University Housing Dining Services:

Logistics System Analysis

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CEE 512 – SPRING 2012

Outline

- Introduction
- Problem Description
- Analysis
- Methodology I: Deterministic Model
- Methodology II: Stochastic Model
- Results & Discussion
- Conclusion

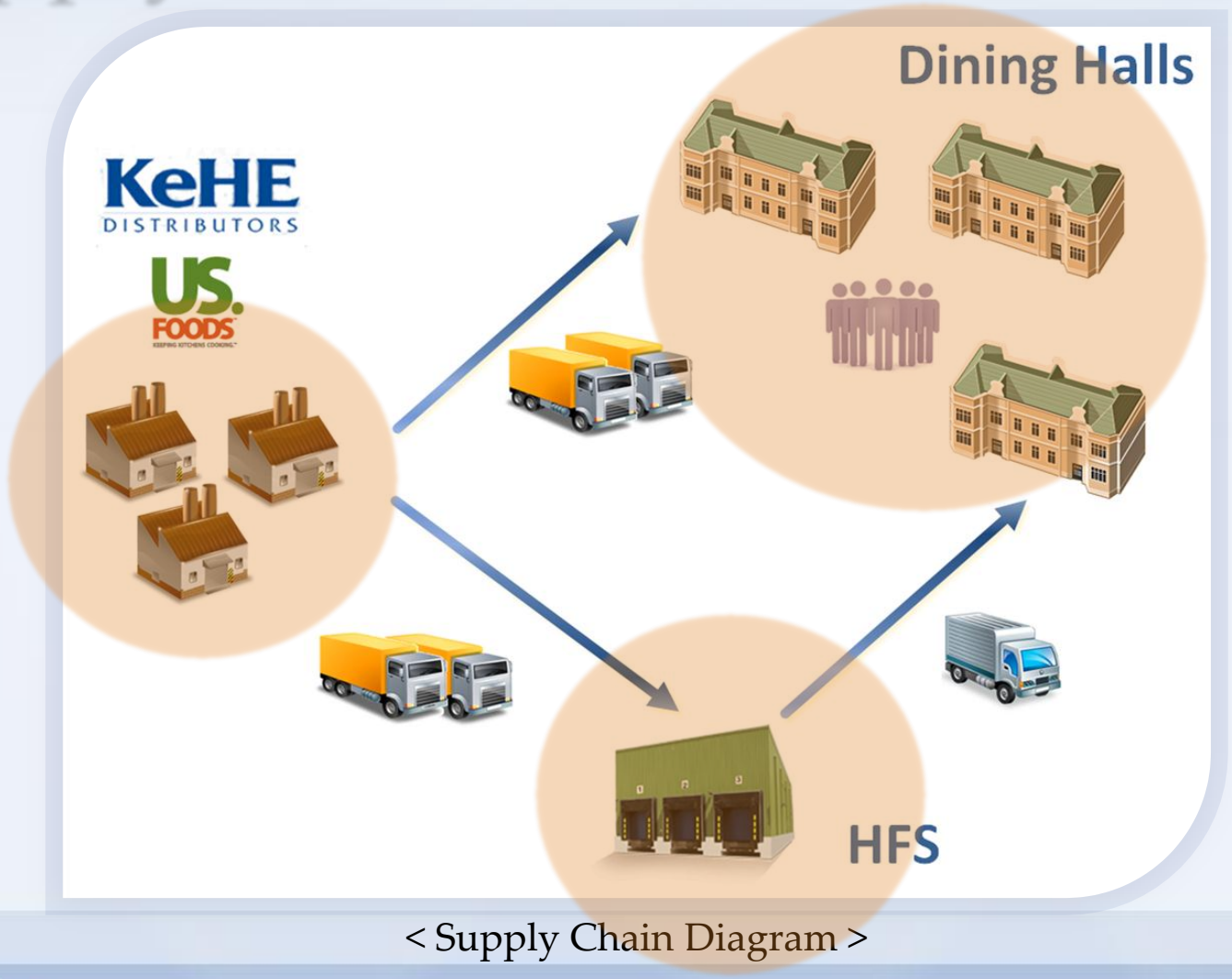
Background

- University Housing Dining Services
  - Cater service for 6,000 events/yr
  - Dining service for 13,000 students/day
  - Produce approx. 24,000 meals/day

- Housing Food Store (HFS)
  - Provide a complete logistics food supply mgmt.

    (Supports all phases of food production)
    - Coordinating orders
    - Overseeing the operation of the dining halls
    - Managing and distributing certain items to all dining halls.

Supply Chain Overview

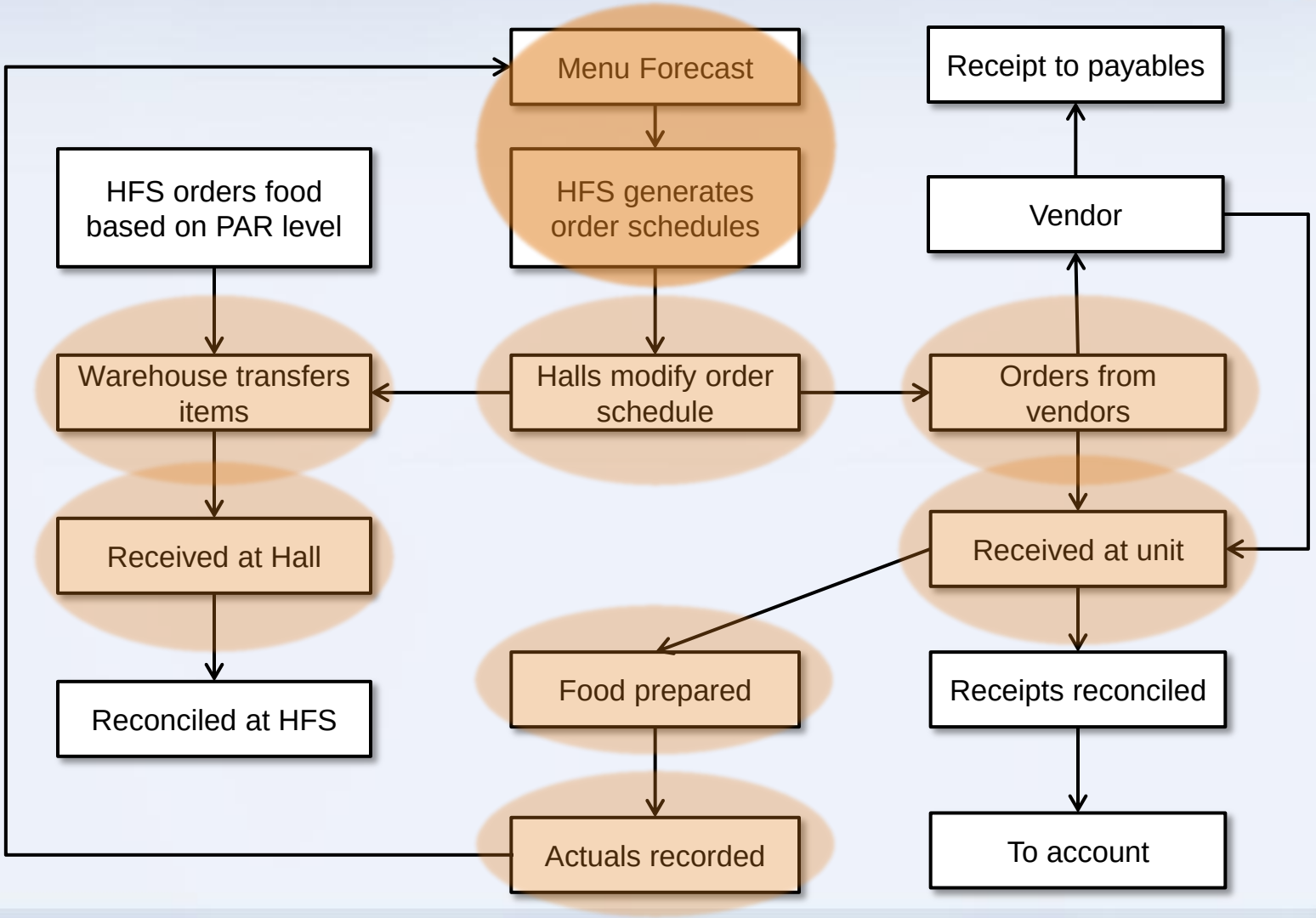


< Supply Chain Diagram >

< Local Route Map of Distribution from HFS>

Logistics Challenges

- Large, complex inventory problem
- HDS deals with over 20,000 total items annually.
- Approx. 1,650 items by each dining hall
  - independent operation
- 387 items by HFS warehouse
  - Items have a large shipment size requirement
  - Each item is re-distributed to each dining hall everyday



< Schematic diagram of HFS's warehouse operation system>

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Project Scope

- Focusing on the operation of the HFS
- HFS often has problems with the perishability and ordering of special vegan items.
- Vegan items are supplied from a ***single*** supplier.
- The potential of improvement and applicability to logistics.

➡ *Special vegan items inventory mgmt. & logistics*

- "Special vegan items" are categorized as

1) Vegetarian Citrus Chicken (VCC)
2) Vegetarian Fish Filet (VFF)
3) Vegan Chicken Teriyaki (VCT)
4) Vegan Beef Teriyaki (VBT)
5) Vegan Sliced Baked Ham (VSBH)

< Special vegan items>

- Main Problems
  - HFS **orders a large quantity** of vegan raw ingredients especially **at the beginning of each semester**.
  - Large shipment size leads to extremely **high inventory cost**.
  - Vegan items
    - **remain** in the refrigerators in the HFS warehouse **for an extensive period of time**.
    - **take a large storage area and high electricity cost** for maintaining low temperature to prevent food from being perished.
  - The long inventory time **reduces the freshness and quality of the food**, resulting in a inferior customer experience.

Motivation

- Why inventory costs?
  - one of the most expensive assets of many companies representing as much as 50% of total invested capital (Heizer 2005)
  - In 2009, the U.S. business logistics system cost was equivalent to 7.7% of the GDP (over $1.85 trillion)
- Why perishability?
  - U.S. food industry annually discards $35 billion worth of spoiled goods (Forbes, 2006)
  - up to 20% of food is discarded due to spoilage(Black 2003)

Project Objective

- The main goal of the project was
  - to evaluate, analyze and improve the current **inventory management system** of the University of Illinois Housing Food Stores.
- More specifically, the objective was
  - to determine **joint replenishment policies** for the special vegan items to minimize the total inventory cost consisting of ordering and holding costs.

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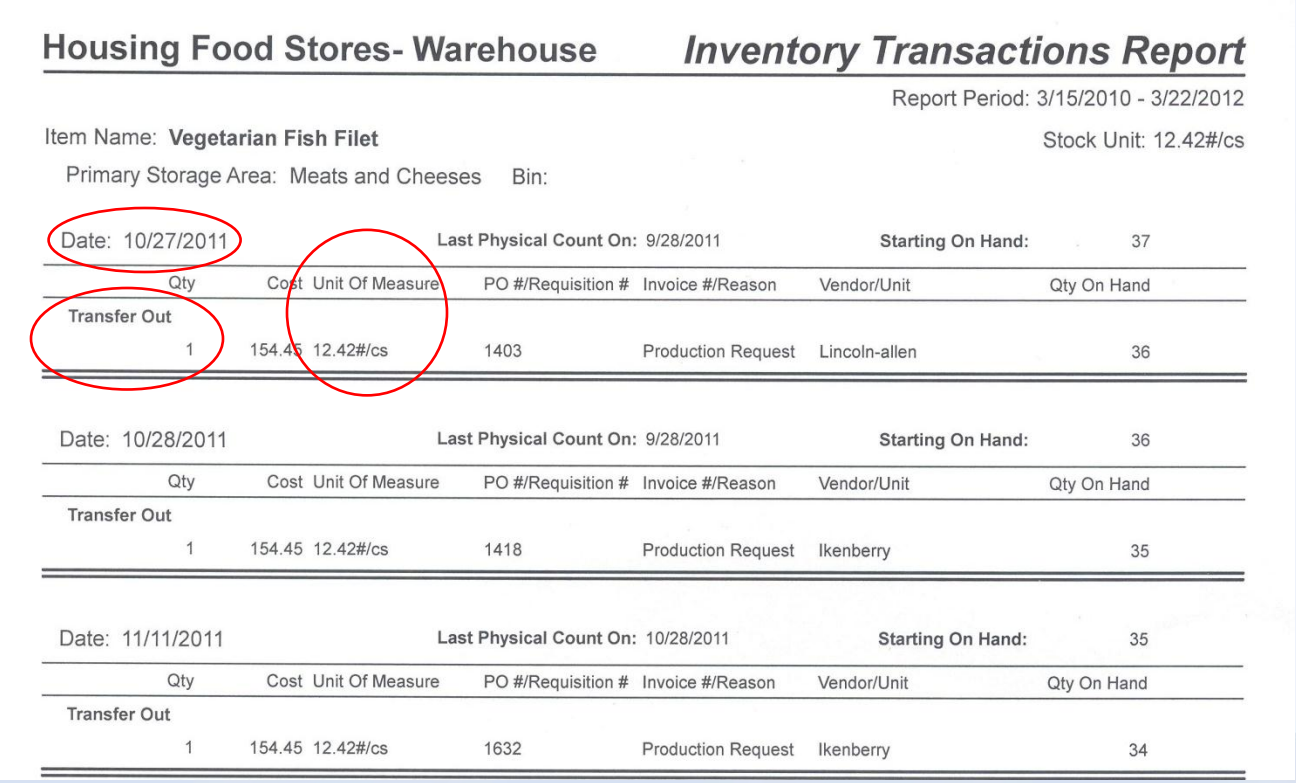
Data Collection

- Relevant data gathered
  - demand (actual quantities consumed)
  - miscellaneous costs related to the value of items, ordering and inventory.
- The transaction report was obtained for the five special vegan items
- Covering period: 72 weeks
  - from December 4th, 2010 to April 14th, 2012.

- Excluded periods
  - The data for the 38-week period from December 4th, 2010 to August 20th, 2011, contained only five scattered transaction records.
  - the data for Spring 2012 semester was excluded since it was incomplete.
- Studied periods:
  - Only the data from the 17-week period (Fall 2011 semester) from August 27, 2011 to December 10th, 2011 was considered.

- Determining the demand for each vegan item
  - All units of each item was converted to the same unit in packs (1 pack = 6.62 lbs = 1/4 case).
  - the quantities of items were grouped by week.



Housing Food Stores- Warehouse ***Inventory Transactions Report***

Report Period: 3/15/2010 - 3/22/2012

Item Name: **Vegetarian Fish Filet** Stock Unit: 12.42#/cs

Primary Storage Area: Meats and Cheeses Bin:

Date: 10/27/2011 **Last Physical Count On:** 9/28/2011 **Starting On Hand:** 37

	Qty	Cost	Unit Of Measure	PO #/Requisition #	Invoice #/Reason	Vendor/Unit	Qty On Hand
Transfer Out	1	154.45	12.42#/cs	1403	Production Request	Lincoln-allen	36

Date: 10/28/2011 **Last Physical Count On:** 9/28/2011 **Starting On Hand:** 36

	Qty	Cost	Unit Of Measure	PO #/Requisition #	Invoice #/Reason	Vendor/Unit	Qty On Hand
Transfer Out	1	154.45	12.42#/cs	1418	Production Request	Ikenberry	35

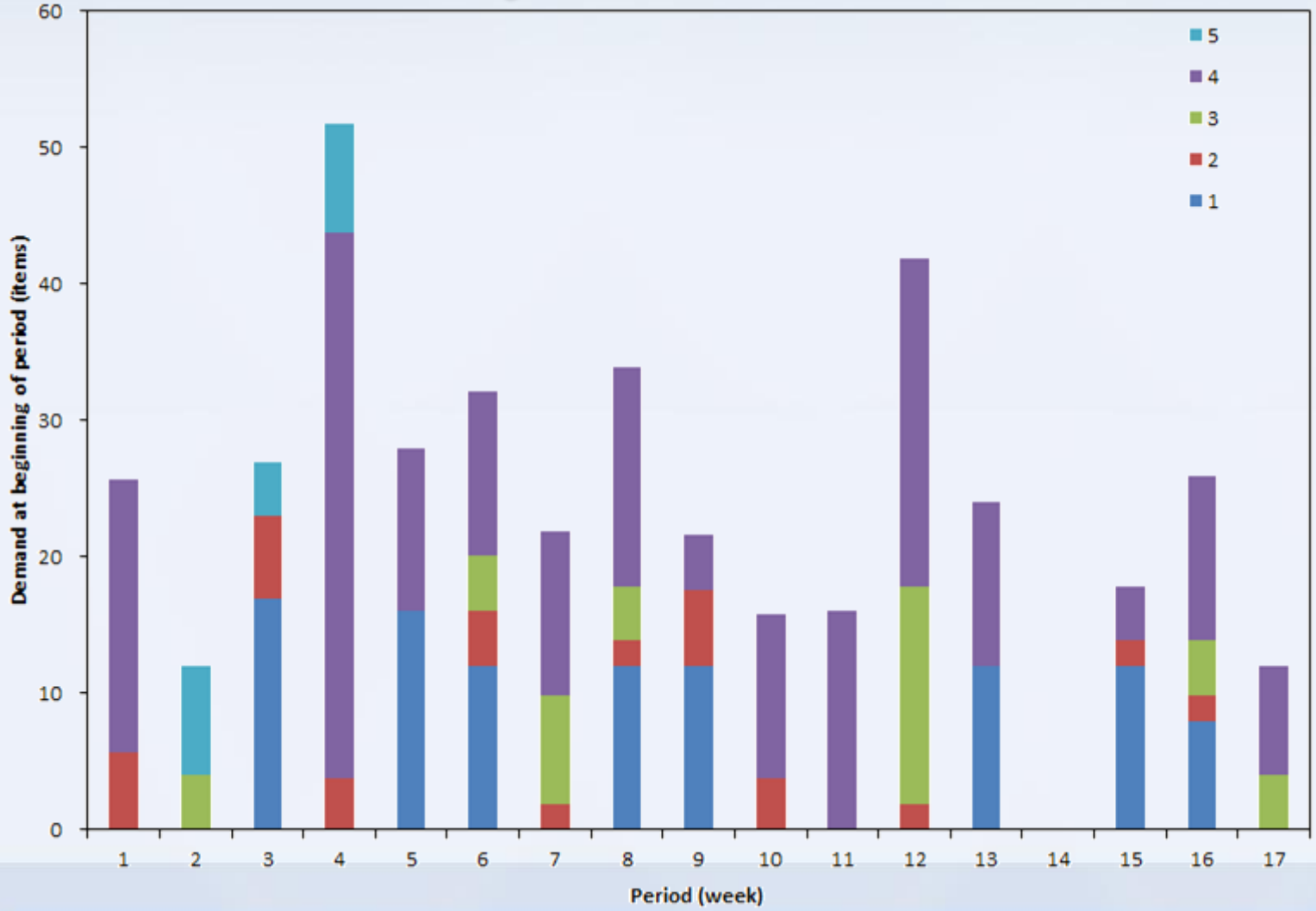
Date: 11/11/2011 **Last Physical Count On:** 10/28/2011 **Starting On Hand:** 35

	Qty	Cost	Unit Of Measure	PO #/Requisition #	Invoice #/Reason	Vendor/Unit	Qty On Hand
Transfer Out	1	154.45	12.42#/cs	1632	Production Request	Ikenberry	34

Analysis -> Data Collection – Demand for each item

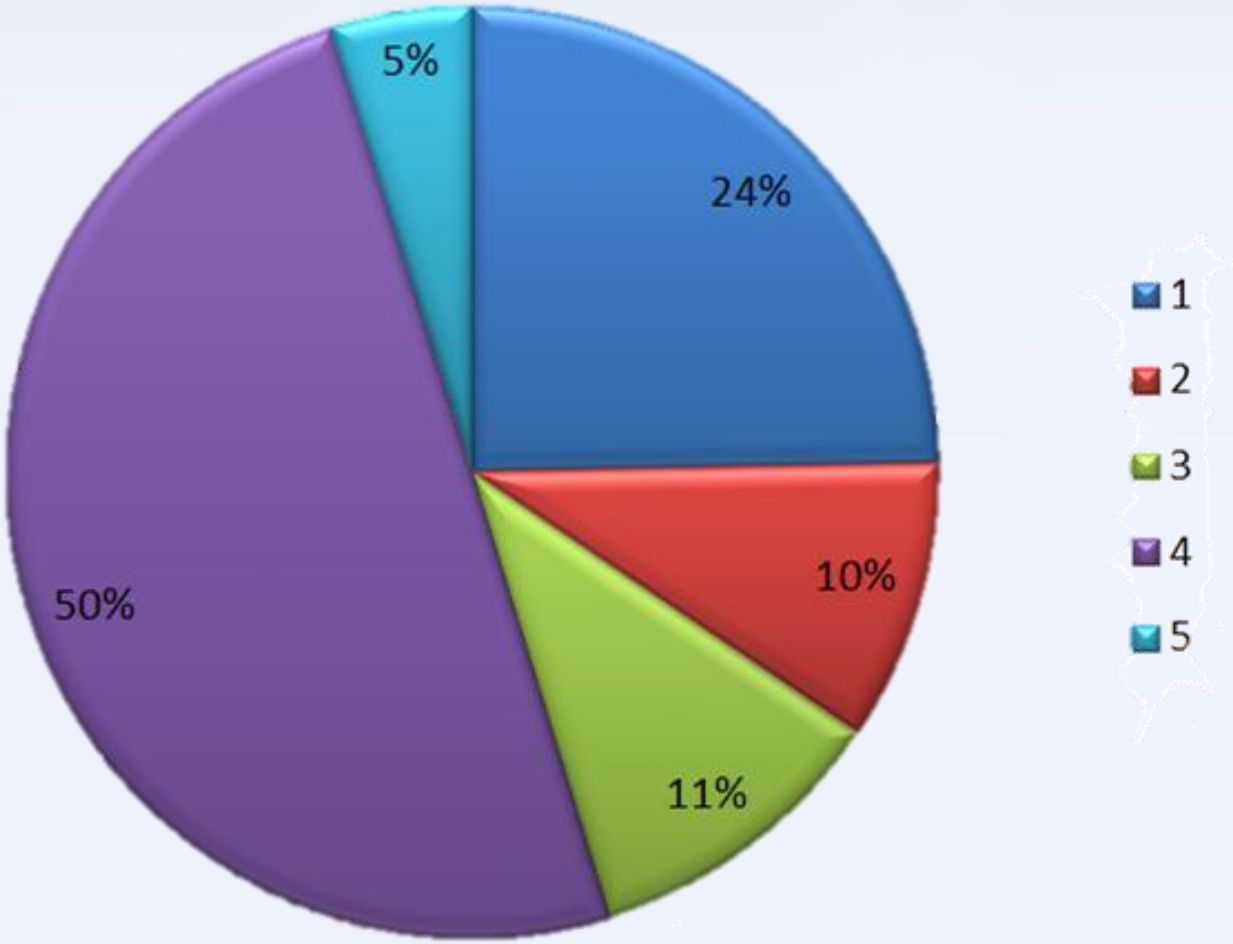
d_{it}	Item 1	Item 2	Item 3	Item 4	Item 5
1		6		20	
2			4		8
3	17	6			4
4		4		40	8
5	16			12	
6	12	4	4	12	
7		2	8	12	
8	12	2	4	16	
9	12	6		4	
10		4		12	
11				16	
12		2	16	24	
13	12			12	
14					
15	12	2		4	
16	8	2	4	12	
17			4	8	

Demand Analysis



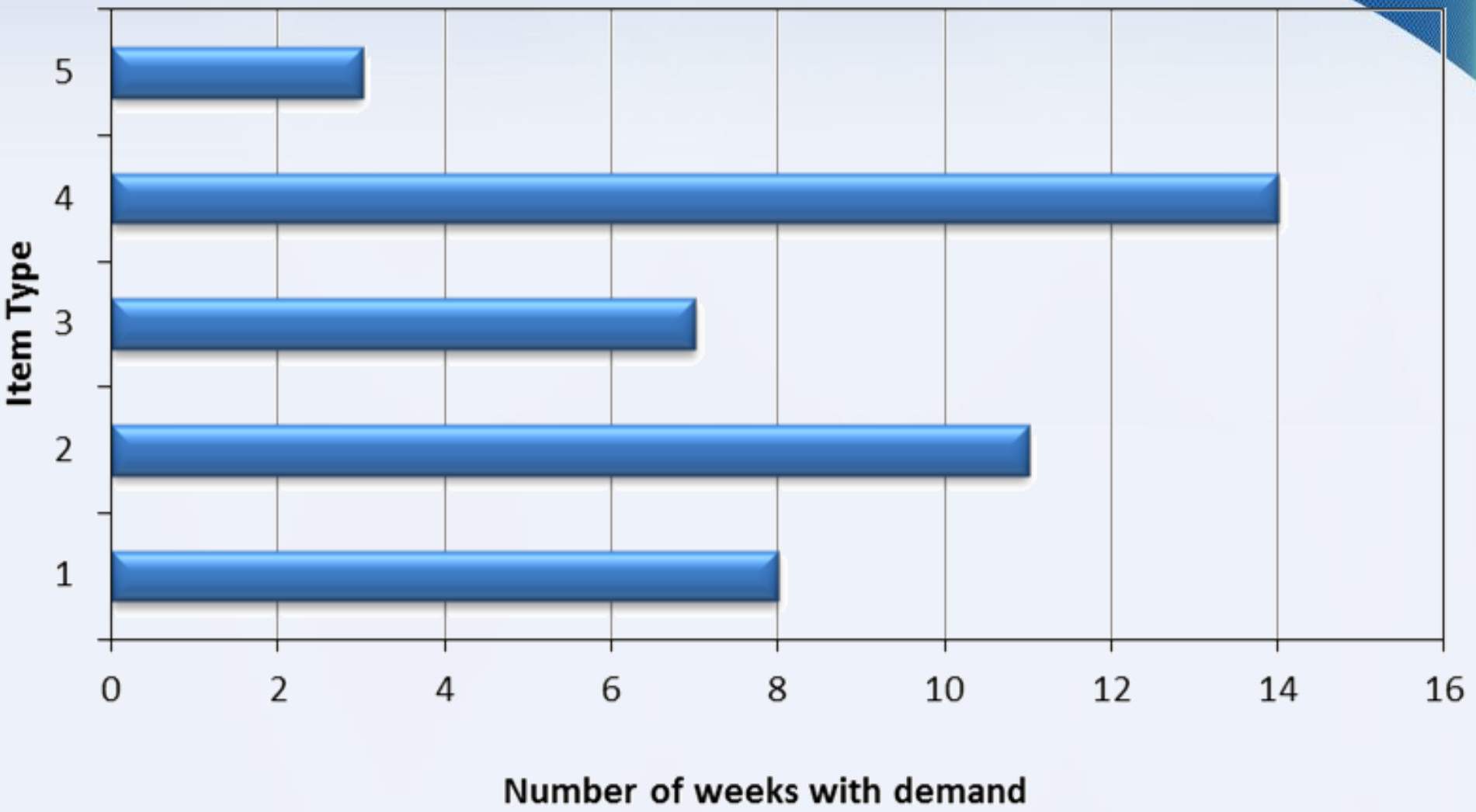
< Demand per week by item (Fall 2011) >

- Demand Distribution



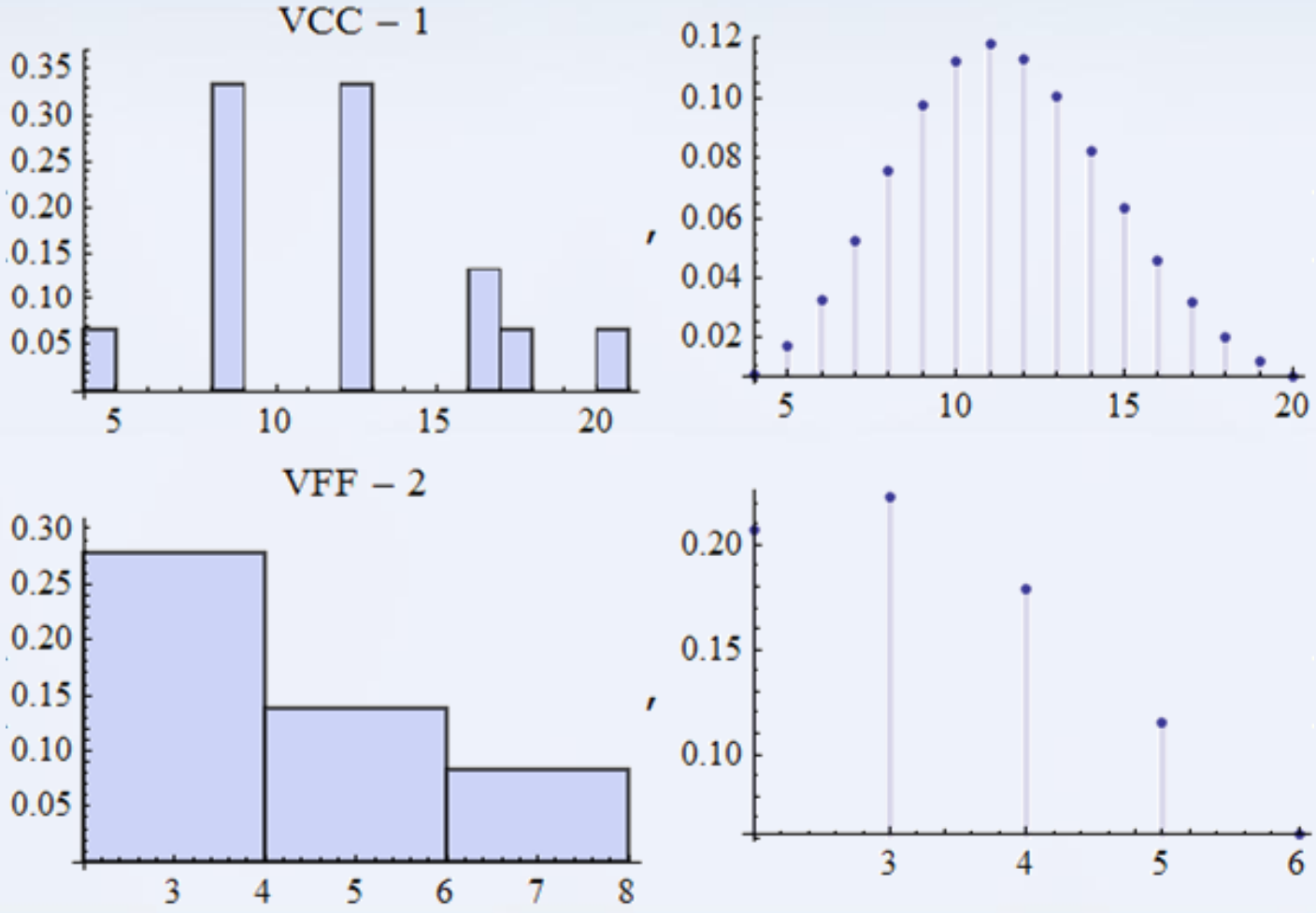
< Distribution of total demand by type of item (Fall 2011) >

Analysis -> Demand Analysis – Demand Distribution



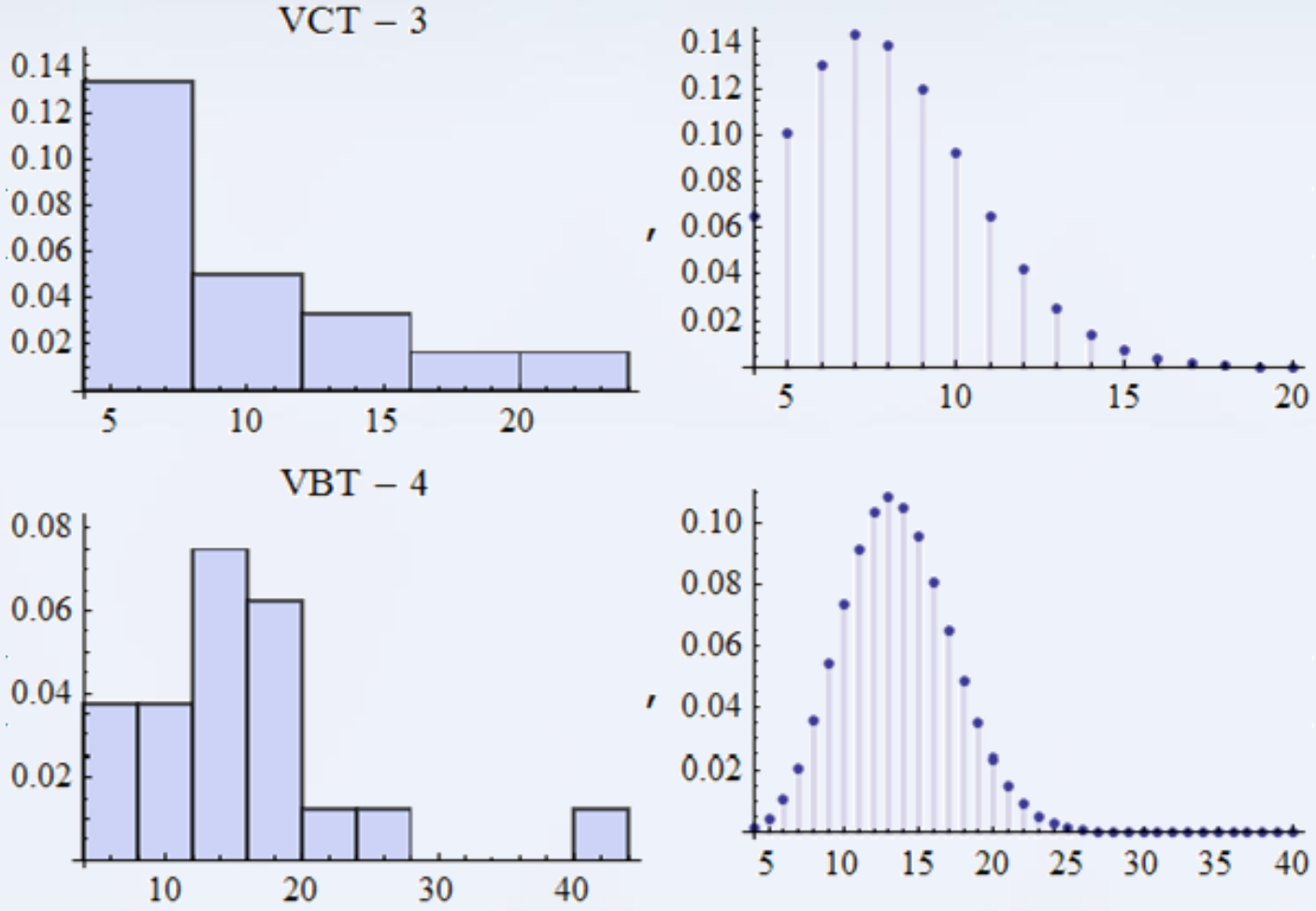
< Number of weeks with demand by item type >

- Histogram and fitted Poison distribution



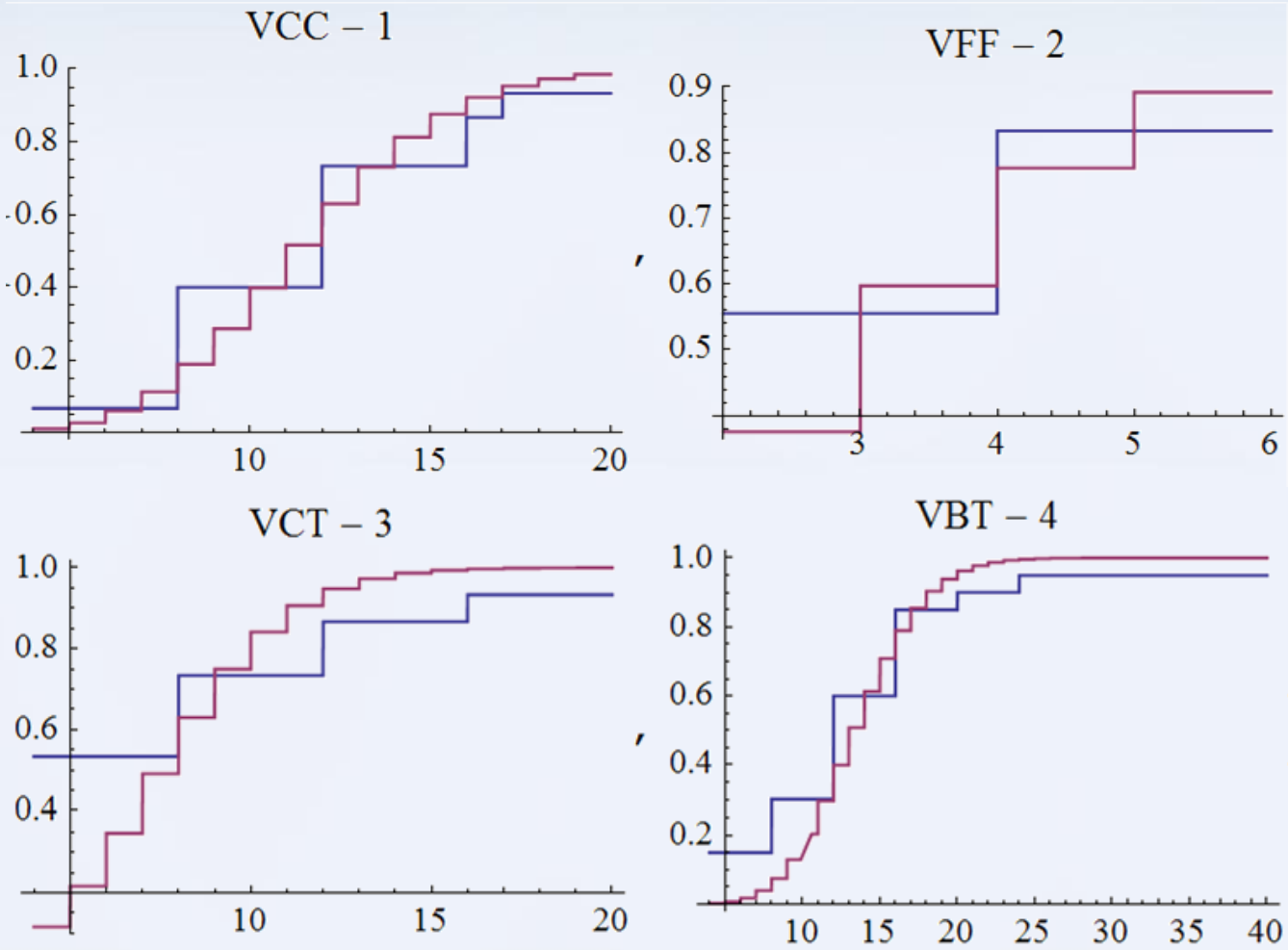
< Histogram and Estimated (Poisson) distribution for items 1-2 >

- Histogram and fitted Poison distribution (Cont'd.)



< Histogram and Estimated (Poisson) distribution for items 3-4 >

- Analyzing distribution type



< Empirical and Theoretical (Poisson) Cumulative Distributions for items 1-4 >

Item	Poisson Test (p-value χ^2 test)	Poisson Distribution Reasonable?	Normality Test (p-value Watson U^2)	Normal Distribution Reasonable?
1	0.0068	No	0.0623	Yes
2	0.0003	No	0.0004	No
3	0.0090	No	0.0009	No
4	0.1068	Yes	0.0227	No

< Goodness of fit tests, α=0.05 >

Cost Estimates

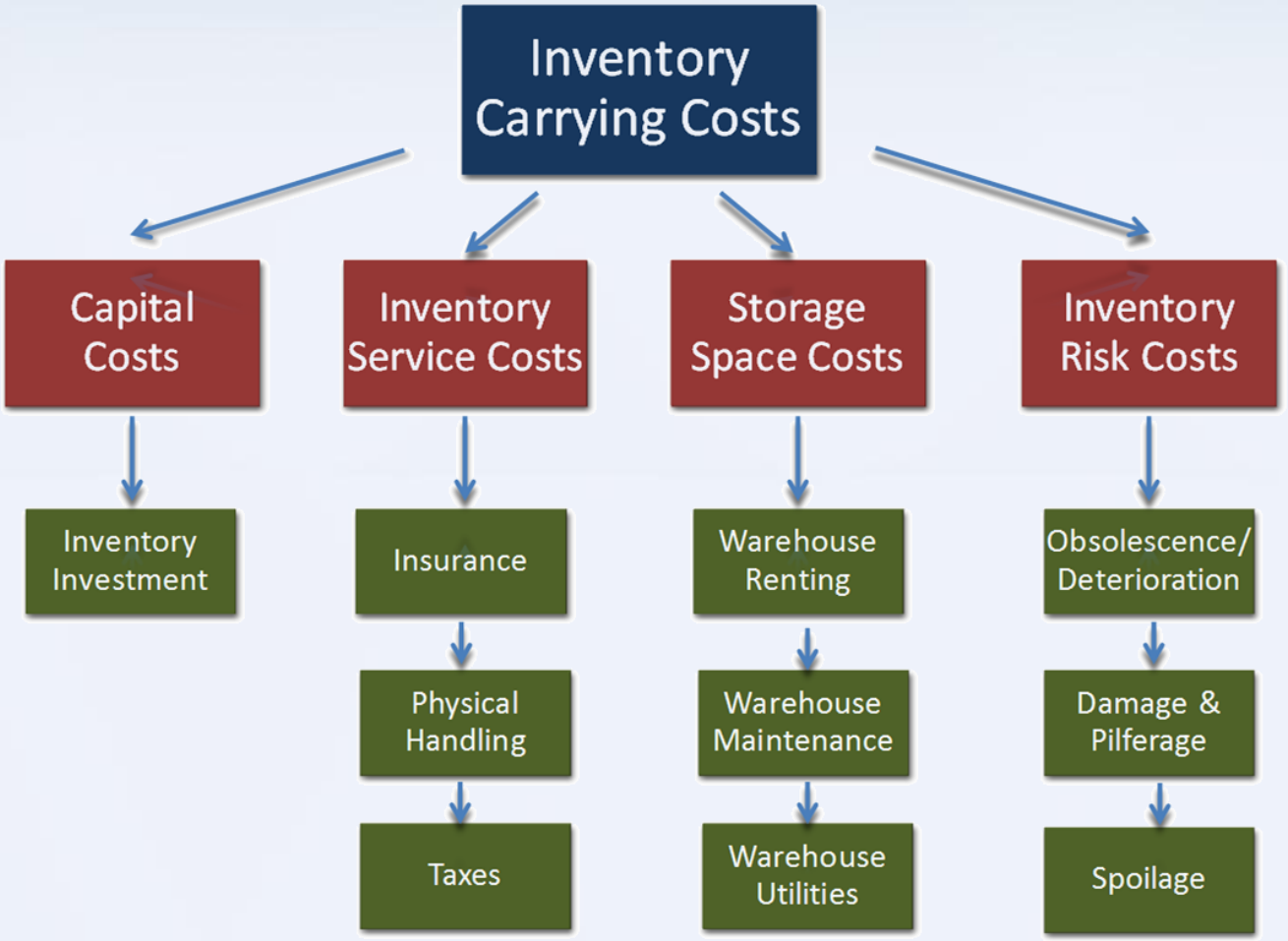
- Total costs = Ordering costs + Holding costs
- Ordering Costs
  - the cost of preparing & receiving the order + transportation cost
  - A major ordering cost
    : independent of the number of different products in the order
  - A minor ordering cost
    : depends on the number of different products in the order
- Holding costs
  - Inventory cost or carrying cost
  - Up to 50% of total value of items

Cost Estimates

- The following costs were considered and estimated for the JRP:

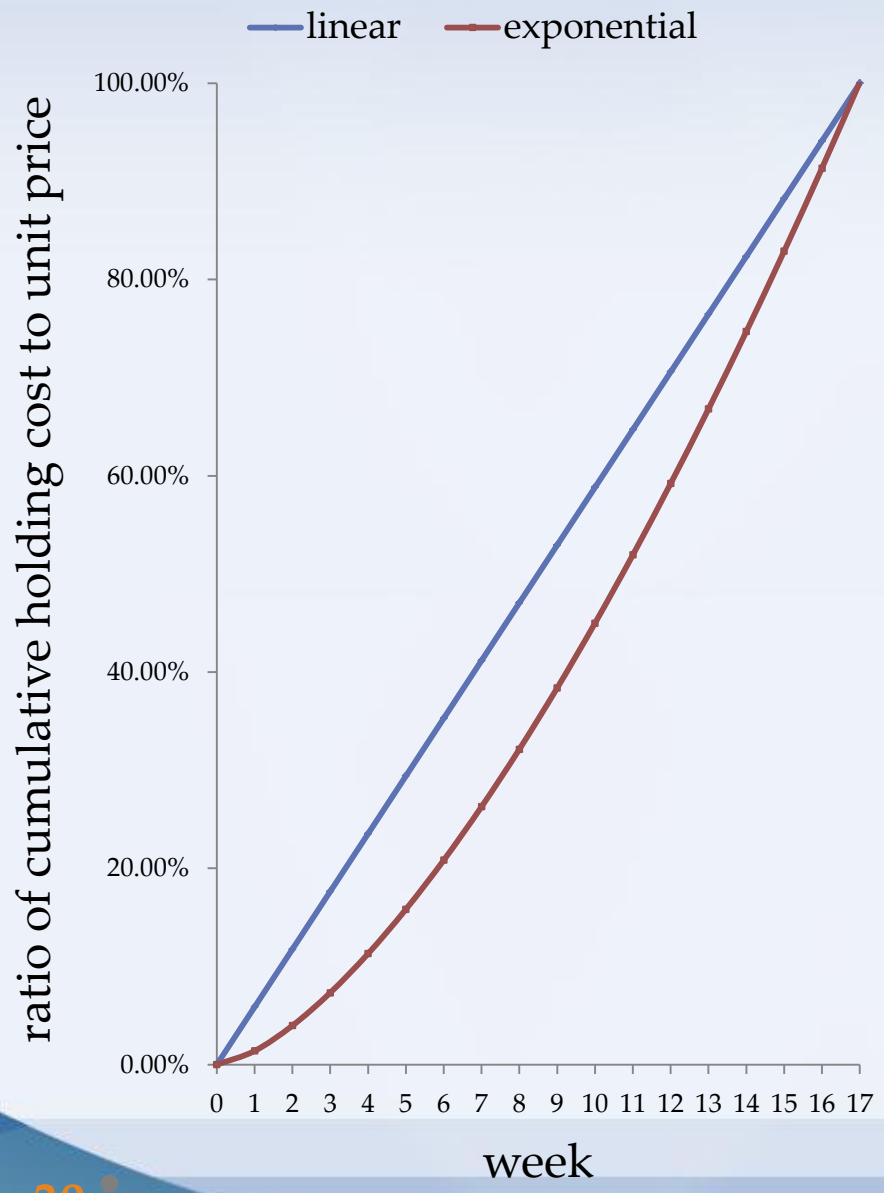
S	common ordering cost (units: \$/order)
s_i	individual ordering cost for item type i (units: \$/order)
c_i	unit cost for item type i (units: \$/item)
p	percentage of unit cost during period t for holding an item (units: %)
h_i	unit inventory holding cost for item type i during period t (units: \$/item)

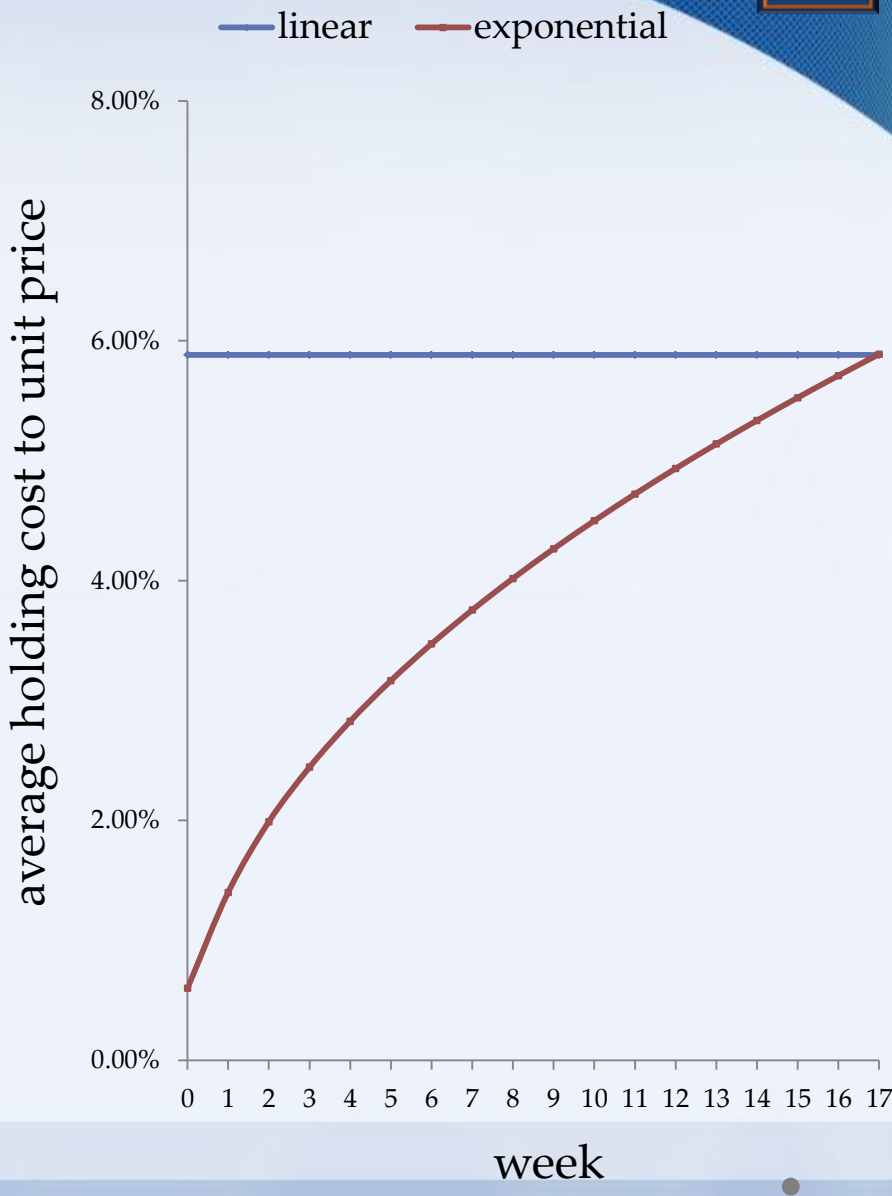
- Inventory carrying costs breakdown



< Holding Cost Breakdown >

Analysis -> Cost Estimates





Item Name	VCC	VFF	VCT	VBT	VSBH
Item Number i	1	2	3	4	5
S ($/order)			$500		
c_i ($/pack)	$34.59	$37.97	$39.24	$38.30	$41.07
s_i ($/order)	$65.03	$71.38	$73.77	$72.00	$77.21
p (%)	5%	5%	5%	5%	5%
h_i ($/pack)	$1.73	$1.90	$1.96	$1.92	$2.05

< Cost parameters for each vegan item analyzed >

Current System Evaluation

- Total cost of the current system = **$7,086** / semester
  - Total holding cost: **$6,226**
  - Total ordering cost: **$860**

$500 + ($65.03 + $71.38 + $73.77 + $72.00 + $77.21) = $860

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Literature Review

- Dynamic Joint Replenishment Problem (DJRP)
- Time-varying deterministic demand
- Linear Integer Program
- NP-hard (Arkin 1989)
- Exact algorithms
- Heuristics

Assumptions

- Time-varying deterministic demand
  - Exactly know when demand is going to occur
  - Number of students served constant
  - Demand pattern predictable

Assumptions

- Replenishments made at the beginning of each period
- Items are consumed at beginning of period *t* (i.e. no holding cost)
- Initial inventory is zero
- No quantity discounts from supplier
- No backlogging
- No exogenous constraints

Formulation ▶Notation

- Inputs

S	common ordering cost (units: \$/order)
s_i	individual ordering cost for item type i (units: \$/order)
c_i	unit cost for item type i (units: \$/item)
p	percentage of unit cost during period t for holding an item (units: %)
h_i	unit inventory holding cost for item type i during period t (units: \$/item)
D_{it}	demand for item type i for period t (units: item)
$I_{0,i}$	initial inventory level of item type i (units: item)

Formulation ▶Notation

- Decision Variables

I_{it}	Inventory level of item type i at the end of period t (for t>0) (units: item)
x_{it}	Replenishment quantity of item type i at the beginning of period t (units: item)
y_{it}	Binary variable = 1 if and only if item type i is replenished at the beginning of period t, i.e. y_{it} = 1 if x_{it} >0
z_t	Binary variables taking the value 1 if an order is placed for period t

Formulation ▶ Objective

- Minimize total cost
  - ▶ Major ordering cost
  - ▶ Minor ordering cost
  - ▶ Inventory holding cost

$$min \sum_{t=1}^{T} \left[Sz_t + \sum_{i=1}^{N} \{ s_i y_{it} + h_i I_{it} \} \right]$$

Formulation ▶ Constraints

- Subject to:

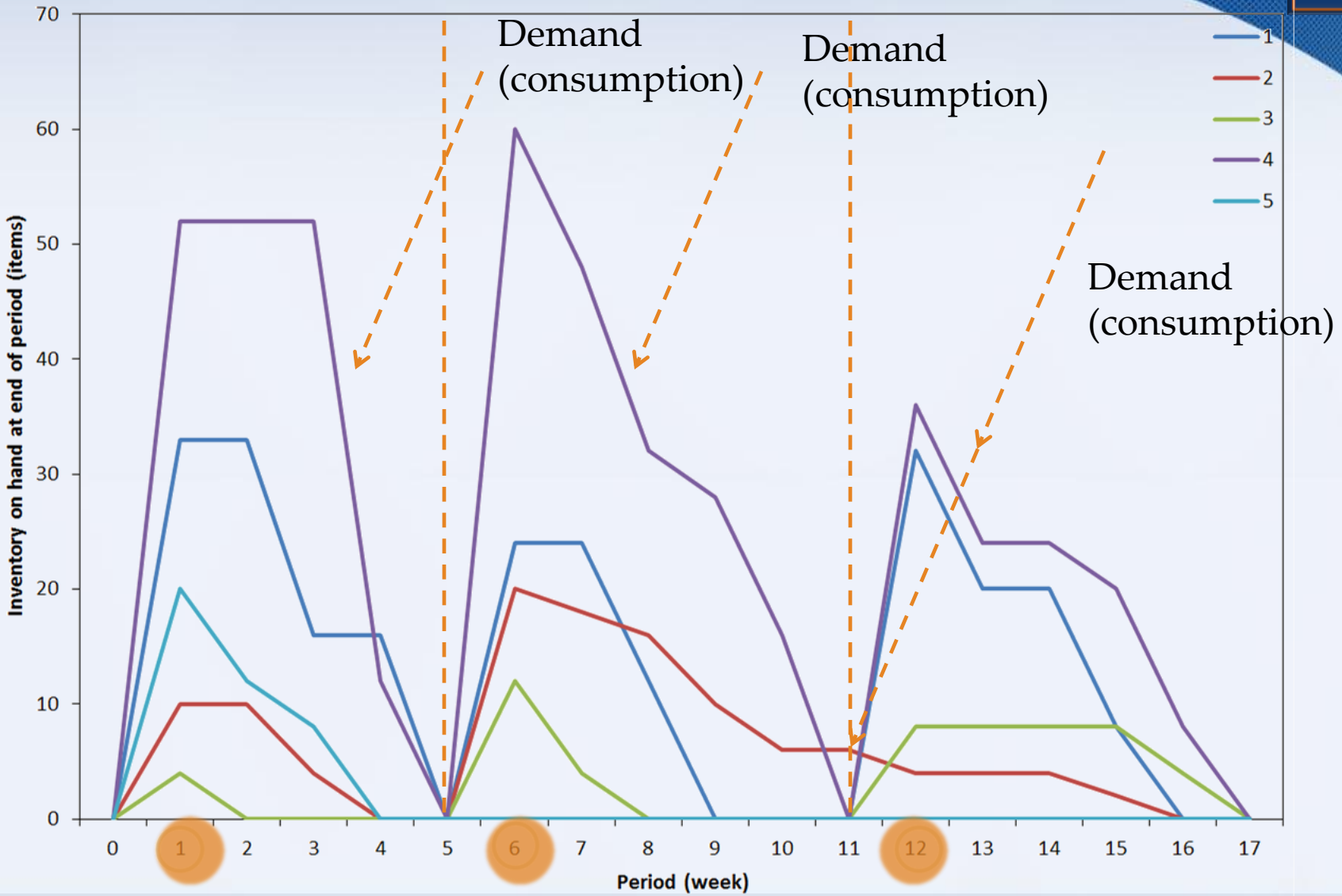
$I_{i,t-1} + x_{it} - I_{it} = d_{it}$	$\forall\, i,t$	Satisfy Demand
$x_{it} \leq M y_{it}$	$\forall\, i,t$	Quantity in order
$\sum_{i=1}^{N} y_{it} \leq N z_t$	$\forall\, t$	Item type in order
$I_{it} \geq 0\ ,\ x_{it} \geq 0$	$\forall\, i,t$	Non-negativity
$y_{it} = 0\ or\ 1\ ,\ z_t = 0\ or\ 1$	$\forall\, i,t$	Binary

Solution ▸

- CPLEX 11.2.0
- Objective value = $ 4,061
- Optimal order quantity:

x_{it}	1	2	3	4	5	x_{it}	1	2	3	4	5
1	33	16	4	72	20	10	0	0	0	0	0
2	0	0	0	0	0	11	0	0	0	0	0
3	0	0	0	0	0	12	32	0	24	60	0
4	0	0	0	0	0	13	0	0	0	0	0
5	0	0	0	0	0	14	0	0	0	0	0
6	36	24	16	72	0	15	0	0	0	0	0
7	0	0	0	0	0	16	0	0	0	0	0
8	0	0	0	0	0	17	0	0	0	0	0
9	0	0	0	0	0						

Methodology I: Deterministic Model -> Solution



< Inventory level with optimal order quantities >

Solution ►Sensitivity Analysis

p	# orders	Objective
1%	1	$1,956
5%	3	$4,061
10%	4	$5,395
15%	5	$6,290
20%	6	$6,939
25%	7	$7,506

< Sensitivity Analysis of holding cost >

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Literature Review

- Stochastic Joint Replenishment Problem (SJRP)
  - Two approaches available:
    - continuous & periodic reviews
- Periodic Review:
  - Coordinating replenishments of multi-items:
    - when and how much to order for the whole system
  - Fixed review period → order quantity → cover demand until next review period + demand during lead time
  - Cannot meet demand → backlogging cost incurred

Literature Review

- *Effective and Simple EOQ-like Solutions for Stochastic Demand Period Review System (2007) by* Eynan and Kropp
  - Given service level and variable stockout costs

  →find cycle time that minimizes the total cost
  - Solution to SJRP ~ Economic Order Quantity solution, yet it provides a near optimal value.

Assumptions

- Demand stationary and normally distributed
  - Analysis: one item Poisson, another one Normal
  - Normal: more robust, better fit in most cases, analytically tractable (Eynan 1997)
- Backlogging allowed
  - Substitute out-stocked products
  - Penalty = item unit price
- Lead time = two weeks

Formulation

- Inputs

A	major setup cost (units: $/order)
a	minor setup cost (units: $/order)
h	holding cost per unit item per unit of time (units: $/pack-week)
B	penalty cost per unit short (units: $/pack)
D	average demand during one unit of time (units: pack/week)
σ	standard deviation of demand during one unit of time (units: pack/week)
L	lead time (units: week)

- Decision Variables

z	**multiplier of σ (safety stock factor)**
T	cycle time (units: /week)

- The Average Cost Per Week function for an n product family is:

$$\widehat{TC} = \frac{A}{T} + \frac{\sum_{i=1}^{n} \frac{a_i}{k_i}}{T} + \sum_{n=1}^{n} \left[\frac{D_i k_i T h_i}{2} + \frac{B_i}{k_i T} \sigma_i \sqrt{k_i T + L} f[z_i(k_i T)] \right]$$

Major Cost | Minor Cost | Holding Inventory Cost | Backlogging Penalty Cost

- For safety stock,

$$F[z_i(k_i T)] = 1 - \frac{h_i}{B_i} k_i T$$

< Notation used for stochastic model >

Solution

item	Unit Price ($/pack)	A ($/order)	a ($/order)	h ($/pack-week)	D (pack /week)	σ (pack/ week)	L (week)	B ($/pack)	Safety Stock (pack)
1	34.59	500	65.03	1.7295	5.94	6.75	2	34.59	19
2	37.97	500	71.38	1.8985	2.35	2.26	2	37.97	6
3	39.24	500	73.77	1.962	2.59	4.23	2	39.24	12
4	38.3	500	72	1.915	12	10	2	38.3	28
5	41	500	77.21	2.05	1.18	2.74	2	41	7

Review Period or Cycle Time = 6.50 weeks

Average Cost Per Week = $290.10/week

Total Cost In a Semester = $4945.32

Inventory Level

$$RS = D_{RP+L} + SS$$

Item	Restocking Quantity (pack)	Demand Quantity for Each Cycle Time with Lead Time (pack)	Safety Stock Quantity (pack)
1	130	102	28
2	69	51	19
3	26	20	6
4	34	22	12
5	17	10	7

	Inventory at the end of period (packs)					Ordering Quantity (pack)				
Week /Item	1	2	3	4	5	1	2	3	4	5
1	69	20	34	110	17	69	26	34	130	17
2	69	20	30	110	9	0	0	0	0	0
3	52	14	30	110	5	0	0	0	0	0
4	52	10	30	70	-3	0	0	0	0	0
5	36	10	30	58	0	0	0	0	0	0
6	24	6	26	46	0	0	0	0	0	0
7	24	4	18	34	0	0	0	0	0	0
8	57	22	22	102	0	45	20	8	84	0
9	45	16	22	98	0	0	0	0	0	0
10	45	12	22	86	0	0	0	0	0	0
11	45	12	22	70	0	0	0	0	0	0
12	45	10	6	46	0	0	0	0	0	0
13	33	10	6	34	0	0	0	0	0	0
14	33	10	6	34	0	0	0	0	0	0
15	21	8	6	30	0	0	0	0	0	0
16	13	6	2	18	0	0	0	0	0	0
17	13	6	-2	10	0	0	0	0	0	0

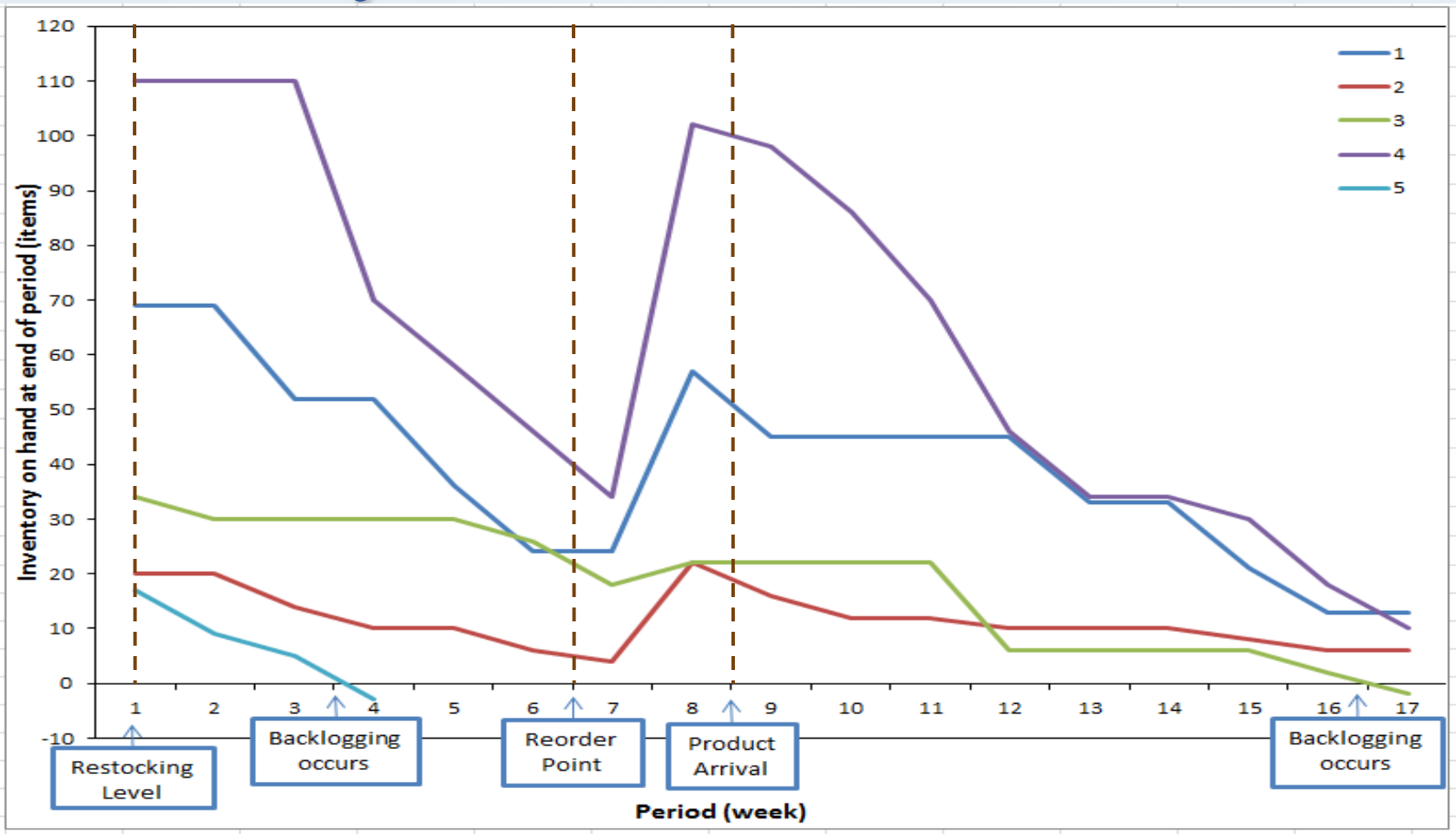
Initial Order

Reorder Point

Item Arrival Point

<Inventory Level and Ordering Quantity Based on the Stochastic Model>

Inventory Level



<Inventory Level and Ordering Quantity Based on the Stochastic Model>

Sensitivity Analysis

P	Safety Stock (Item)				Average Cost Per Week ($/Week)	Periodic Review Time (Week)
	1	2	3	4		
1%	22	7	14	33	116.63	12.44
4%	19	6	12	28	234.14	6.98
5%	19	6	12	28	262.71	6.49
6%	18	6	11	27	289.19	6.16
9%	17	6	10	26	379.38	5.52
10%	17	6	9	25	431	5

σ	Safety Stock (Item)				Average Cost Per Week ($/Week)	Periodic Review Time (Week)
	1	2	3	4		
0.1	2	1	1	3	259.09	6.09
0.5	9	3	6	14	260.58	6.25
0.7	13	4	8	19	261.39	6.34
0.9	17	6	11	25	262.25	6.44
1	19	6	12	28	262.71	6.49
1.1	21	7	13	31	263.17	6.54

<Sensitivity Analysis of Holding cost and Demand Standard Deviation>

Note: item 5 is not included in the sensitivity analysis

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Discussion ▶ Results

- Current System:
  - Number of orders: 1
  - Total Cost: $7,086
- Deterministic:
  - Number of orders: 3
  - Total Cost: $4,061 → **43% Savings**
- Stochastic:
  - Number of orders: 2 (Cycle Time = 6.5 weeks)
  - Total Cost: $4965 → **30% Savings**
  - Backlogs: 2

Discussion ▶ Pros & Cons

- Deterministic:
  - \+ Lowest Cost
  - \+ Reasonable Assumptions
  - \- Computational intractable for large N items
  - \- No uncertainty
- Stochastic:
  - \+ Uncertainty considered (demand + lead time)
  - \+ Easy to implement
  - \- Normal Assumption
  - \- Not optimal

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Conclusion ► Summary

- Identified improvement opportunities
- Analyzed data
- Evaluated current system
- Conducted literature review
- Determined replenishment policies

Conclusion ▶ Recommendations

- Implement proposed solutions
- Evaluate performance
- Apply to other items
- Consider heuristics
- Investigate item substitution
- Improve data collection

THANK YOU, ANY QUESTION?

Appendix