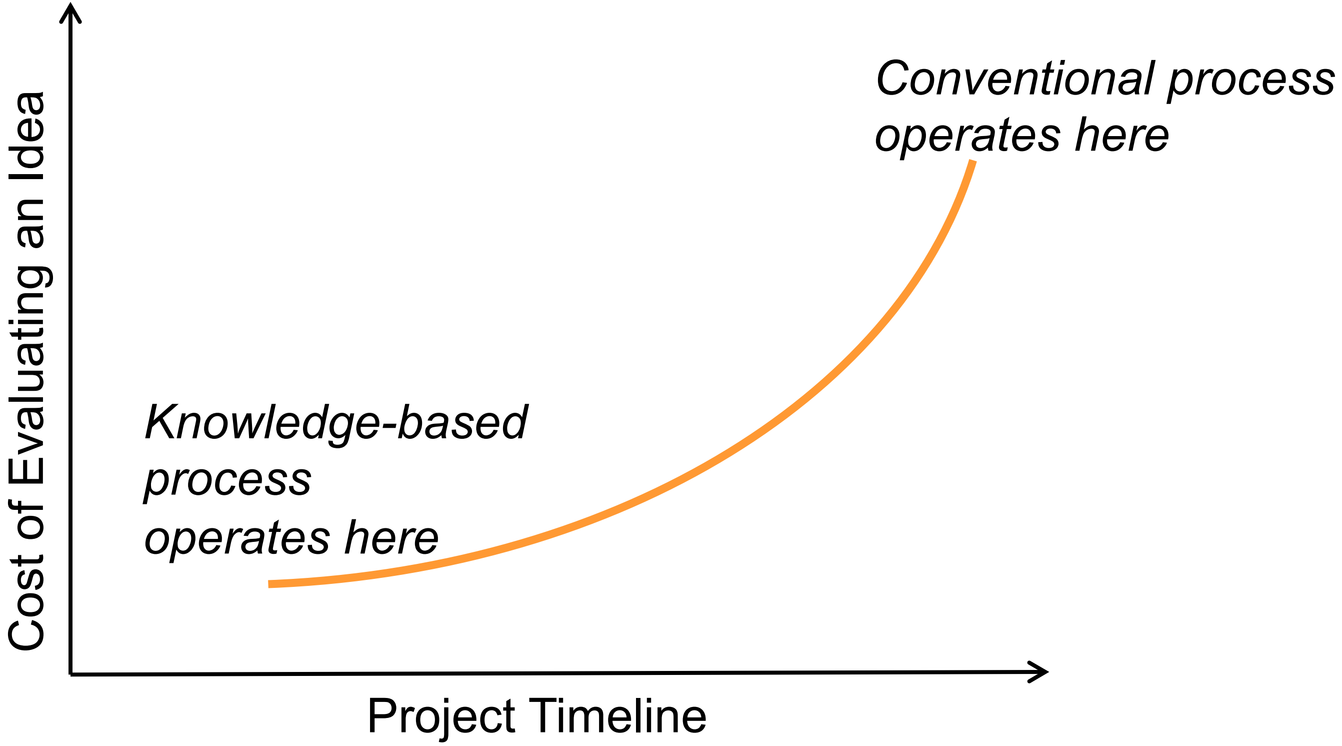
Have you produced any reusable knowledge?

How can teams work concurrently?

Knowledge-based Development

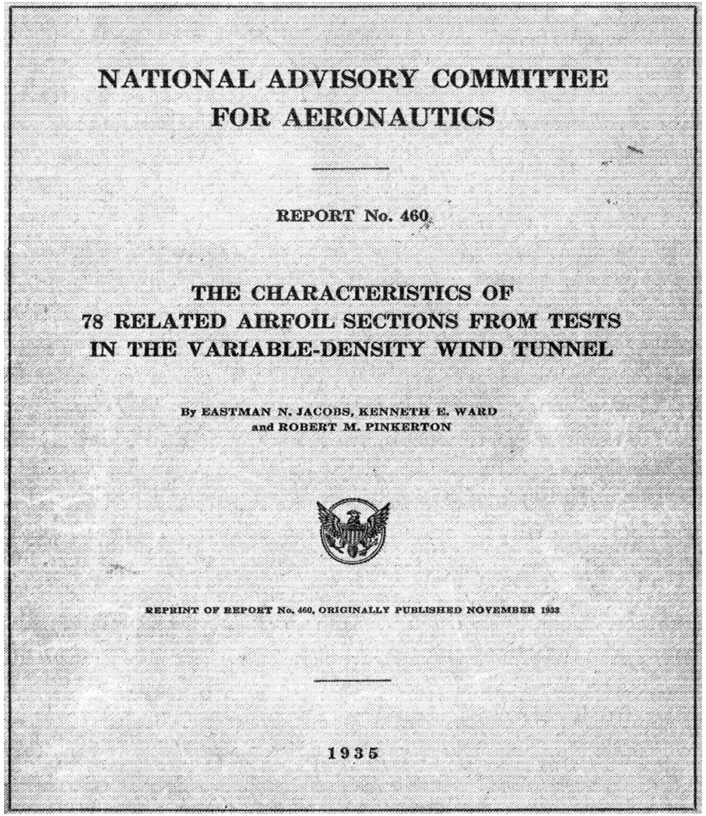


Is it More Expensive?



Take-aways

1. Design-build-test vs. learning first
2. Re-usable "visible" knowledge


NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

REPORT No. 460

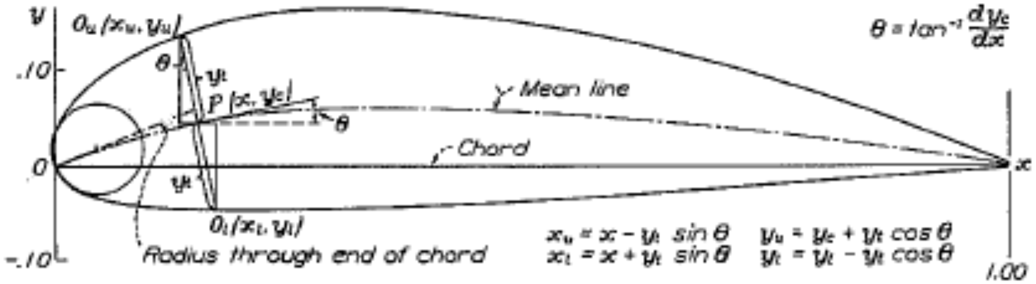
THE CHARACTERISTICS OF
78 RELATED AIRFOIL SECTIONS FROM TESTS
IN THE VARIABLE-DENSITY WIND TUNNEL

By EASTMAN N. JACOBS, KENNETH E. WARD
and ROBERT M. PINKERTON

REPRINT OF REPORT No. 460, ORIGINALLY PUBLISHED NOVEMBER 1933

1935

Source:
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930091108_1993091108.pdf



Sample calculations for derivation of N.A.C.A. 6321

x	y_t	y_c	$\tan\theta$	$\sin\theta$	$\cos\theta$	$y_t \sin\theta$	$y_t \cos\theta$	x_u	y_u	x_l	y_l
0	0	0	[1] 0.40000	0.37140	0.92840	0	0	----	----	0	0
0.01250	0.03314	0.00489	.38333	.35793	.93375	0.01186	0.03094	0.00064	0.03583	0.02436	−0.02605
.30000	.10503	.06000	0	0	1	0	.10503	.30000	.16503	.30000	−.04503
.60000	.07986	.04898	−.07347	−.07327	.99731	−.00585	.07965	.60585	.12863	.59415	−.03067
1	.00221	0	−.17143	−.16897	.98562	−.00037	.00218	1.00037	.00218	.99963	−.00218

[1] Slope of radius through end of chord.

FIGURE 2.—Method of calculating ordinates of N.A.C.A. cambered airfoils.

115 airfoils tested!

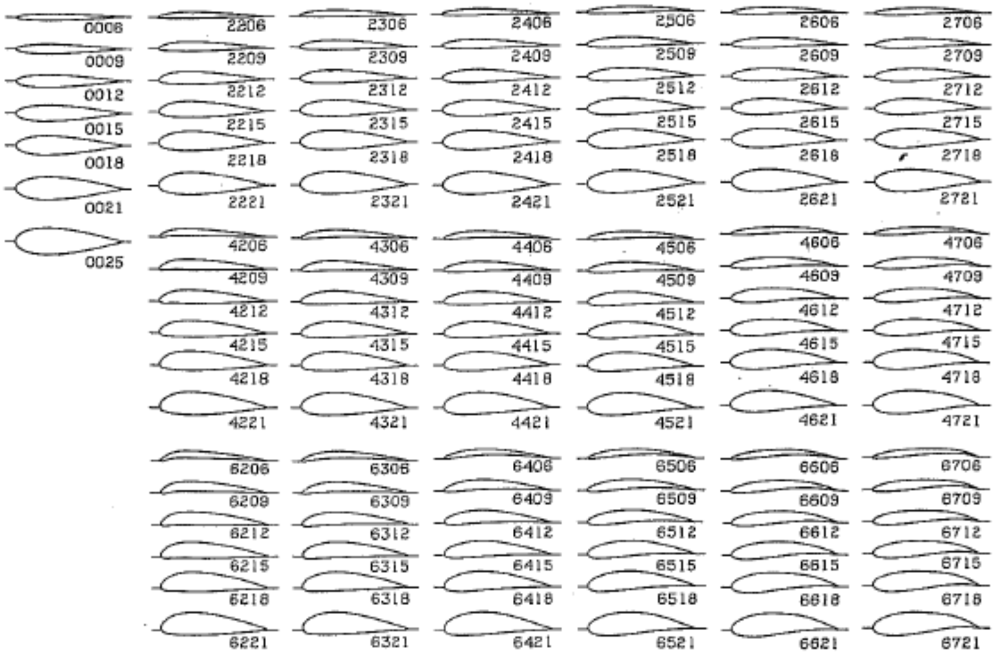


FIGURE 3.—N.A.C.A. airfoil profiles.

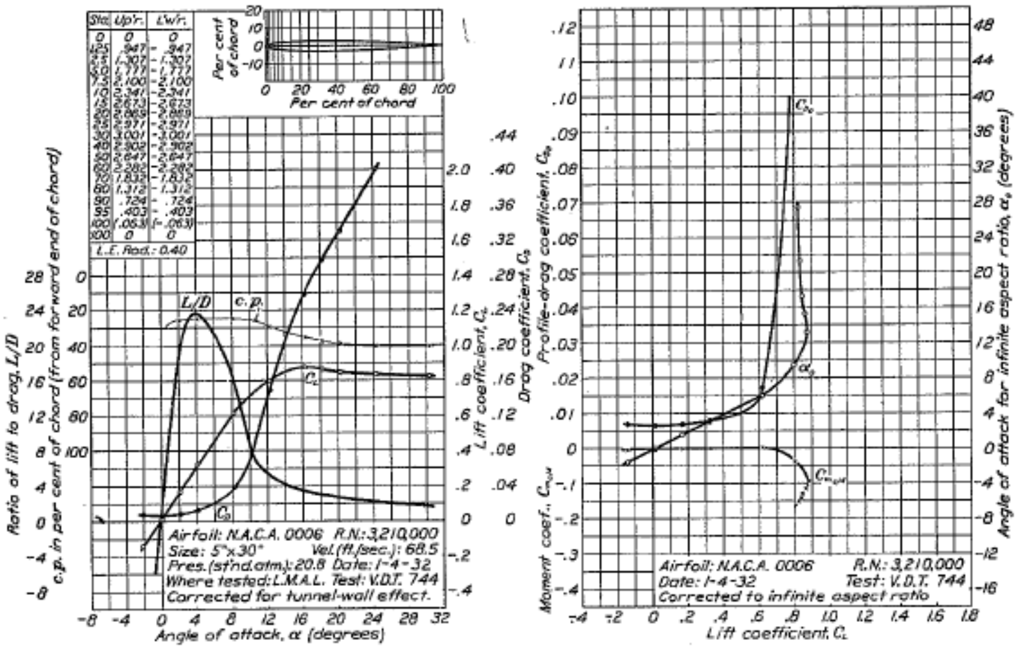


FIGURE 4.—N.A.C.A. 0006 airfoil.

P-51 Mustang

Take-aways

1. Design-build-test vs. learning first
2. Re-usable "visible" knowledge
3. Other?

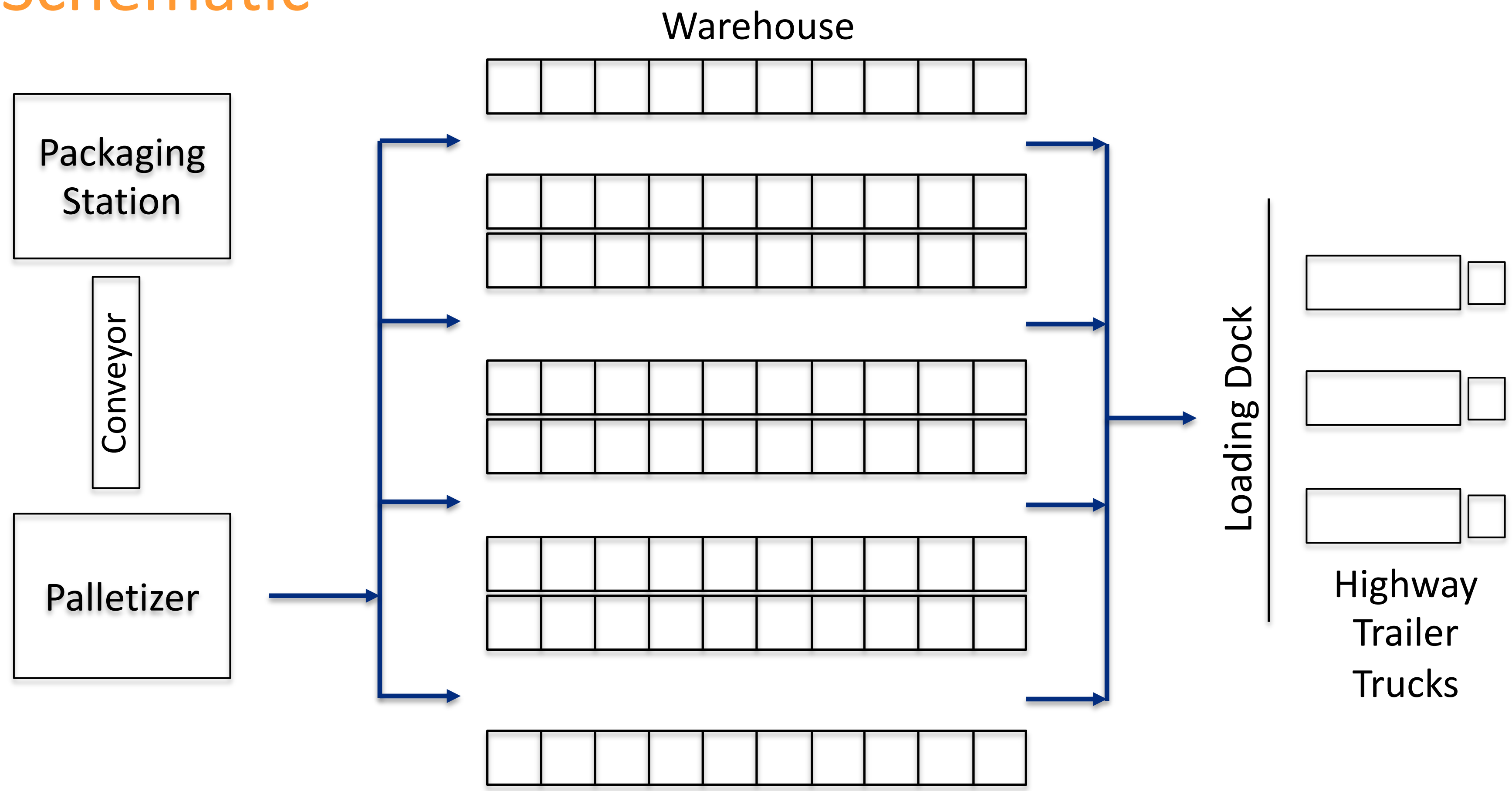
Let’s try this idea on a “real” design problem….

A Logistics Design Problem: Context

- Finished goods are packaged into cardboard cartons
- Cartons transported to a palletizer via belt conveyor, where pallet loads are formed
- Full pallet loads stored in finished goods warehouse using a powered lift truck
- Pallet loads transferred from warehouse to loading dock via lift truck, then loaded onto highway trailer truck for delivery to customers.

Adapted from Tanchoco and Agee, “Plan Unit Loads to Interact with All Components of Warehouse System,” *Industrial Engineering*, pp. 36-48, June 1981.

Schematic


Warehouse
Packaging Station
Conveyor
Palletizer
Loading Dock
Highway Trailer Trucks

Objectives

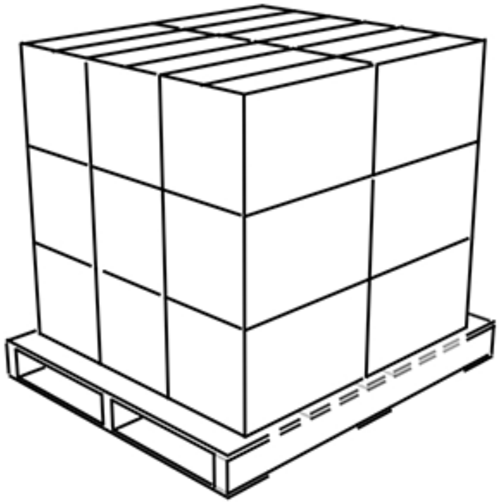
Minimize the warehouse area required to store 500,000 parts

and

Minimize the number of truckloads required to deliver 500,000 parts

Design Decisions

1. Select carton size:
   - 12”L x 10”W x 10”H -- holds 17 parts, weighs 27.2 lbs.
   - 10”L x 8”W x 8”H -- holds 9 parts, weighs 15.7 lbs.
2. Select pallet size:
   - 36”L x 36”W four-way
   - 40”L x 48”W two-way
   - 48”L x 40”W two-way
3. Determine the number of layers in pallet load.



Assumptions / Givens

- Pallet height = 6 in.
- Pallet weight = 25 lbs.
- Palletizer max height = 70 in.
- Lift truck capacity = 3,000 lbs.
- Lift truck max height = 106 in.
- Warehouse clear height = 20 ft.
- Number of warehouse aisles = 4
- Warehouse aisle width = 10 ft.
- Block storage with 6” spacing between stacks
- Truck trailer interior = 40’(L) x 7.5’(W) x 11’(H)

How would you approach this design problem?

- *Say "hello" to someone nearby and introduce yourself.*
- *Discuss with them how to approach the problem.*
    - *Do some calculations, if possible.*
- How long do you estimate it will take you to get an answer?
- How much iteration do you estimate will happen?

Book Solution

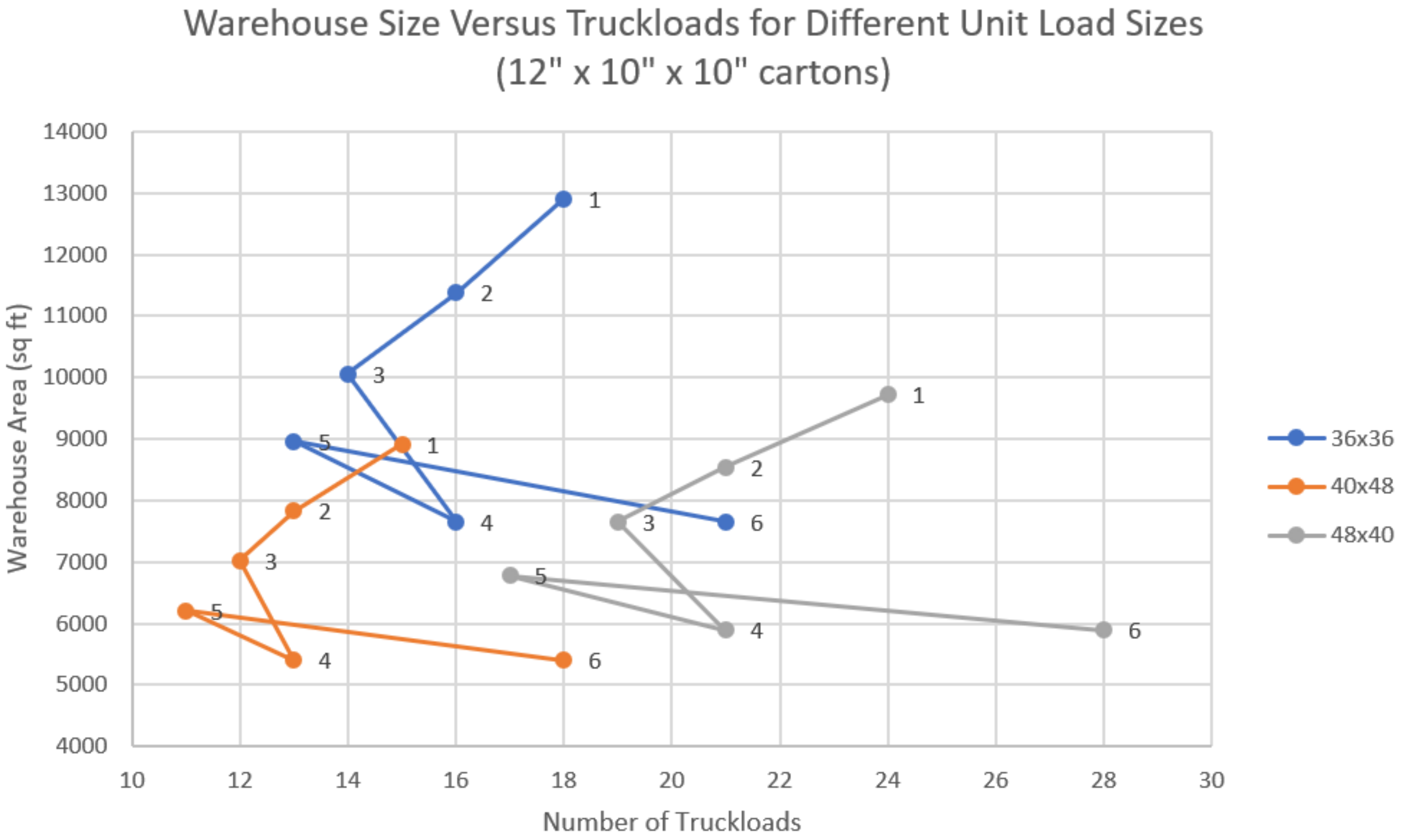
Carton	Pallet	Cartons/ Layer	# of Layers	Total # of Unit Loads	Warehouse Area	# of Truckloads
12”x10”x10”	36” x 36”	9	4	817	7394	18
	40” x 48”	16	4	460	5426	13
	48” x 40”	16	4	460	5781	21
10”x8”x8”	36” x 36”	16	5	695	6283	15
	40” x 48”	24	5	463	5462	13
	48” x 40”	24	5	463	5819	22

From Tanchoco and Agee, “Plan Unit Loads to Interact with All Components of Warehouse System,” *Industrial Engineering*, pp. 36-48, June 1981.

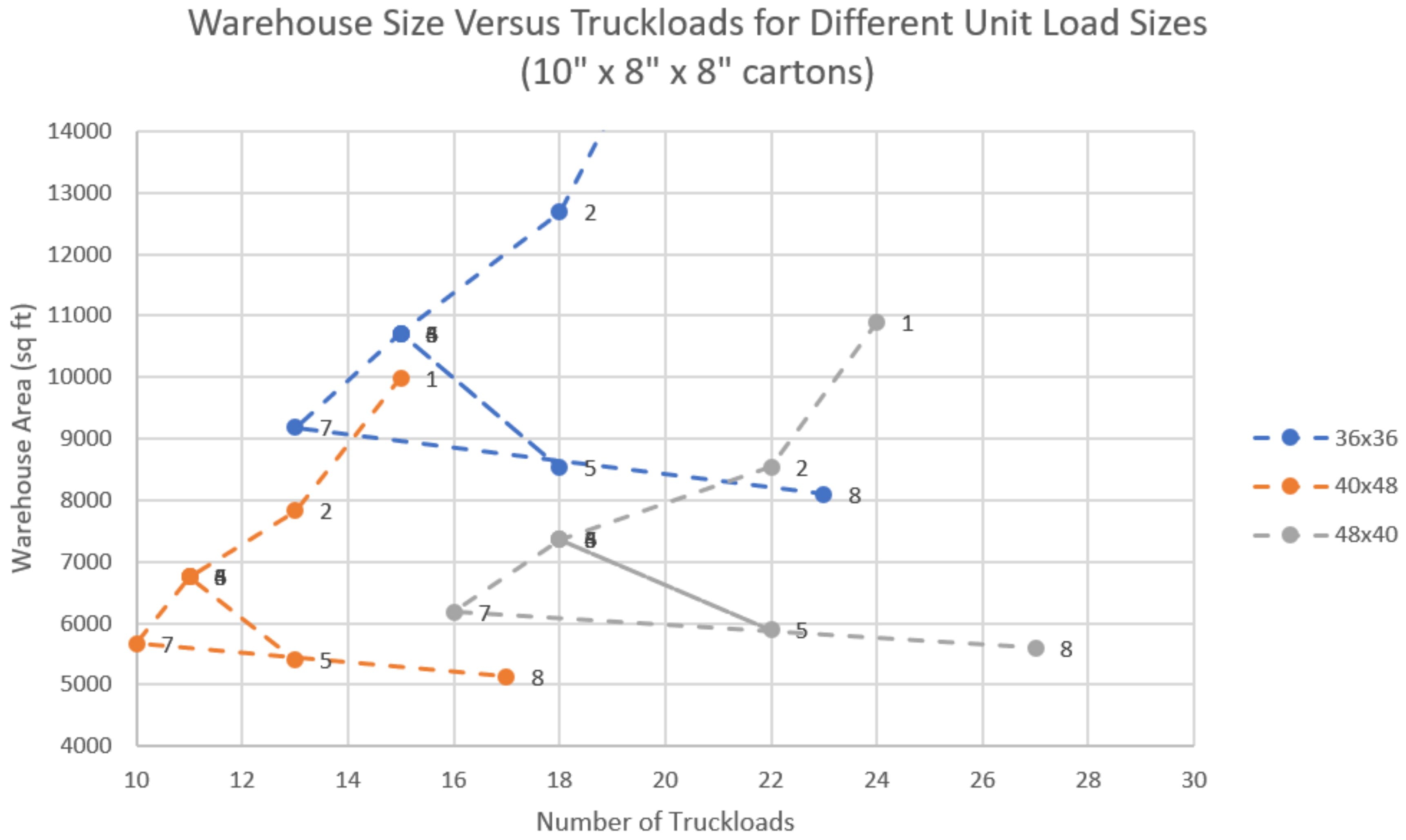
Questions…

1. How quickly can you identify the best solution in the set?
2. How confident are you that this is the best solution?
3. What trade-offs did the designers make in their analysis?
4. How much reusable knowledge was produced?

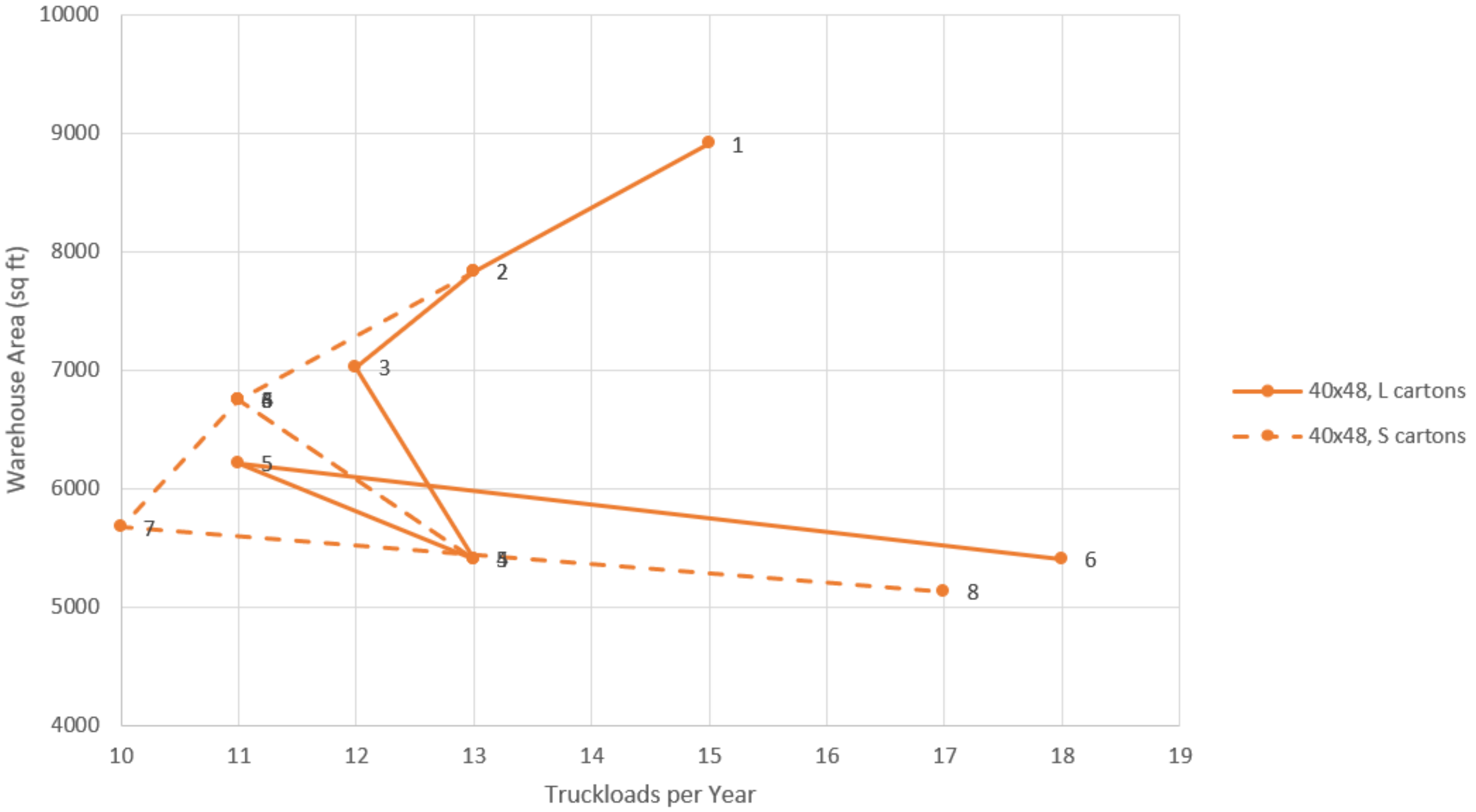
What if we had “visible knowledge” for this problem…?



Warehouse Size Versus Truckloads for Different Unit Load Sizes
(12" x 10" x 10" cartons)
Warehouse Area (sq ft)
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
10
12
14
16
18
20
22
24
26
28
30
Number of Truckloads
36x36
40x48
48x40
1
2
3
4
5
6


Warehouse Size Versus Truckloads for Different Unit Load Sizes
(10" x 8" x 8" cartons)
Warehouse Area (sq ft)
Number of Truckloads
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
10
12
14
16
18
20
22
24
26
28
30
36x36
40x48
48x40

Top Two Contenders



Questions…

1. How quickly can you identify the best solution in the set?
2. How confident are you that this is the best solution?
3. What trade-offs did the designers make in their analysis?
4. How much reusable knowledge was produced?

How do you develop visible knowledge?

Allen Ward Procedure

1. State the issue
2. Draw a picture
3. Create a causal diagram
4. Find data and create curves
5. Develop countermeasures

Let's try this together….

Issue:

Picture of System:

Causal Diagram:

Hypothesized Relationships and Equations:

1. With a partner, state the issue.

1. With a partner, state the issue.

Which of these do you like best?

a. Improved pallet loads.
b. Pallet load design to minimize storage space and shipping frequency.
c. Logistics trade-offs.
d. 40” wide pallets maximize space utilization.

2. Sketch a diagram of the issue.

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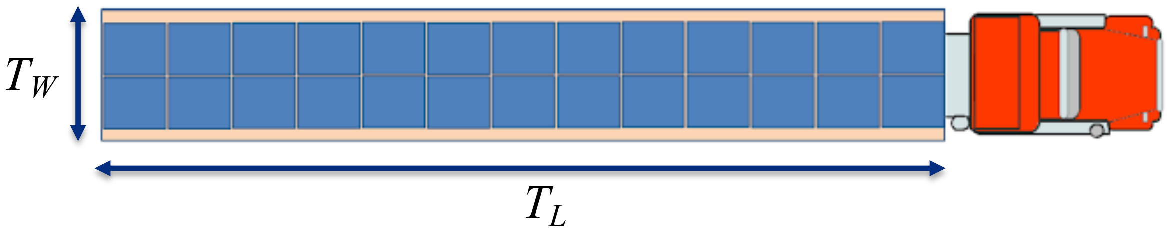
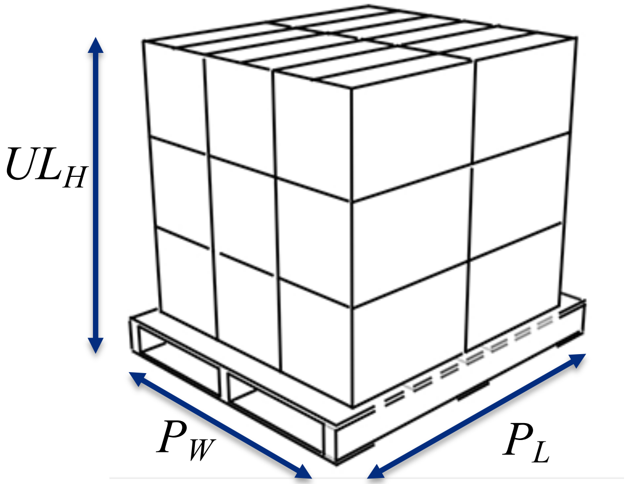
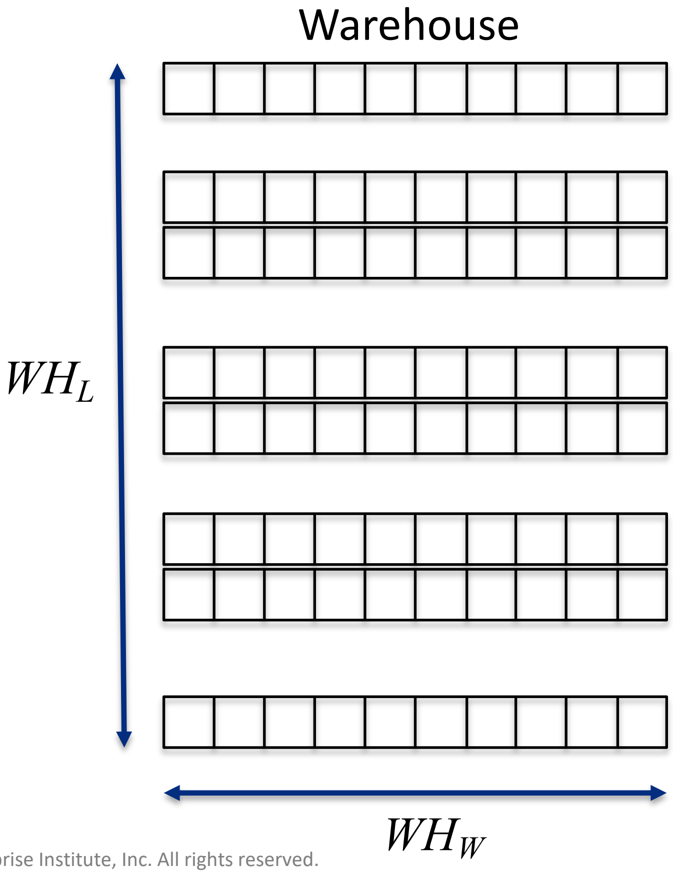




Variables:

- T_W = Truck width
- T_L = Truck length
- T_H = Truck height
- P_W = Pallet width
- P_L = Pallet length
- UL_H = Unit Load height

2. Sketch a diagram of the issue, cont.



Variables:

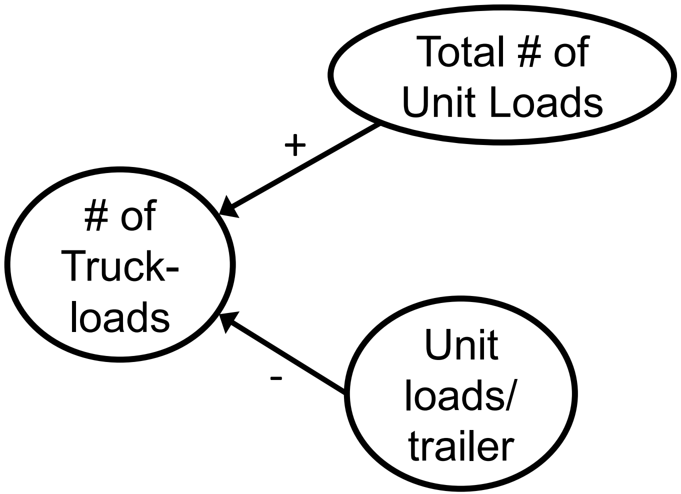
WH_W = Truck width

WH_L = Truck length

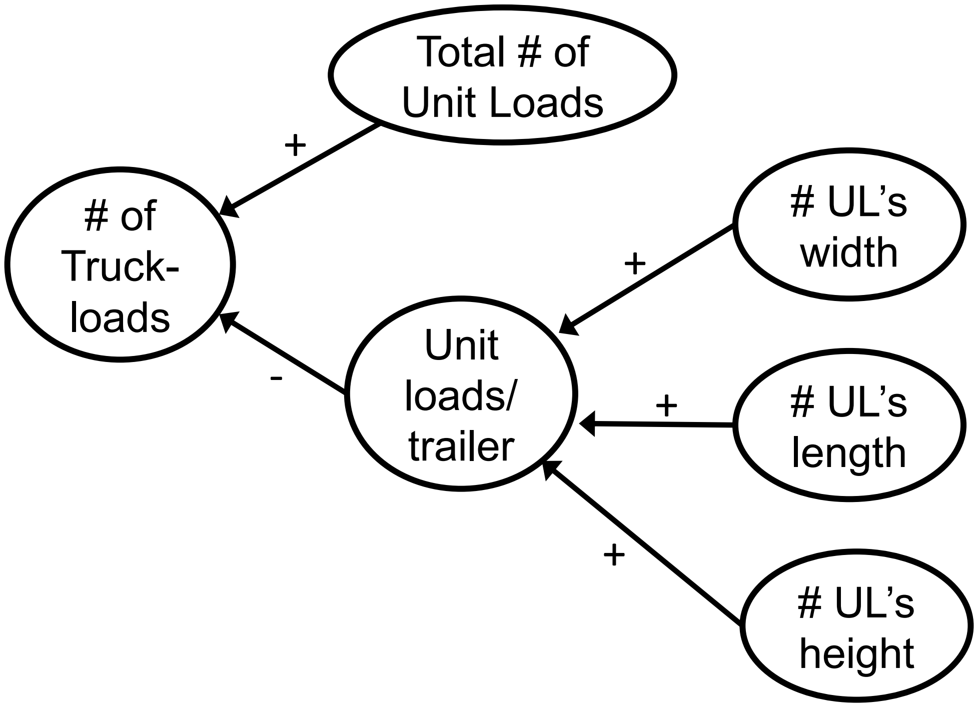
3. Create a causal diagram.

A. On the left, write the result variable we want to influence.
B. Just to the right, write the variables that directly affect that result.
C. Draw arrows that show directionally what affects what.
D. Label arrows with “+” or “-” to show positive or negative relationship.
E. Repeat substeps B-D until you reach variables that are **directly controllable**.

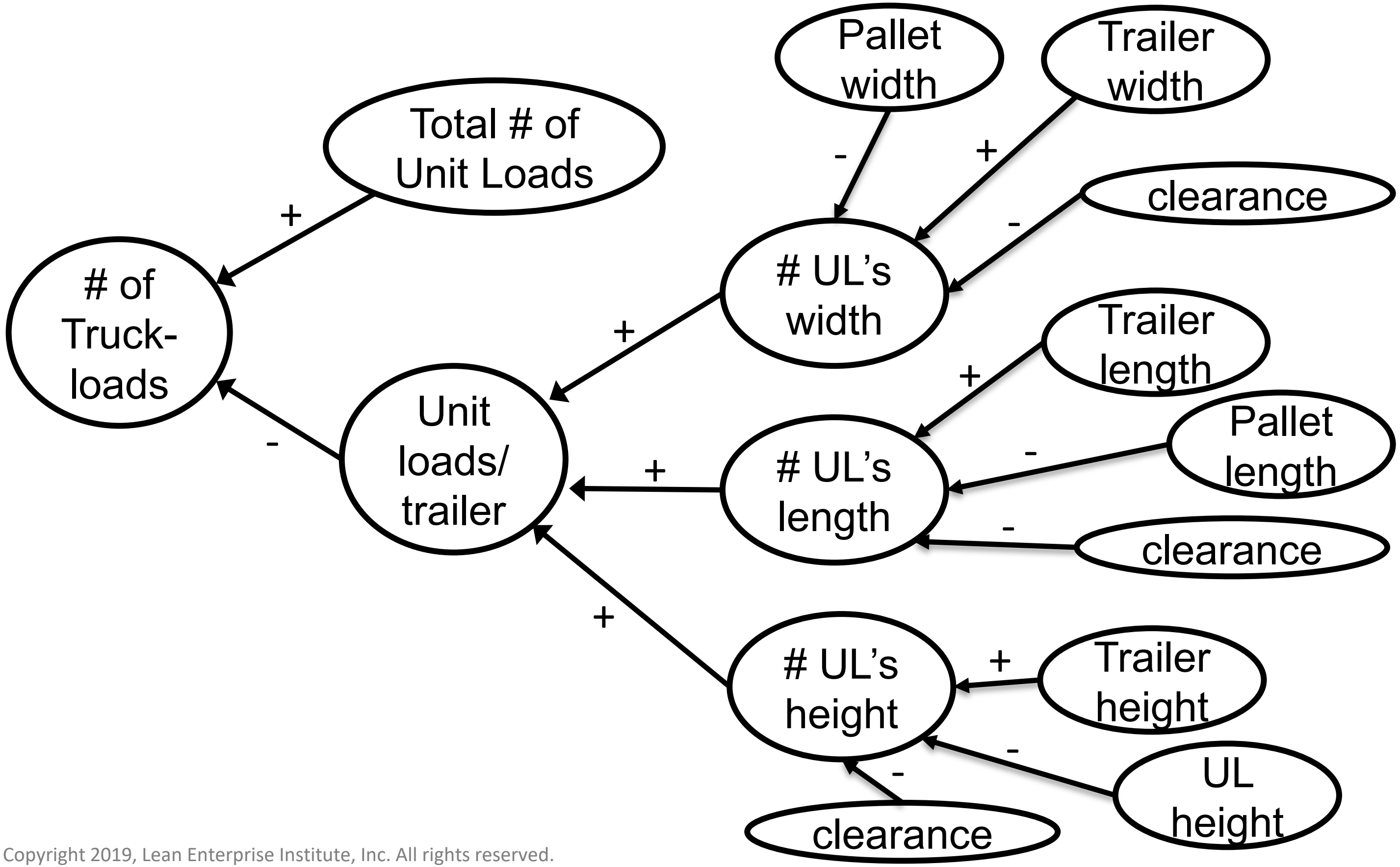
Start of Causal Diagram



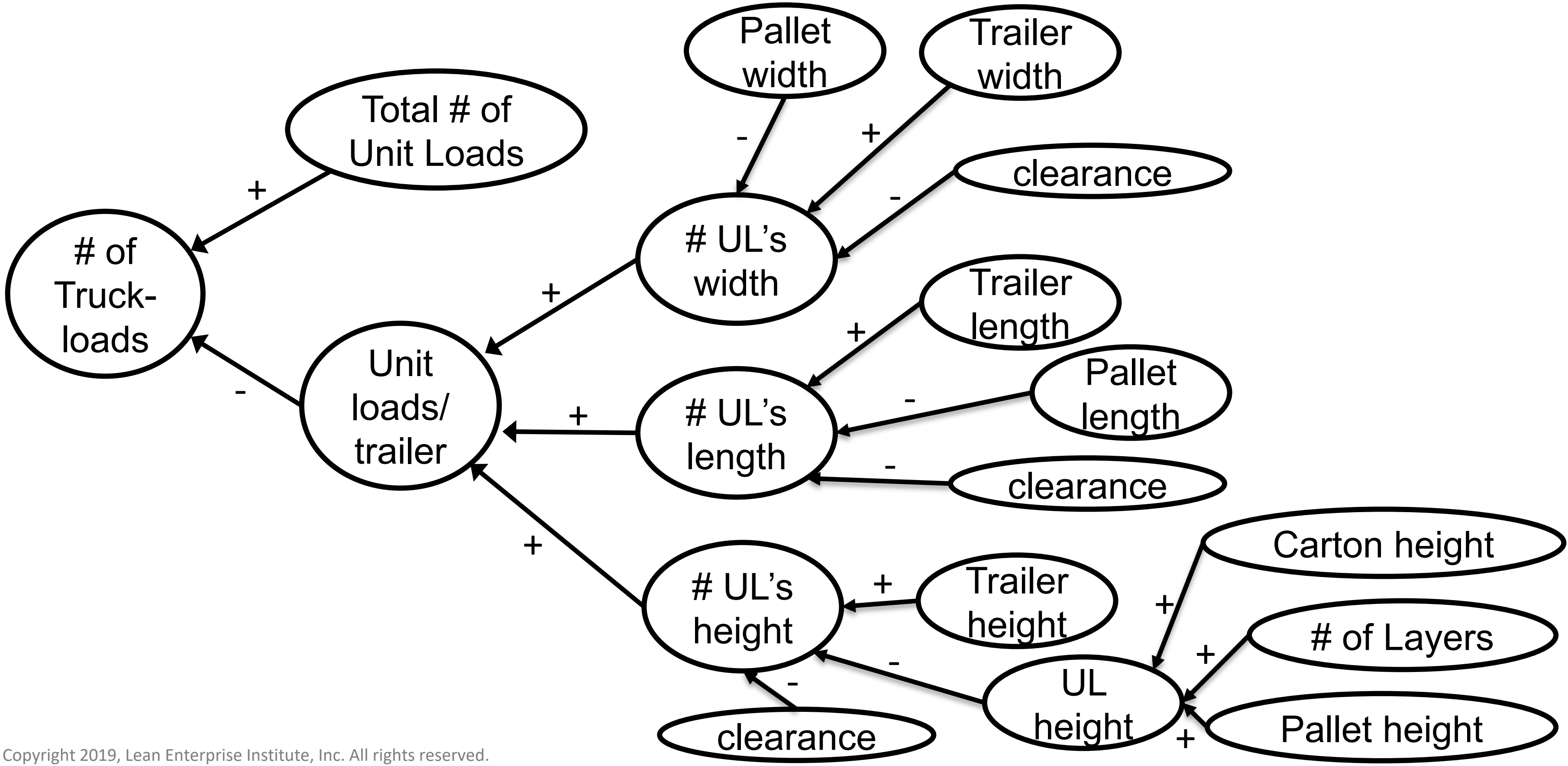
Start of Causal Diagram



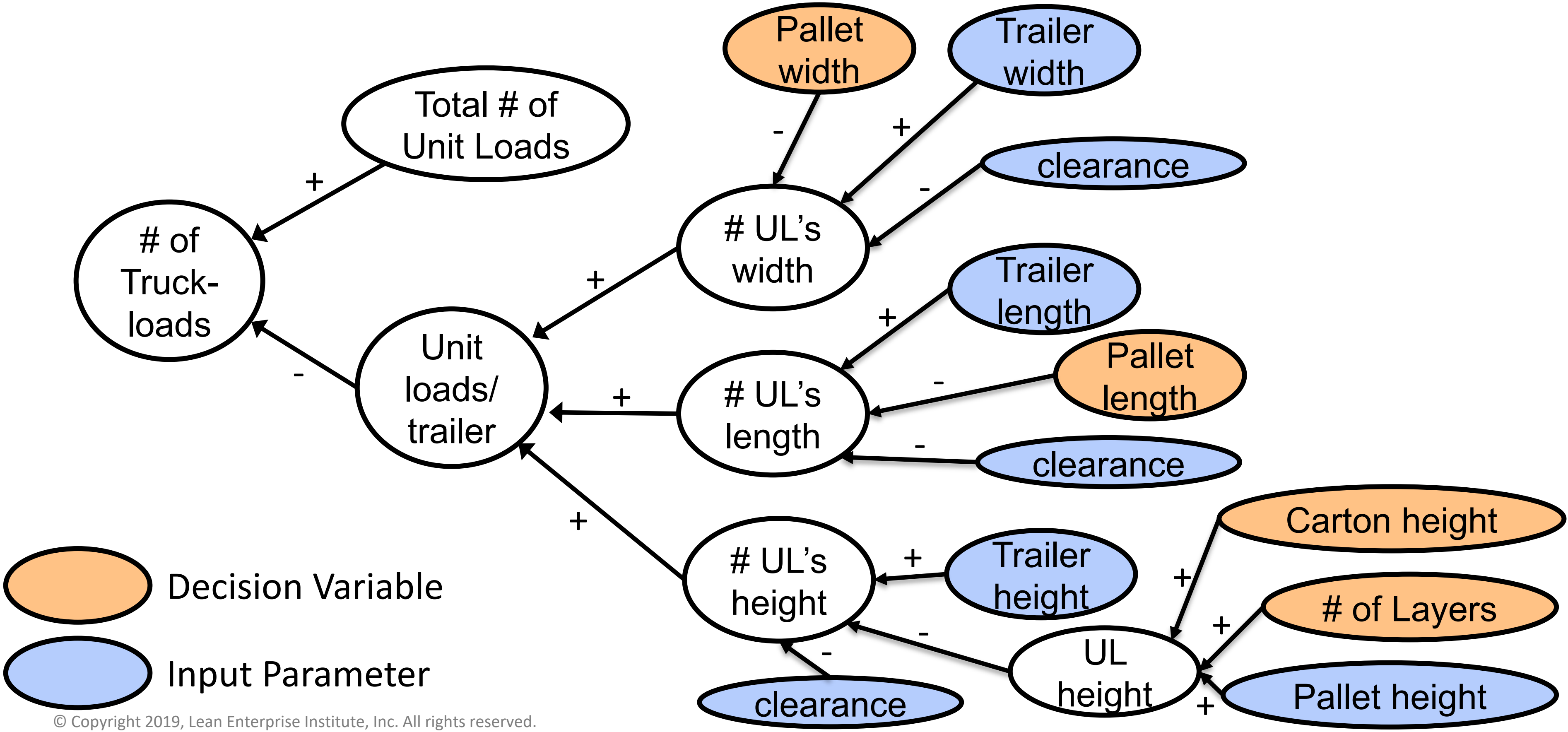
Start of Causal Diagram



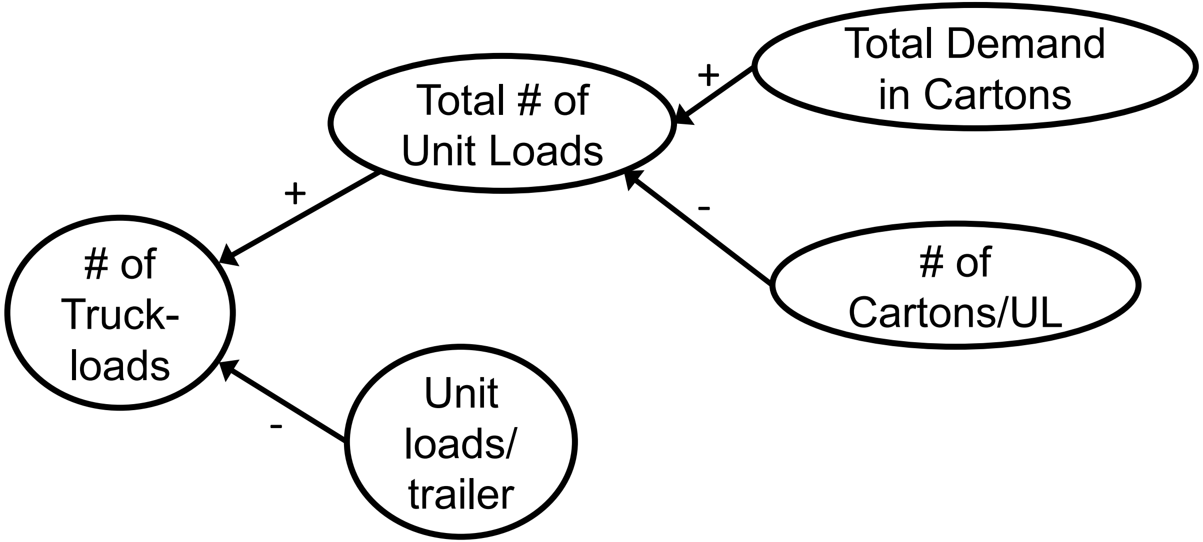
Start of Causal Diagram



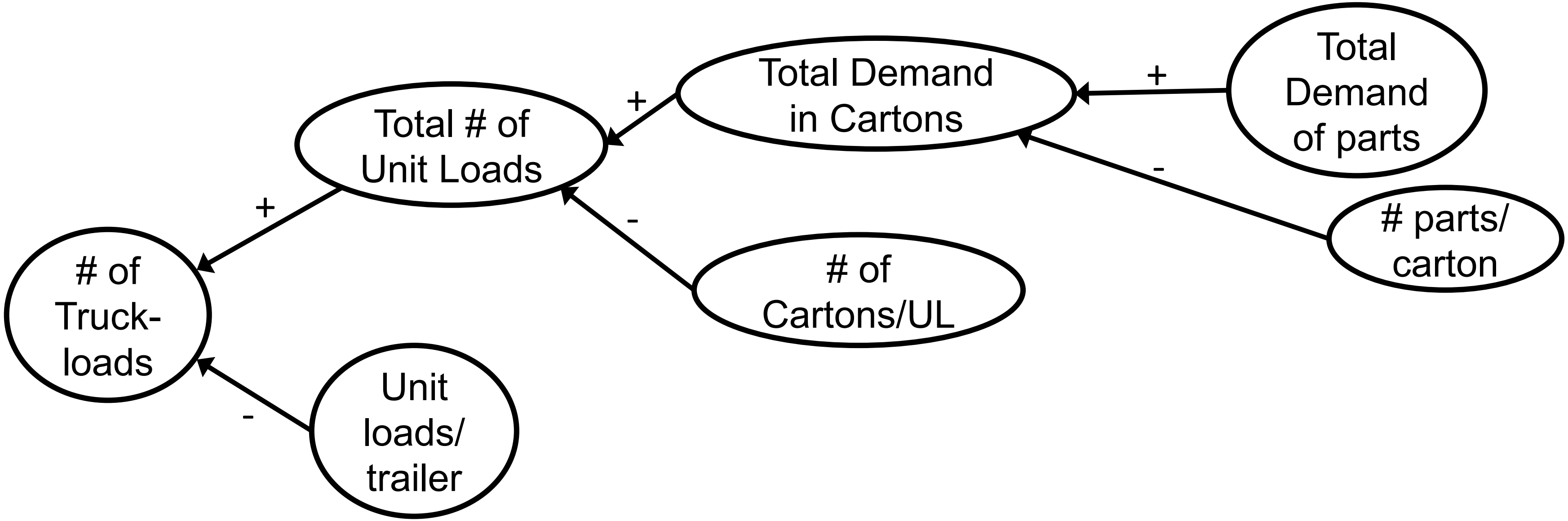
Start of Causal Diagram



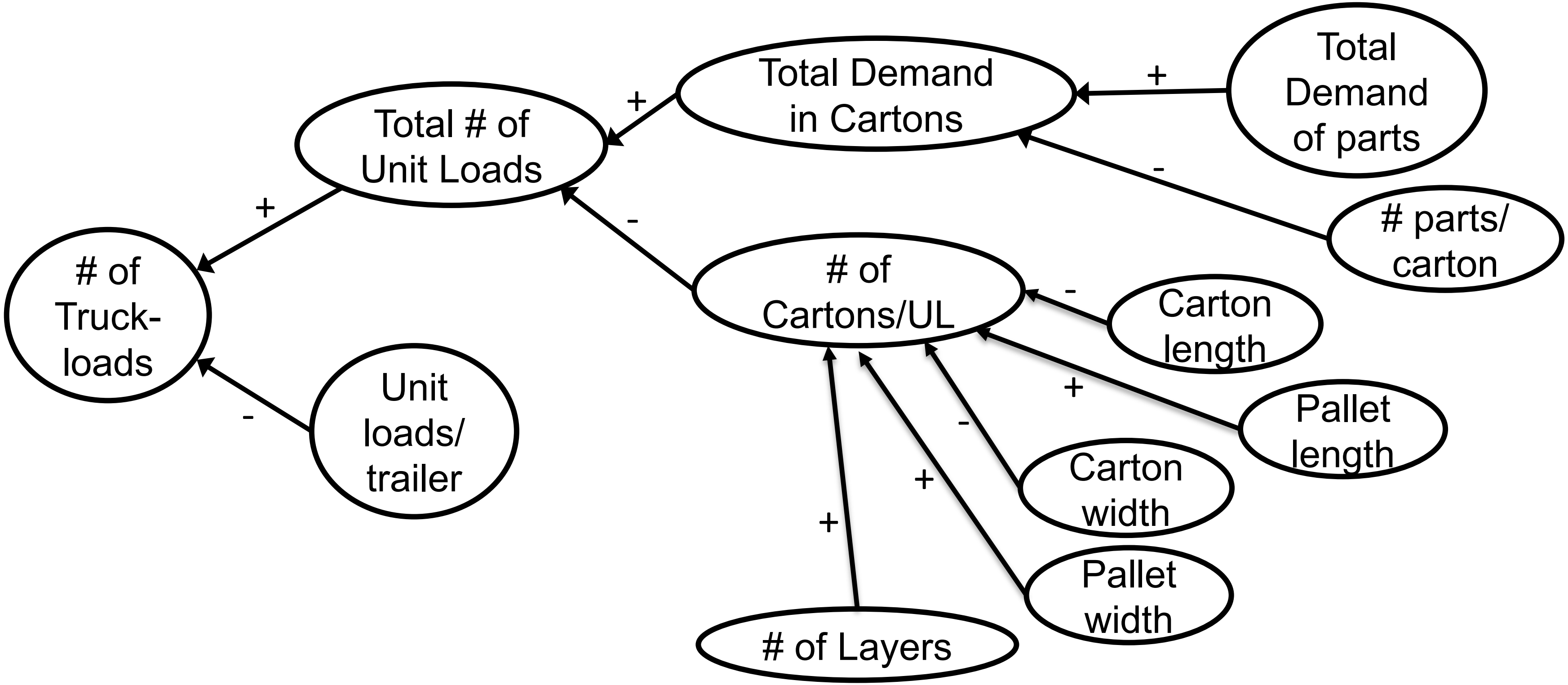
Causal Diagram, cont.



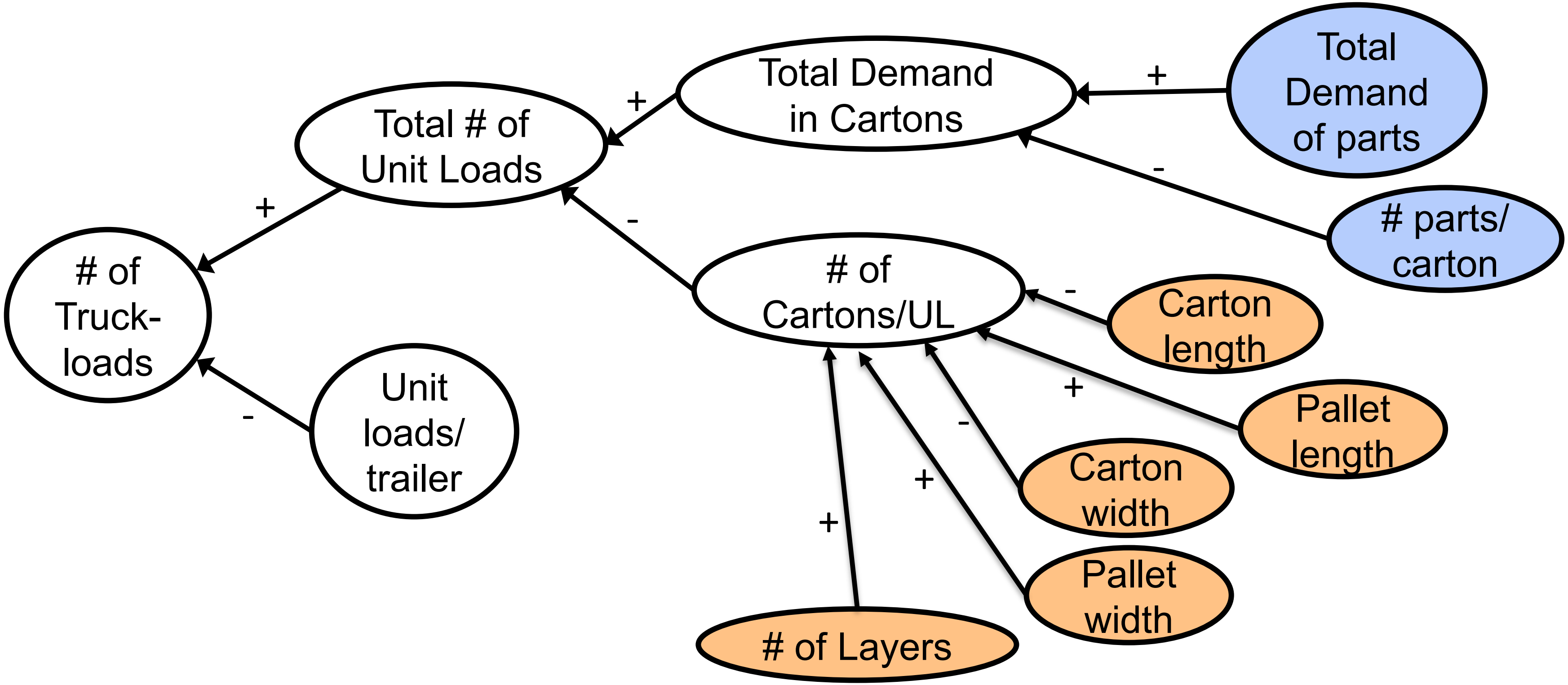
Causal Diagram, cont.



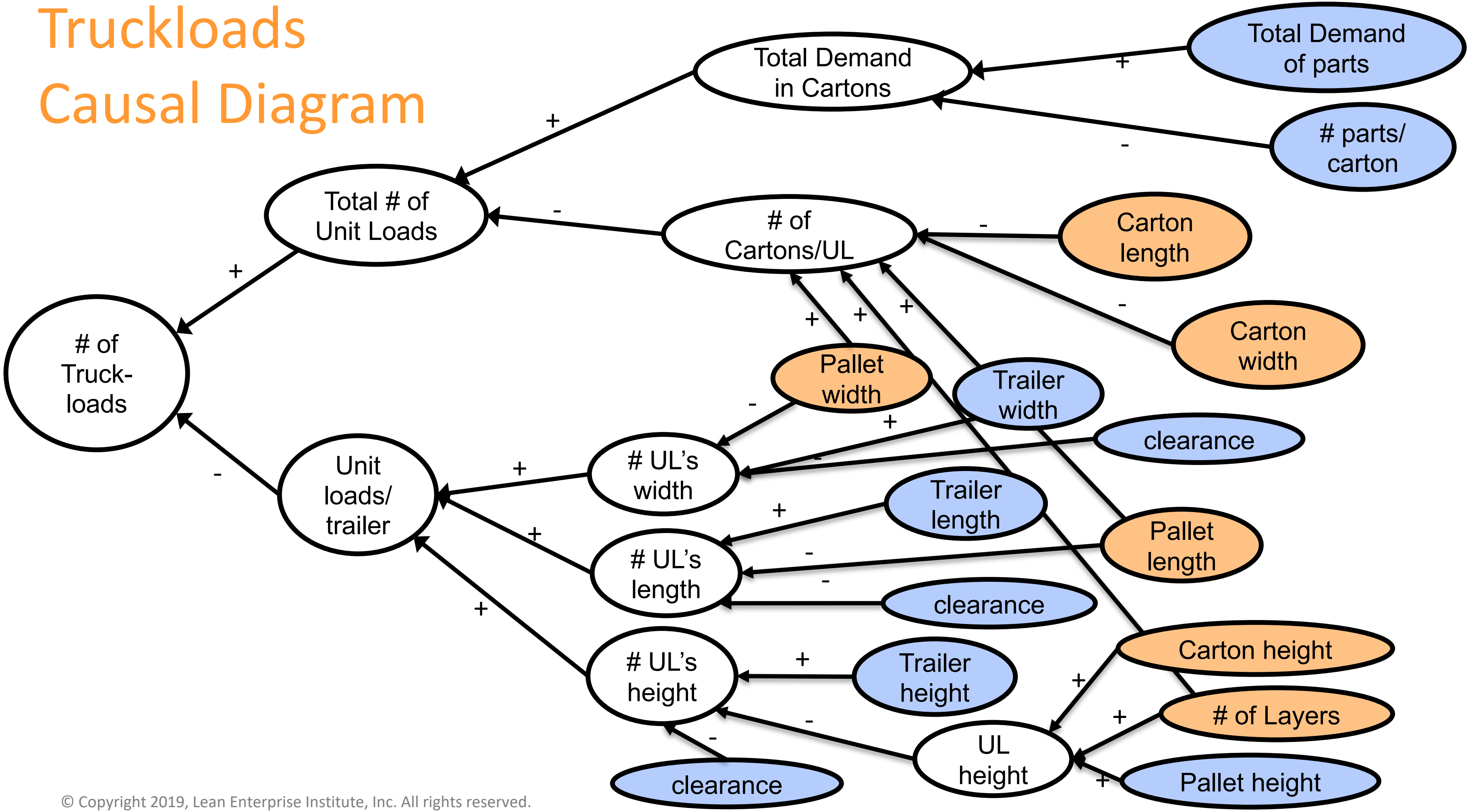
Causal Diagram, cont.



Causal Diagram, cont.

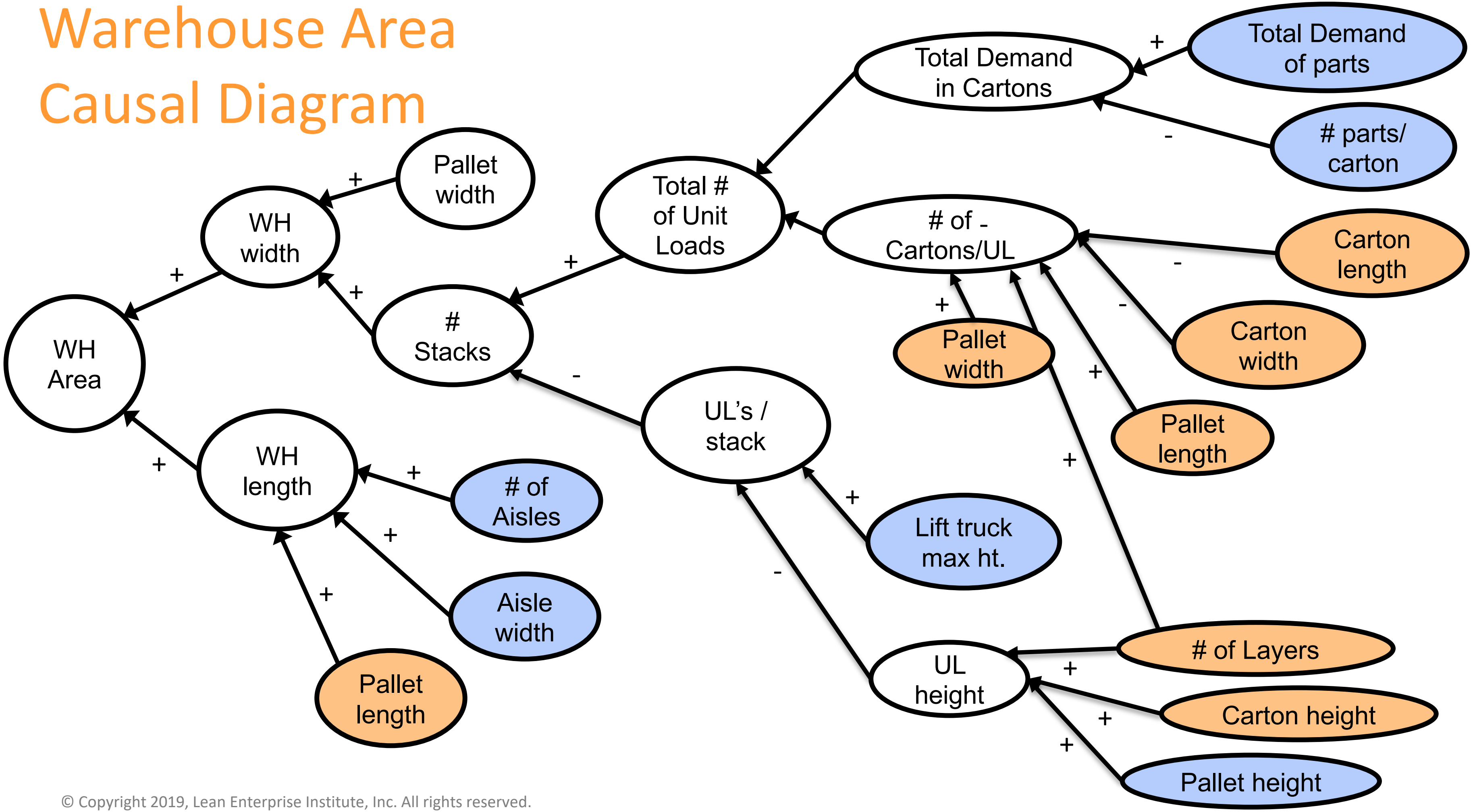


Truckloads Causal Diagram



Do similarly for Warehouse Area

Warehouse Area Causal Diagram

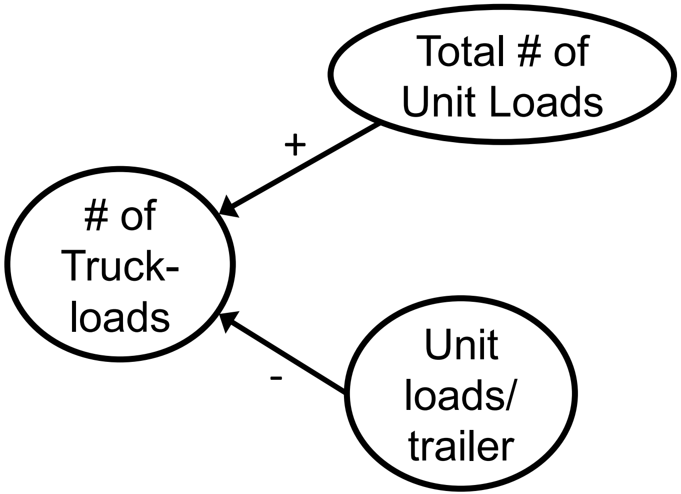


4. Find data and create curves.

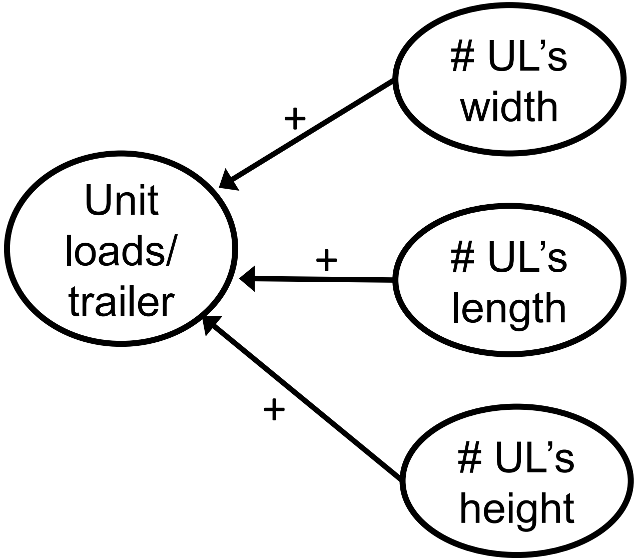
A. Identify clusters of variables that we can handle analytically.
B. Hypothesize relationships among the variables graphically.
C. Find or derive equations relating the variables.
D. Combine equations into compact, generalized parameters.
E. Input parameter values over appropriate ranges and plot curves.

In place of C, D and E you may be able to use historical data or conduct a designed experiment (virtual or physical).

How are these related?

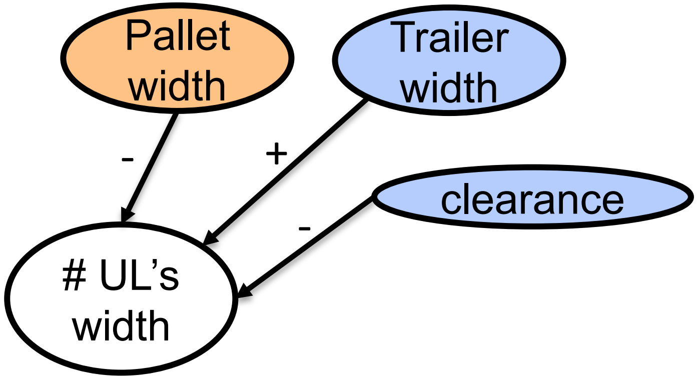


$$\# \text{ TL's} = \frac{\text{Total \# UL's}}{\text{UL's / trailer}}$$

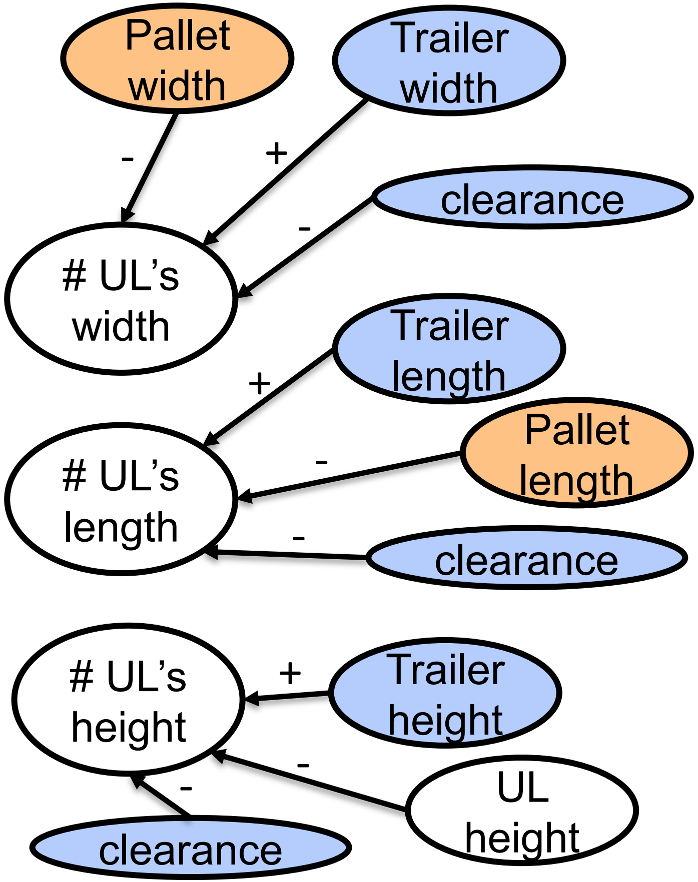


UL's / trailer =

(# UL's width)(# UL's length)(#UL's height)



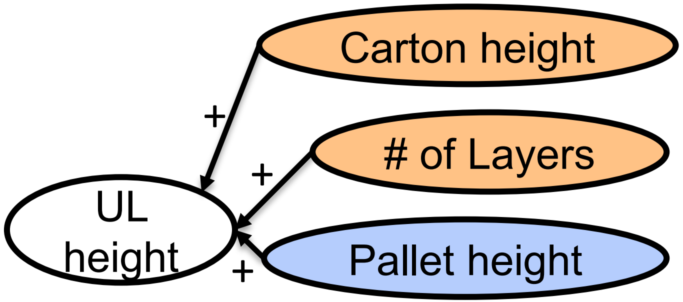
$$\text{\# UL's width} = \frac{\text{Trailer width}}{\text{Pallet width} + \text{Clearance}}$$



$$\text{\# UL's width} = \frac{\text{Trailer width}}{\text{Pallet width + Clearance}}$$

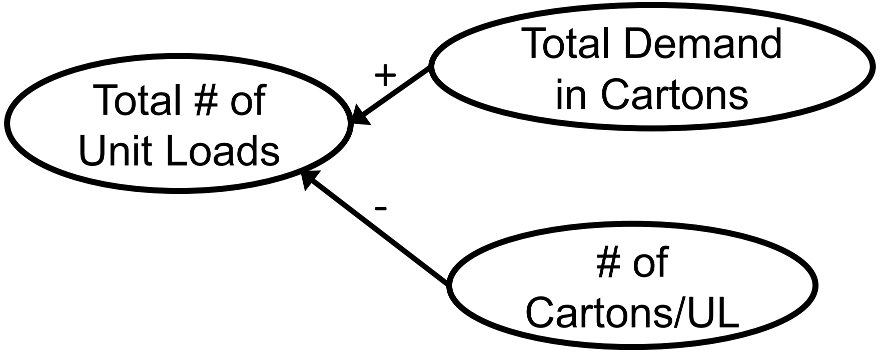
$$\text{\# UL's length} = \frac{\text{Trailer length - clearance}}{\text{Pallet length}}$$

$$\text{\# UL's height} = \frac{\text{Trailer height - clearance}}{\text{UL height}}$$

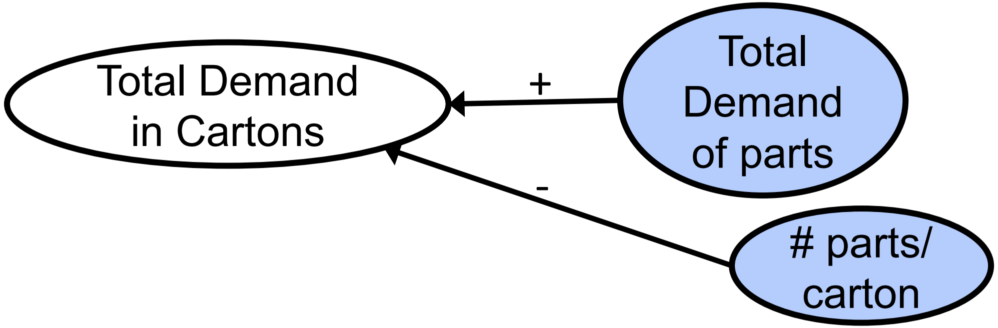


UL height =

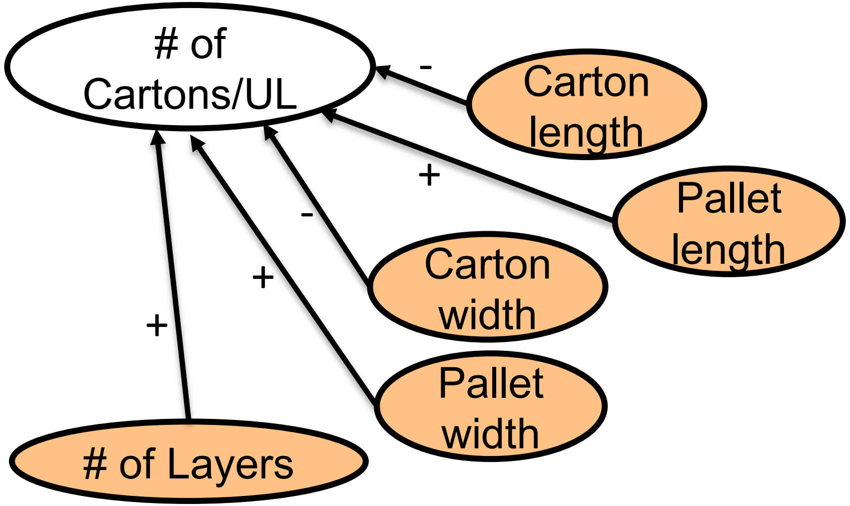
(Carton height)(# of Layers) + Pallet height



$$\text{Total \# UL's} = \frac{\text{Total Demand in Cartons}}{\text{\# Cartons / UL}}$$



$$\text{Total Demand in Cartons} = \frac{\text{Total Demand of Parts}}{\text{\# parts / carton}}$$

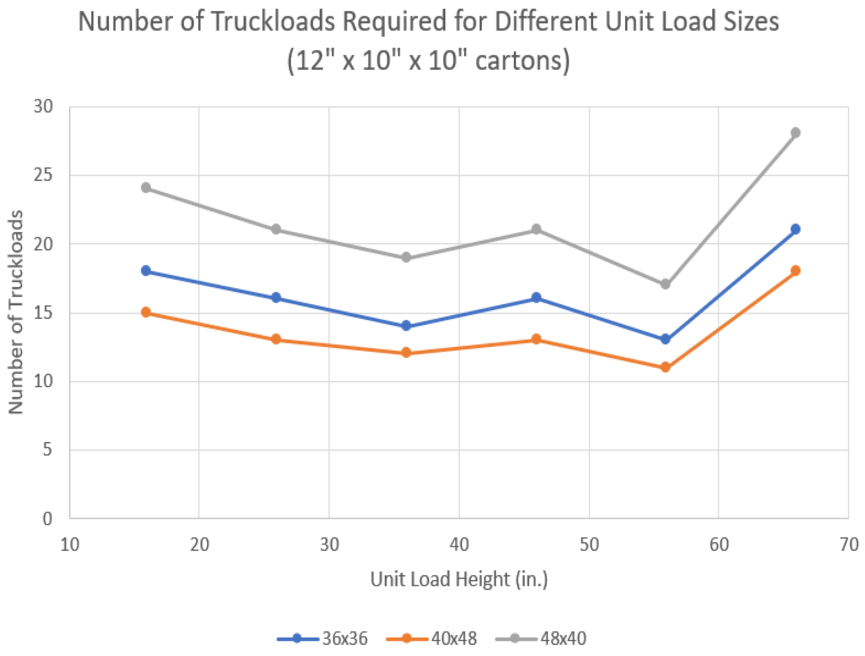


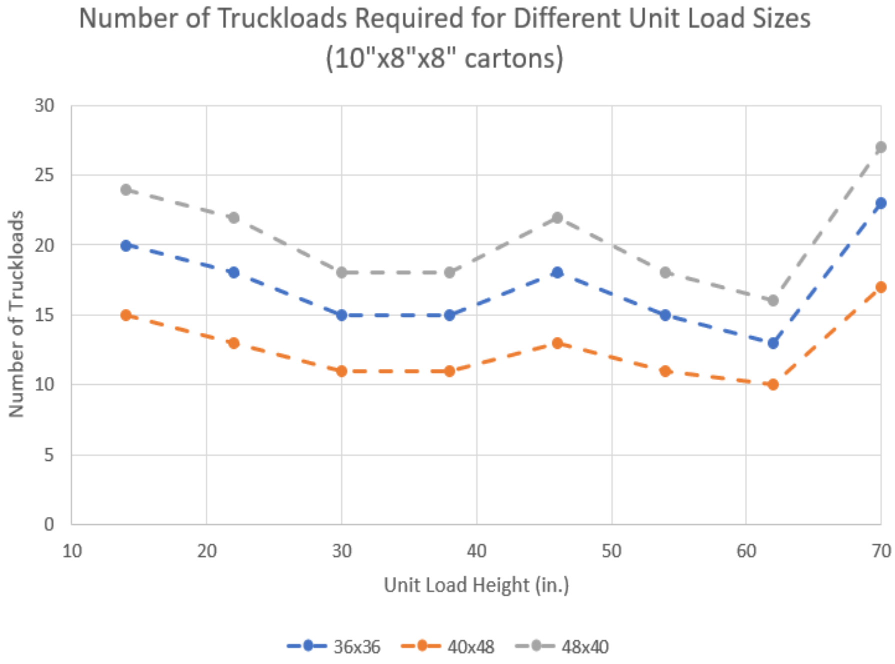
# of Cartons / UL =

(# of Cartons/layer)(# of Layers) =

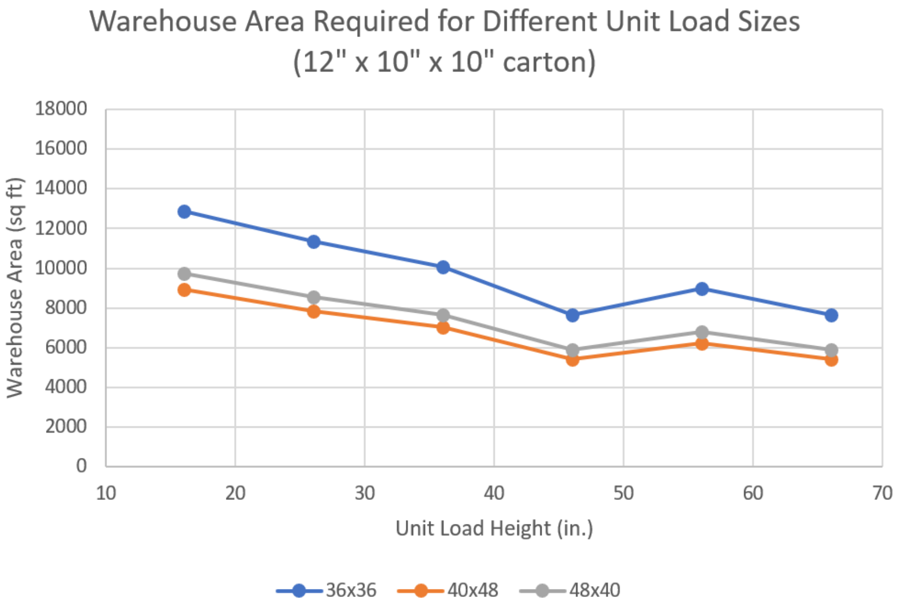
$$\left(\frac{\text{Pallet width}}{\text{Carton width}}\right)\left(\frac{\text{Pallet length}}{\text{Carton length}}\right)(\text{\# of Layers})$$

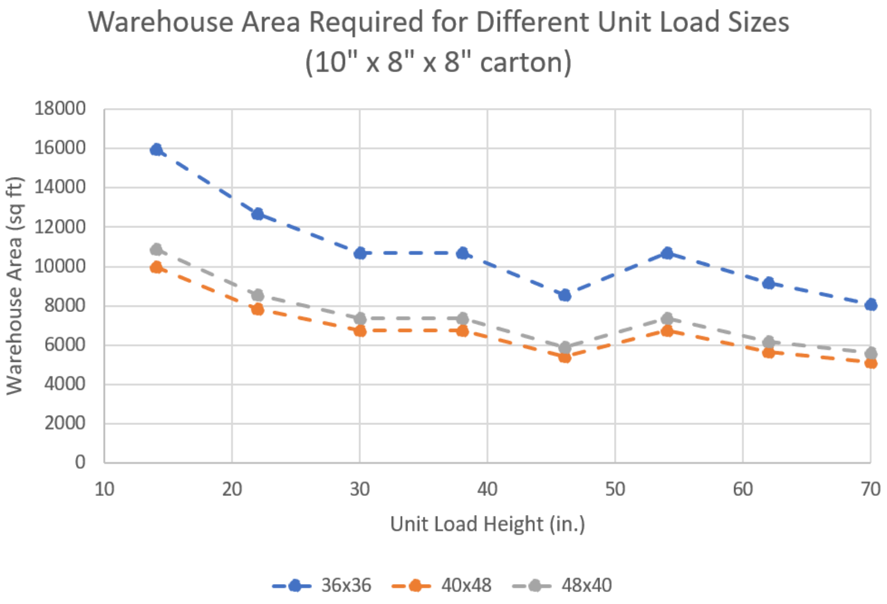
Some interesting trade-off curves





A few more trade-off curves





Wrap-up

A visible knowledge approach enables us to:

- Break down complex problems into manageable chunks.
- Visualize key relationships and trade-offs.
- Identify the efficient frontier for a design space.
- Avoid iterations.
- Solve problems more generally.
- Generate knowledge that is reusable.

Key Points

- Knowledge is a central theme within LPPD.
- Conventional "iterative" development is slow with uncertain outcome.
- Building knowledge early, before detailed design, speeds development and increases innovation.
    - Eliminates iteration from guess-and-check.
- Visible knowledge maps out the possibilities, finds the limits, and makes learning reusable.

What are your key learnings?