Warehouse Automation

- Historically, warehouse automation has been a craft industry, resulting highly customized, one-off, high-cost solutions
- To survive, need to
  - adapt mass-market, consumer-oriented technologies in order to realize to economies of scale
  - replace mechanical complexity with software complexity
- How much can be spent for automated equipment to replace one material handler:

$$\$45,432\left(\frac{1-1.017^{-5}}{0.017}\right)=\$45,432(4.75)=\$216,019$$

  - \$45,432: median moving machine operator annual wage + benefits
  - 1.7% average real interest rate 2005-2009 (real = nominal – inflation)
  - 5-year service life with no salvage (service life for Custom Software)

KIVA Mobile-Robotic Fulfillment System

- Goods-to-man order picking and fulfillment system
- Multi-agent-based control
  - Developed by Peter Wurman, former NCSU CSC professor
- Kiva now called Amazon Robotics
  - purchased by Amazon in 2012 for $775 million

Public WH Design (Problem 25)

- A *public warehouse* is a business that rents storage space to other firms on a month-to-month basis. They are often used by firms to supplement their own *private warehouses*.
- Min cost = Avg move cost ($/move) + storage time cost ($/slot-yr)

$$(a) \qquad AC_{\$/\text{mov}} = \frac{TC_{\$/\text{yr}}}{f_{\text{mov/yr}}} = \frac{TC_{\$/\text{yr}}}{2{,}000{,}000} \Rightarrow$$

$$TC_{\$/\text{yr}} = m_{\text{tr}} K_{\$/\text{tr-yr}} + \left(m_{\text{tr}} + 12\right) c^{\text{lab}}_{\$/\text{lab-yr}} + c^{\text{fuel}}_{\$/\text{hr}} f_{\text{mov/yr}}\, t_{\text{hr/mov}}$$

$$= m_{\text{tr}} K_{\$/\text{tr-yr}} + \left(m_{\text{tr}} + 12\right) c^{\text{lab}}_{\$/\text{lab-yr}} + 2.75(2{,}000{,}000)\frac{t_{\text{min/mov}}}{60} \Rightarrow$$

$$t_{\text{min/mov}} = t_{SC} = \frac{d_{SC}}{v} + 2t_{L/U} = \frac{d_{SC}}{616} + 2\left(\frac{35}{60}\right) \Rightarrow d_{SC} = \sqrt{2}\sqrt{TA'}$$

Still need to determine: $m_{\text{tr}}, K_{\$/\text{tr-yr}}, c^{\text{lab}}_{\$/\text{lab-yr}}, TA'$

Public WH Design (Problem 25)

$$(b) \quad AC_{\$/\text{slot-yr}} = \frac{K_{\$/\text{yr}}}{M_{\text{slot}}}$$

Demand assumed uncorrected since it belongs to different customers $\Rightarrow$

$$M = \left\lfloor \sum_{i=1}^{N} \left(\frac{M_i - SS_i}{2} + SS_i \right) + \frac{1}{2} \right\rfloor$$

$$= \left\lfloor 4,800 \left(\frac{250 - 0.06(250)}{2} + 15 \right) + \frac{1}{2} \right\rfloor = 636,000 \text{ slots}$$

$$IV_{0,\text{bldg}} = SV_{N,\text{bldg}} \Rightarrow K_{\$/\text{yr}} = i\, IV_{0,\text{bldg}} = 0.05\, IV_{0,\text{bldg}}$$

$$IV_{0,\text{bldg}} = \$15.50\, TA' \Rightarrow TA' = 1.15\, TA \Rightarrow$$

$$TA(D) = xL(D) \cdot \left(yD + \frac{A}{2} \right) = \frac{42}{12} L(D) \cdot \left(\frac{40}{12} D + \frac{7}{2} \right) \Rightarrow$$

Public WH Design (Problem 25)

$(b, cont)$

$$L(D) = \left\lceil \frac{M + NH\left(\frac{D-1}{2}\right) + N\left(\frac{H-1}{2}\right)}{DH} \right\rceil$$

$$= \left\lceil \frac{636{,}000 + 4800H\left(\frac{D-1}{2}\right) + 4800\left(\frac{H-1}{2}\right)}{DH} \right\rceil \Rightarrow$$

$$H = \left\lfloor \frac{18}{z} \right\rfloor = \left\lfloor \frac{18}{42/12} \right\rfloor = 5 \quad \text{(building clear-height constraint)}$$

$$D = D^* = \left\lfloor \sqrt{\frac{A(2M-N)}{2NyH}} + \frac{1}{2} \right\rfloor = \left\lfloor \sqrt{\frac{7(2(636{,}000) - 4800)}{2(4800)\frac{40}{12}(5)}} + \frac{1}{2} \right\rfloor = 7$$

Public WH Design (Problem 25)

$(b, cont)$

$$\Rightarrow L = 20,503 \Rightarrow TA = 1,925,573 \Rightarrow TA' = 2,214,409 \Rightarrow$$

$$\Rightarrow IV_{0,\text{bldg}} = \$15.50\,TA' = \$15.50\,(2,214,409) = \$34,323,346$$

$$\Rightarrow K_{\$/\text{yr}} = 0.05\,IV_{0,\text{bldg}} = \$1,716,167 \Rightarrow$$

$$AC_{\$/\text{slot-yr}} = \frac{K_{\$/\text{yr}}}{M_{\text{slot}}} = \$2.70 \text{ per slot-yr}$$

Public WH Design (Problem 25)

$(a, cont)$

$$TA' = 2,214,409 \text{ ft}^2 \Rightarrow$$

$$d_{SC} = \sqrt{2}\sqrt{TA'} = \sqrt{2}\sqrt{2,214,409} = 2,104 \Rightarrow$$

$$t_{\text{min/mov}} = \frac{d_{SC}}{616} + 2\left(\frac{35}{60}\right) = 4.58$$

$$H' = 2(8)5(50) = 4000 \text{ hr/yr} \quad \text{(already using } H\text{)}$$

$$r_{peak} = 1.25\frac{f_{\text{mov/yr}}}{H'} = 1.25\frac{2,000,000}{4000} = 625 \text{ mov/hr}$$

$$m_{\text{tr}} = \left\lfloor r_a t_e + 1 \right\rfloor = \left\lfloor r_{peak} t_{\text{hr/mov}} + 1 \right\rfloor = \left\lfloor 625\frac{4.58}{60} + 1 \right\rfloor = 48 \text{ tr}$$

$$IV^{eff} = IV_0 - SV\left(1+i\right)^{-N} = 35,000 - 0.25(35,000)\left(1+0.05\right)^{-10}$$

$$= \$29,628$$

Public WH Design (Problem 25)

$(a, cont)$

$$K_{\text{tr/yr}} = IV^{eff}\left[\frac{i}{1-(1+i)^{-N}}\right] = 29,628\left[\frac{0.05}{1-(1+0.05)^{-10}}\right] = \$3,837$$

$$c^{\text{lab}}_{\text{\$/lab-yr}} = 15.00H' = \$60,000$$

$$TC_{\text{\$/yr}} = m_{\text{tr}}K_{\text{\$/tr-yr}} + \left(m_{\text{tr}} + 12\right)c^{\text{lab}}_{\text{\$/lab-yr}} + 2.75(2{,}000{,}000)\frac{t_{\text{min/mov}}}{60}$$

$$= 48(3,837) + \left(48+12\right)60,000 + 2.75(2{,}000{,}000)\frac{4.58}{60}$$

$$= \$4,204,286.27 \Rightarrow$$

$$AC_{\text{\$/mov}} = \frac{TC_{\text{\$/yr}}}{f_{\text{mov/yr}}} = \frac{4,204,286.27}{2{,}000{,}000} = \$2.10 \text{ per move}$$

Public WH Design (Problem 25)

- (c) What are other costs that should be added to each charge to better reflect the true costs of each activity?
  - most significant missing costs are the facility non-move-related operating costs, which should be added to the slot-year charge
- What about average unit cost of $46.75?
  - only possible impact of unit cost would be for any insurance coverage provided by the warehouse for items stored in the warehouse
- *Note*: Number of slots of max inventory, M, used to determine $AC_{\$/\text{slot-yr}}$ instead of the total slots in warehouse since unused HCL slots would underestimate cost:

$$\text{Total Slots} = L \times D \times H = 717{,}605$$

$$M = 636{,}000$$

$$HCL = 81{,}605$$

Most Significant Concepts

The following represents the most significant concepts covered in this class, listed in order of decreasing significance, where the significance of each concept is determined by its importance and nonobviousness: *significance* = *importance* × *nonobviousness*

1. **Savings-based payback:** operating cost savings can be used as profit to determine the payback of additional investment

$$Payback\ period = \frac{IV_{\text{new}} - SV_{\text{current}}}{OC_{\text{current}} - OC_{\text{new}}}$$

2. **Little's Law:** for any production system in steady state, knowing any two allows the third to be determined

$$TH = \frac{WIP}{CT}, \quad CT = \frac{WIP}{TH}, \quad WIP = TH \cdot CT$$

3. **Discounting:** one-time investment costs and salvage values are made commensurate with per-period operating costs via discounting

$$IV^{\text{eff}} = IV - SV\left(1+i\right)^{-N}, \quad K = IV^{\text{eff}}\left[\frac{i}{1-(1+i)^{-N}}\right], \quad AC = \frac{K+OC}{q}$$

Most Significant Concepts

4. **Buffering:** only three possible kinds of buffers are used to deal with demand variability in a production system:

   Capacity, *Time*, and *Inventory*

5. **Rounding** (365.25 days/year): only round when determining concrete events or entities; otherwise, always keep fractional value (Use of a year as the time period is arbitrary and we could have used a month or week and all we would have to do is scale the data. By not rounding, we get the same result; with rounding, the results would differ a bit for each different time period. So not rounding keeps all information.)

6. **Guesstimation** (Fermi problems): used to provide an estimate within an order of magnitude of correct answer; usually easy to estimate a lower bound (assume perfect control) and practical upper bound (no control) of a parameter X:

   $$\text{Geometric Mean: } X = \sqrt{LB \times UB}$$

Most Significant Concepts

7. **Monetary vs. physical weight:** a production process can be physically weight *losing* $\left(\Sigma f_{\text{in}} > \Sigma f_{\text{out}}\right)$ but monetarily weight *gaining* $\left(\Sigma w_{\text{in}} < \Sigma w_{\text{out}}\right)$

8. **Load density:** freight capacity is determined by both the *weight* and *cube* of a load

9. **Warehouse design:** design of any warehouse involves a tradeoff between minimizing *building* costs (maximizing cube utilization) and minimizing *handling* costs