| This book is in the reading list<br><br>Laguna, M., & Marklund, J. (2013). Business process modelling, simulation, and design.<br>Chapter 5: Managing Process Flows Week 7<br>Chapter 4: Basic Tools for Process Design Week 8 | | | Book pg no |
|---|---|---|---|
| Lecture 7: Analysing Process Flows | | Slide pg no | |
| Process Throughput | **Process Throughput**<br>▪ Inflow and Outflow rates typically vary over time (see figure on next slide)<br>– $R_i(t)$ = Arrival/Inflow rate of jobs at time t<br>– $R_o(t)$ = Departure/Outflow rate of finished jobs at time t<br>– IN = Average inflow rate over time<br>– OUT = Average outflow rate over time<br>▪ A stable system must have IN = OUT = $\lambda$<br>– $\lambda$ = the process flow rate in<br>– $\lambda$ = the process flow rate out<br>– $\lambda$ = **process throughput** | 9 | 149 |
| Work-In-Progress | **Work-In-Process ("WIP")**<br>▪ WIP(t) comprises all jobs that have entered the process but not yet left it<br>– including jobs waiting for the previous batch to be completed<br>▪ WIP(t) = Work in process at time t<br>– WIP(t) increases when $R_i(t)>R_o(t)$<br>– WIP(t) decreases when $R_i(t)<R_o(t)$<br>▪ WIP = Average work in process over time<br> | 12 | 150 |
| Cycle Time | **Process Cycle Time**<br>▪ The difference between a job's departure time and its arrival time = **cycle time**<br>– One of the most important attributes of a process<br>– Also referred to as **throughput time**<br>▪ The cycle time includes both value adding and non-value adding activity times<br>– Processing time<br>– Inspection time<br>– Transportation time<br>– Storage time<br>– Waiting time<br>▪ Cycle time is a powerful tool for identifying process improvement potential | 16 | 152 |
| Little's Law Formula | **Little's Formula**: WIP = $\lambda \cdot$CT | 17 | 153 |
| Turnover ratio (Inventory) | **Turnover ratio = 1/CT** | 17 | 153 |

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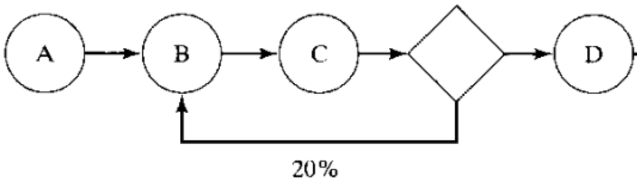
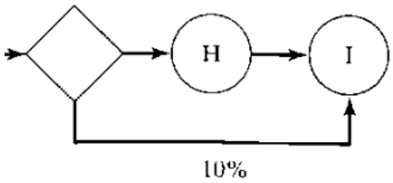
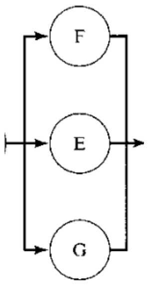
| Rework | <br>▪ Assuming a job is never reworked more than once<br>$CT = (1+r)T$<br>▪ Assuming a reworked job is no different than a regular job<br>$CT = T/(1-r)$ | 22 | 155 |
| Multiple Paths | <br>▪ Assume that **m** different paths originate from a decision point<br>– $p_i$ = The probability that a job is routed to path i<br>– $T_i$ = The time to go down path i<br>$CT = p_1T_1+p_2T_2+\ldots+p_mT_m = \sum_{i=1}^{m} p_i T_i$ | 28 | 156 |
| Parallel Activities | <br>– M process segments in parallel<br>– $T_i$ = Average process time for process segment i to be completed<br>$CT_{parallel} = Max\{T_1, T_2, \ldots, T_M\}$ | 31 | 157 |
| Cycle Time Efficiency | Cycle Time Efficiency = $\frac{\text{Theoretical Cycle Time}}{CT}$ | 33 | 159 |

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| Capacity Needs and Utilization, I | **Step 1 – Calculate unit load for each resource**<br>▪ The total resource time required to process one job<br>– $N_i$ = Number of jobs flowing through activity i for every new job entering the process<br>– $T_i$ = The processing time for activity i in the current resource<br>– M = Total number of activities using the resource<br>Unit load for Resource = $\sum_{i=1}^{M} N_i \cdot T_i$ | 42 | 163 |
| Capacity Needs and Utilization, II | **Step 2 – Calculate the unit capacity**<br>▪ The number of jobs per time unit that can be processed<br>Unit capacity for resource j = 1 / Unit load for resource j<br>**Step 3 – Determine the resource pool capacity**<br>▪ A resource pool is a set of identical resources available for use<br>▪ Pool capacity is the number of jobs per time unit that can be processed<br>– Let M = Number of resources in the pool<br>Pool capacity = M*Unit capacity = M / Unit load | 44 | 163 |
| Capacity Needs and Utilization, III | Capacity is related to resources not to activities!<br>▪ The process capacity is determined by the **bottleneck**<br>– The bottleneck is the resource or resource pool with the **smallest capacity** (the **slowest** resource in terms of jobs/time unit)<br>– The slowest resource will limit the process throughput<br>**Capacity Utilization**<br>▪ The theoretical process capacity is obtained by focusing on processing times as opposed to activity times<br>– Delays and waiting times are disregarded<br>$\Rightarrow$ ***The actual process throughput* $\leq$ *The theoretical capacity***!<br>$\text{Capacity Utilization} = \frac{\text{Actual Throughput}}{\text{Theoretical Process Capacity}}$ | 46 | 164 |
| Theory of Constraints (TOC)I | **Theory of Constraints (TOC) (I)**<br>▪ An approach for identifying and managing bottlenecks<br>– To increase process flow and thereby process efficiency<br>▪ TOC is focusing on improving the bottom line through<br>– Increasing throughput<br>– Reducing inventory<br>– Reducing operating costs<br>$\Rightarrow$ ***Need operating policies that move the variables in the right directions without violating the given constraints***<br>▪ Three broad constraint categories<br>1. Resource constraints<br>2. Market constraints<br>3. Policy constraints<br> | 53 | |

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| Theory of Constraints (TOC)II<br><br>Examples of Applying TOC Methodology pp. 55 onwards | **Theory of Constraints (TOC) (II)**<br><br>**TOC Methodology**<br>**1. Identify the system's constraints**<br>**2. Determine how to exploit the constraints**<br>– Choose decision/ranking rules for processing jobs in bottleneck<br>**3. Subordinate everything to the decisions in step 2**<br>**4. Elevate the constraints to improve performance**<br>– For example, increasing bottleneck capacity through investments in new equipment or labor<br>**5. If the current constraints are eliminated return to step 1**<br>– Don't loose inertia, continuous improvement is necessary!<br>▪ *See example 5.18 , Chapter 5 in Laguna & Marklund* | 54<br>Examples of Applying TOC Methodology pp. 55 onwards | |

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| Week 8 | Laguna, M., & Marklund, J. (2013). Business process modelling, simulation, and design. Chapter 4: Basic Tools for Process Design – This book is in the reading list | | |
| | **Types of Flow:**<br>1.Work Flow (initiate, process and complete order)<br>2.Information Flow (transmit and receive order)<br>3.Materials Flow (manufacturing)<br>4.Customer Flow (service to customers)<br>5.Cash flow (payment) | 6 | |
| Material flows: Load-Distance analysis | ▪ LD(i,j) = LD score between work stations i and j<br><br>LD(i,j) = Load(i,j)*Distance(i,j)<br><br>▪ The LD score measures the attraction between two work stations (activities)<br>– The larger the traffic volume the higher the score and the higher the incentive to keep the work stations together<br>▪ The goal is to find a design that minimizes the total LD score (the sum of individual scores between work stations)<br>▪ The Load Matrix summarizes the load (flow rate = # of jobs) that needs to be shipped between each pair of work stations | 14 | 112 |
| Workflow: Line Balancing | Line Balancing<br>▪ A useful approach when processing times are fairly constant<br>– Should not be used when processing times display high variability<br>▪ The goal is to balance the capacity of the different workstations constituting the production line (the process)<br>Procedure<br>1. Specify sequential (precedence) relationships among the activities using a precedence diagram<br>2. Use market demand to determine the line's desired cycle time per work station (C)<br><br>$C = \frac{\text{Process time per day}}{\text{Market demand per day (in \# of jobs)}}$ | 39 | 127 |
| Line Balancing | **Line Balancing Procedure (continued)**<br>3. Determine the theoretical minimum # of workstations (TM)<br><br>$TM = \frac{\text{Sum of activity times}}{C}$<br><br>4. Select a primary rule to assign activities to workstations and a secondary rule to break ties<br>5. Assign activities one at a time to workstation 1 as long as the sum of activity times ≤ C. Repeat this for workstations 2,3, …<br>– Must satisfy the activities' precedence relationships<br>6. Evaluate the ***line efficiency = Total process time / (C *#stations)***<br>7. Rebalance using a different priority rule in case the efficiency is unsatisfactory | 40 | 127 |

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| Workflow: Cycle Time Efficiency | ▪ Measured as the percentage of the total cycle time spent on value adding activities.<br>$$\text{Cycle Time Efficiency} = \frac{\text{Theoretical Cycle Time}}{\text{CT}}$$<br>▪ Theoretical Cycle Time = the cycle time which we would have if only value adding activities were performed<br>– That is if the activity times, which include waiting times, are replaced by the processing times | 53 | ?159 |
| Workflow: Capacity analysis | ❖ Capacity is related to resources not to activities!<br>▪ The process capacity is determined by the bottleneck<br>– The bottleneck is the resource or resource pool with the smallest capacity (the slowest resource in terms of jobs/time unit)<br>– The slowest resource will limit the process throughput<br>Capacity Utilization<br>▪ The theoretical process capacity is obtained by focusing on processing times as opposed to activity times<br>– Delays and waiting times are disregarded<br>⇒ ***The actual process throughput ⍰The theoretical capacity***!<br>$$\text{Capacity Utilization} = \frac{\text{Actual Throughput}}{\text{Theoretical Process Capacity}}$$ | 55 | 164 |