ENPM 692
MANUFACTURING AND AUTOMATION

SIMULATION IN MANUFACTURING

Time: Wednesdays 7:00pm - 9:40pm
Location: JMP 2222

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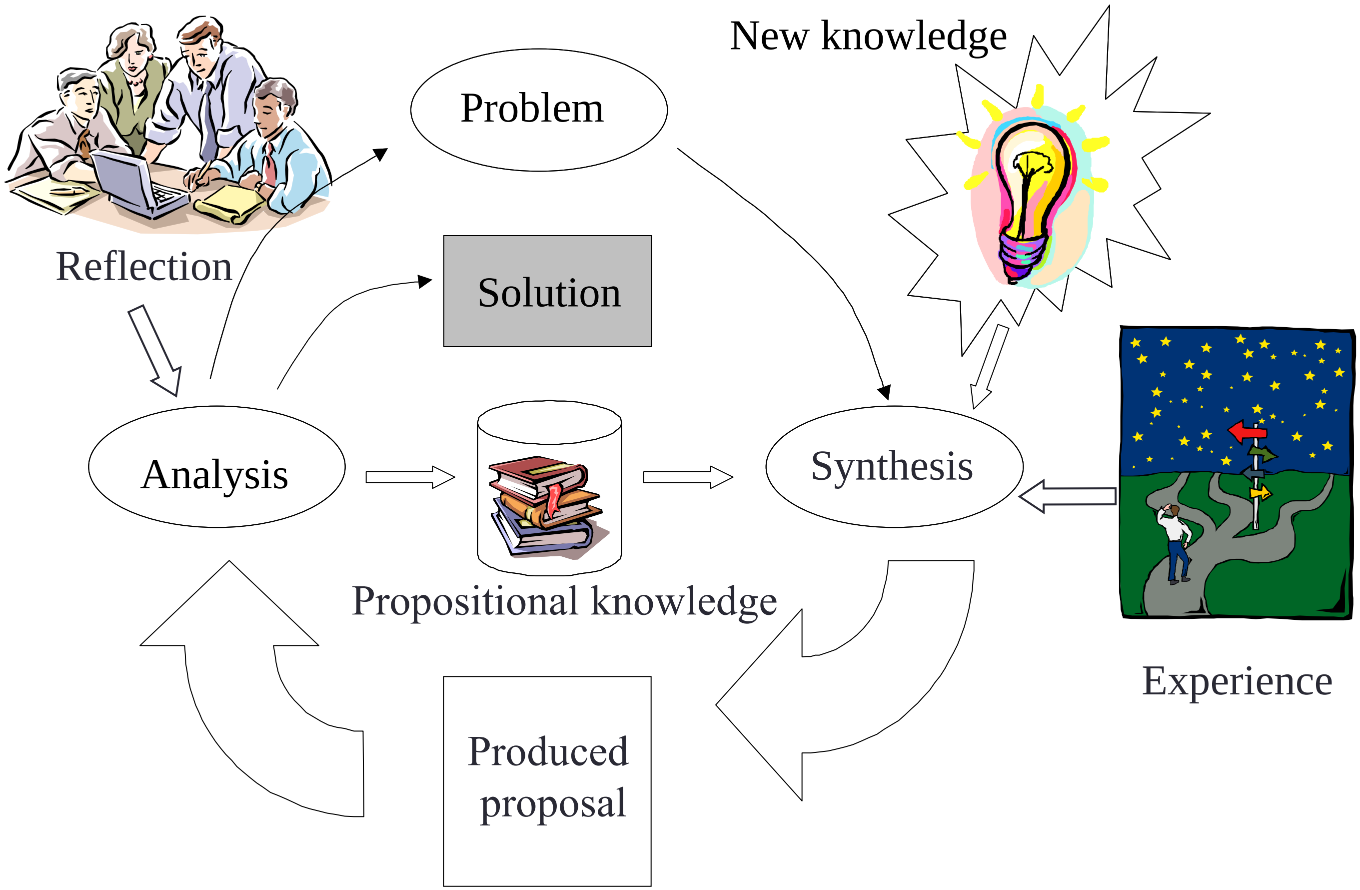
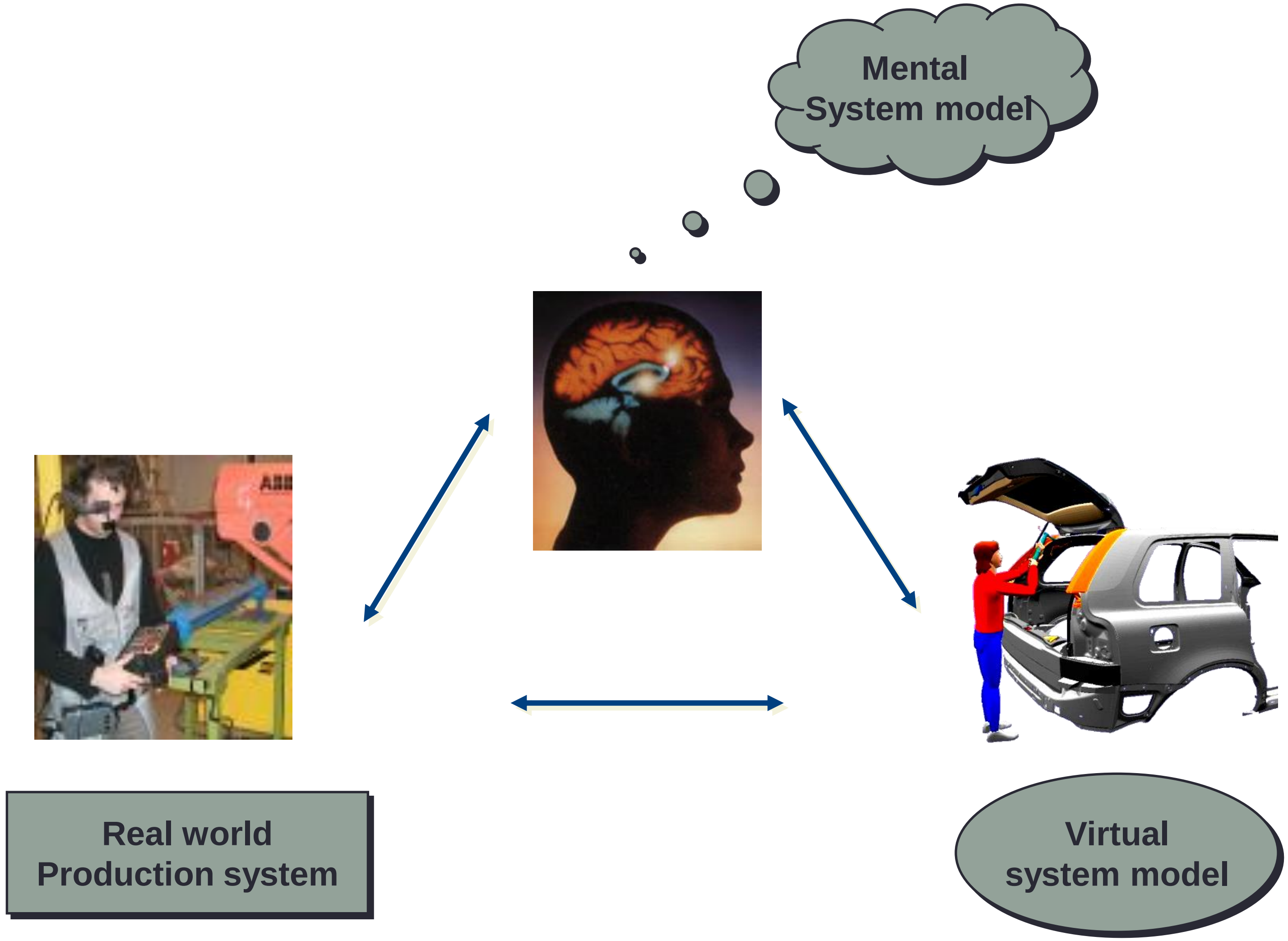
Problem Solving Process



Simulation always present?



Definition

Discrete

Event

Simulation

Discrete means…

- Completely separate and unconnected
- Used to describe elements or variables that are distinct, unrelated, and have a finite number of values

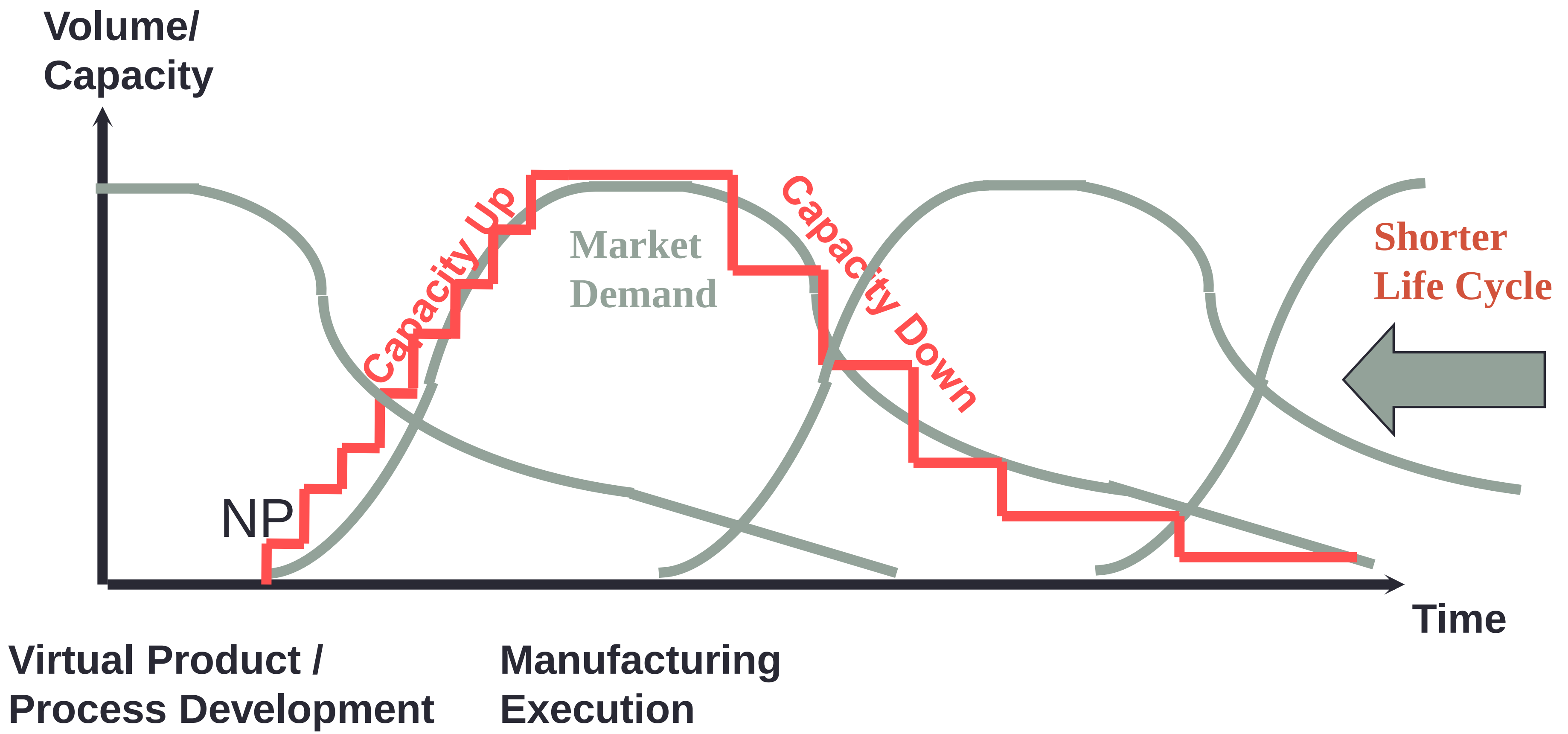
Event means…

- An occurrence, especially one that is particularly significant, interesting, exciting, or unusual
- A happening (occurrence)
- An occurrence or happening of significance to a computer program, for example, the clicking of a mouse button or the completion of a write operation to a disk

Simulation means…

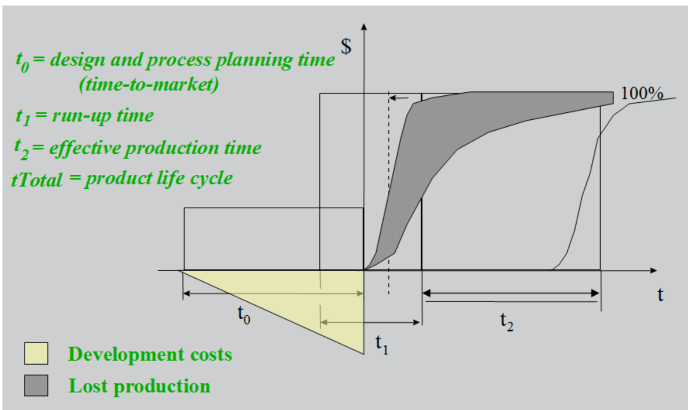
- The reproduction of the essential features of something, for example, as an aid to studies or training
- An artificial or imitation object
- The construction of a mathematical model to reproduce the characteristics of a phenomenon, system, or process, often using a computer, in order to infer information or solve problems

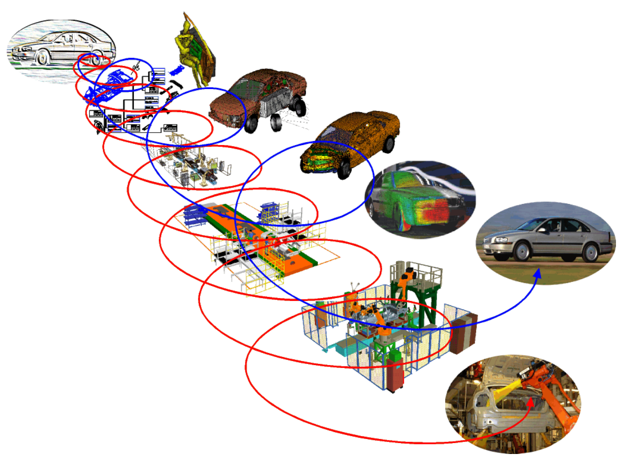
Relevance of Simulation

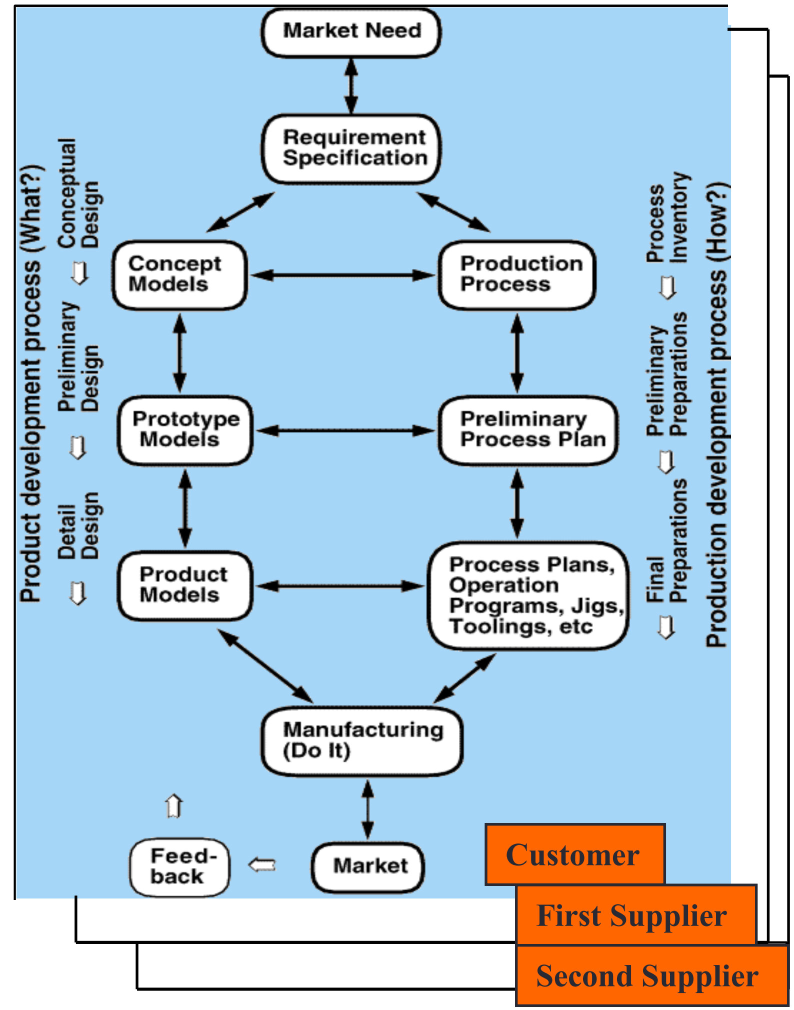


Consequences of shorter product development cycles

Concurrent Engineering



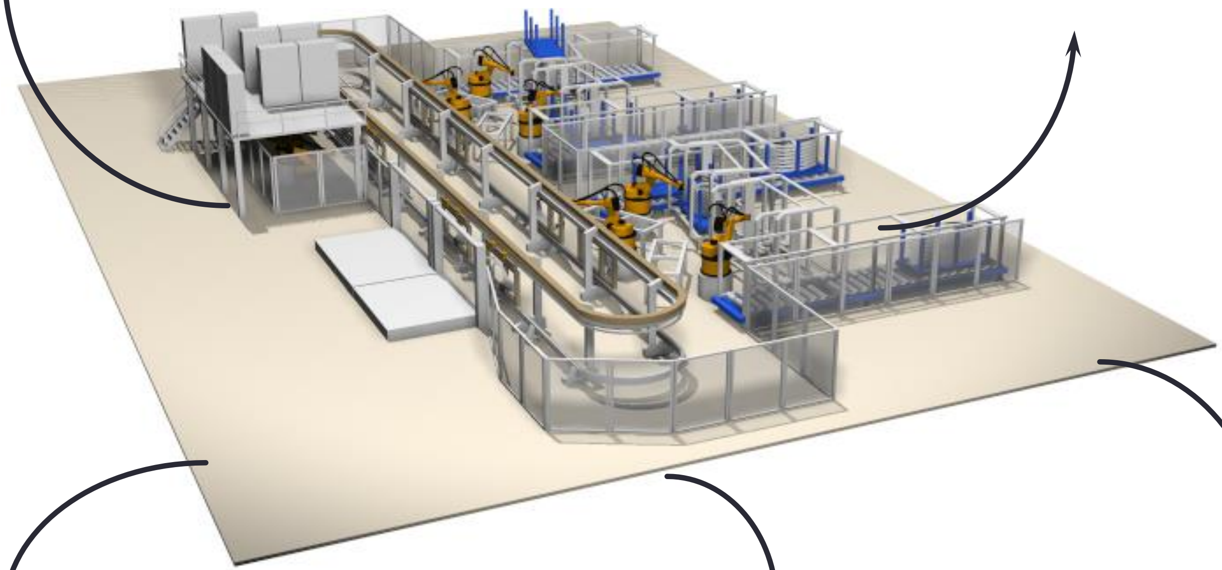




The Purpose

Process-Driven Product Development

Verification of the Integration between Product and Production Process

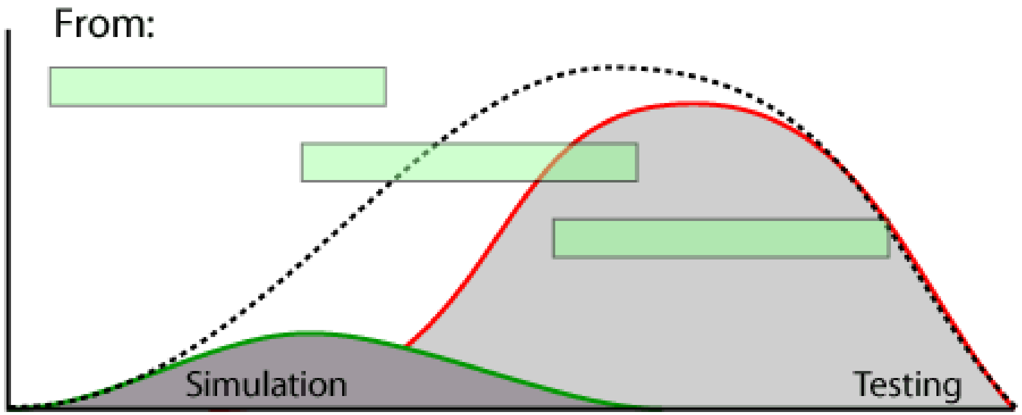


Reduced Lead-time

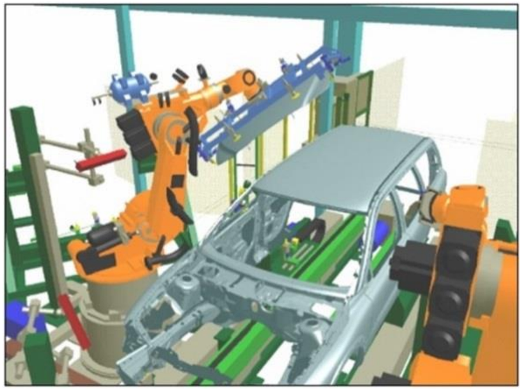
Less need for Physical Prototypes

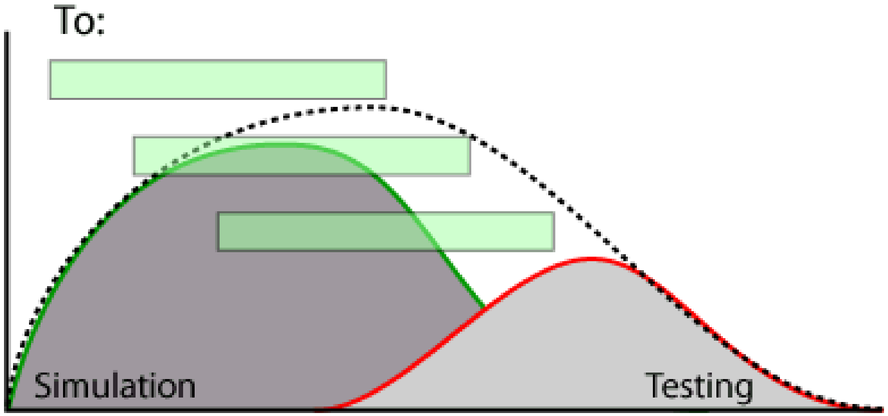
Change-over at any Weekend

Changes the developing process



Real world





Virtual world

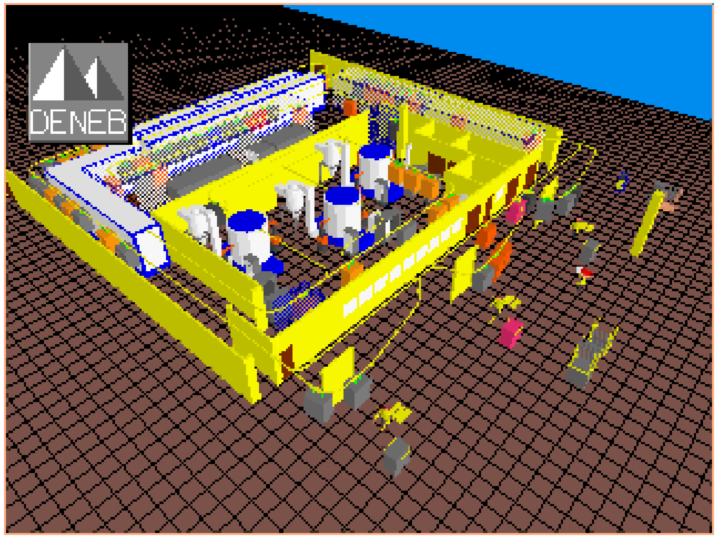
Applications of Discrete Event Simulation

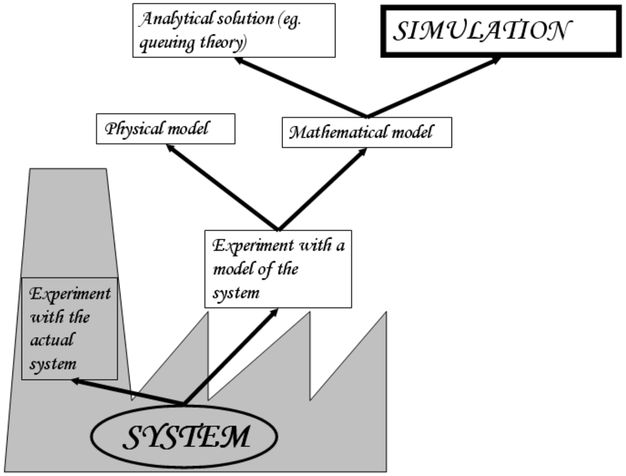
- **Production**

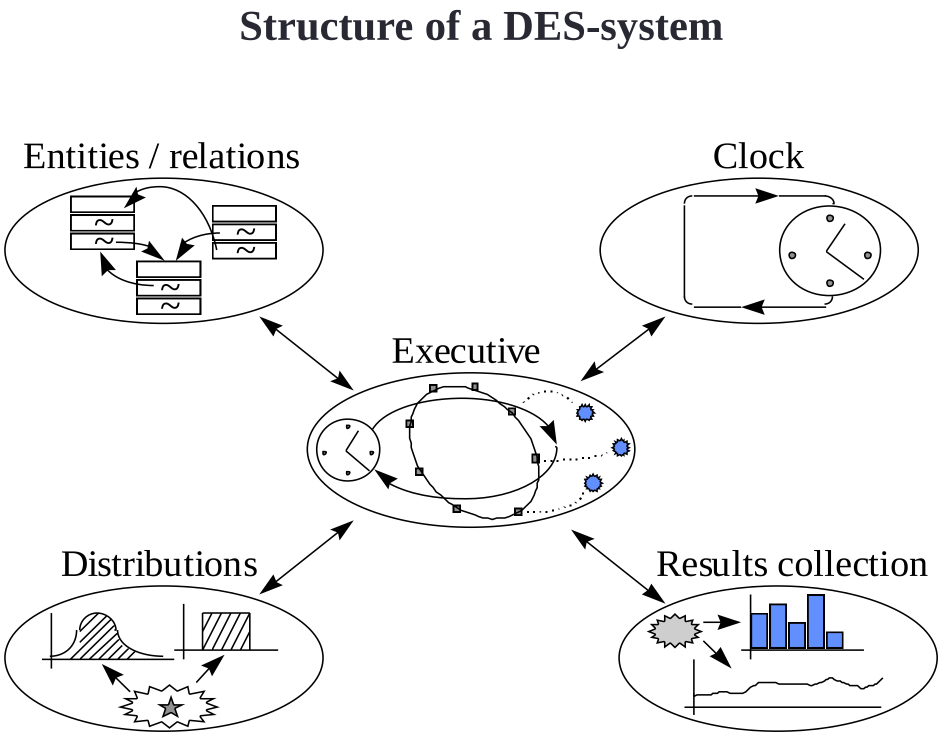
  Fundamental engineering method in modern manufacturing.

- Logistics , Transportation and Distribution
  - Evaluate route planning, simulating sorting strategies in distribution centers
  - Parametric modeling in rail-capacity planning
  - Handle queue problems in Hospitals, in Airports, with public transport and motor traffic in urban environments
- Business processes
  - Banks, restaurant and other business centers forecasting the customer flows
  - Strategic workforce planning
- Military
  - Simulating a lot of areas to gain understanding and knowledge in how to act in reality

Discrete Event Simulation (DES)





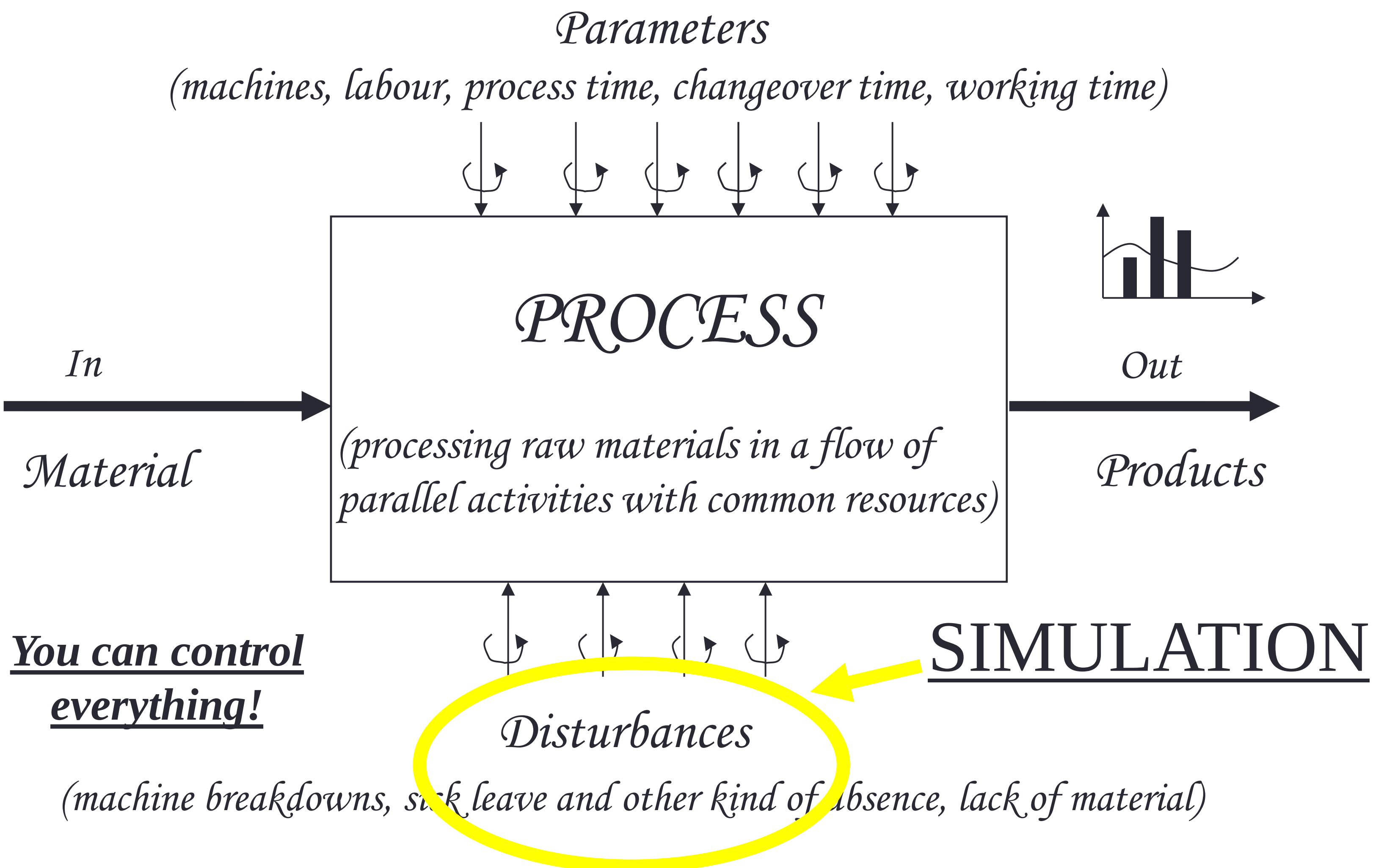


Source: Kreutzer 1986

Example

http://www.mathworks.com/videos/model-a-discrete-event-system-overview-1-of-7-81124.html?requestedDomain=www.mathworks.com#

DES of Production Flows



You can control everything!

Different types of models

- Deterministic vs. Stochastic
- Dynamic vs. Static
- Discrete vs. Continuous
- Change oriented vs. Event oriented

Different types of models:

Deterministic vs. Stochastic

In **deterministic** models, the output of the model is fully determined by the parameter values and the initial conditions.

A phenomenon is defined as **stochastic** when it's course of events is impossible to predict exactly. A state does not fully determine its next state. The randomness makes that different courses of events happens with more or less probability.

Different types of models:

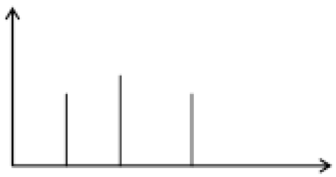
Dynamic vs. Static

A model of a system where it's variables can change also without external influence. The system is influence to it's own history – the passage of time plays a crucial role.

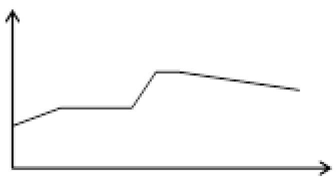
A model of a system with directly instantaneous connections between it's variables. Two events are entirely related.

Discrete vs. Continuous

Different types of models:



Discrete event models:
They are time-based jumping between events, when a new event has occurred a new state for the system is calculated.



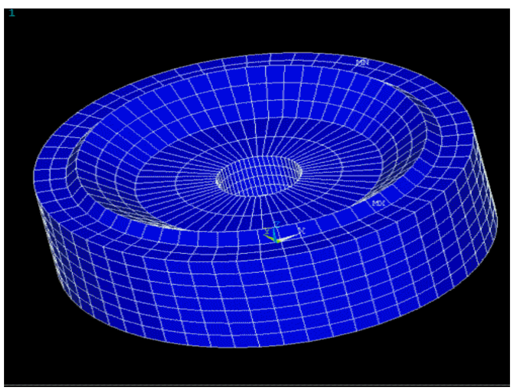
Time continuous models:
Time flows continuous, the system state is represented by dependent variables that change continuously over time, as defined by differential equations.

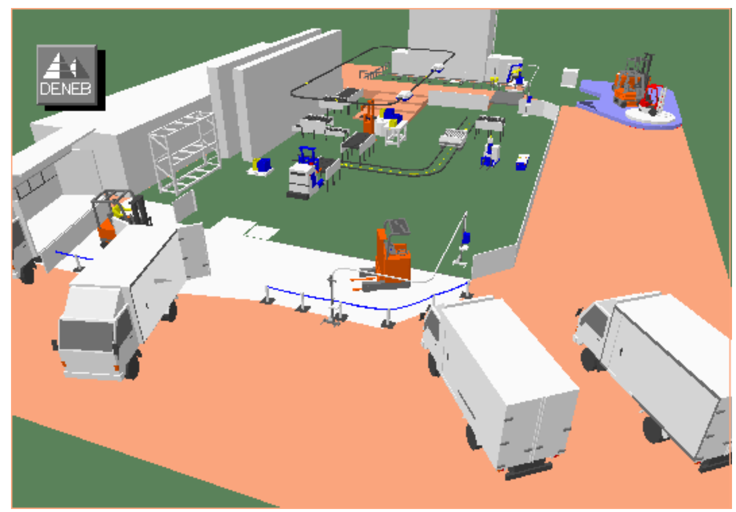
Different types of models:

Change oriented vs. Event oriented

Physical processes are often best described in terms of continuous changes. They use formulas such as mathematical models from physics.

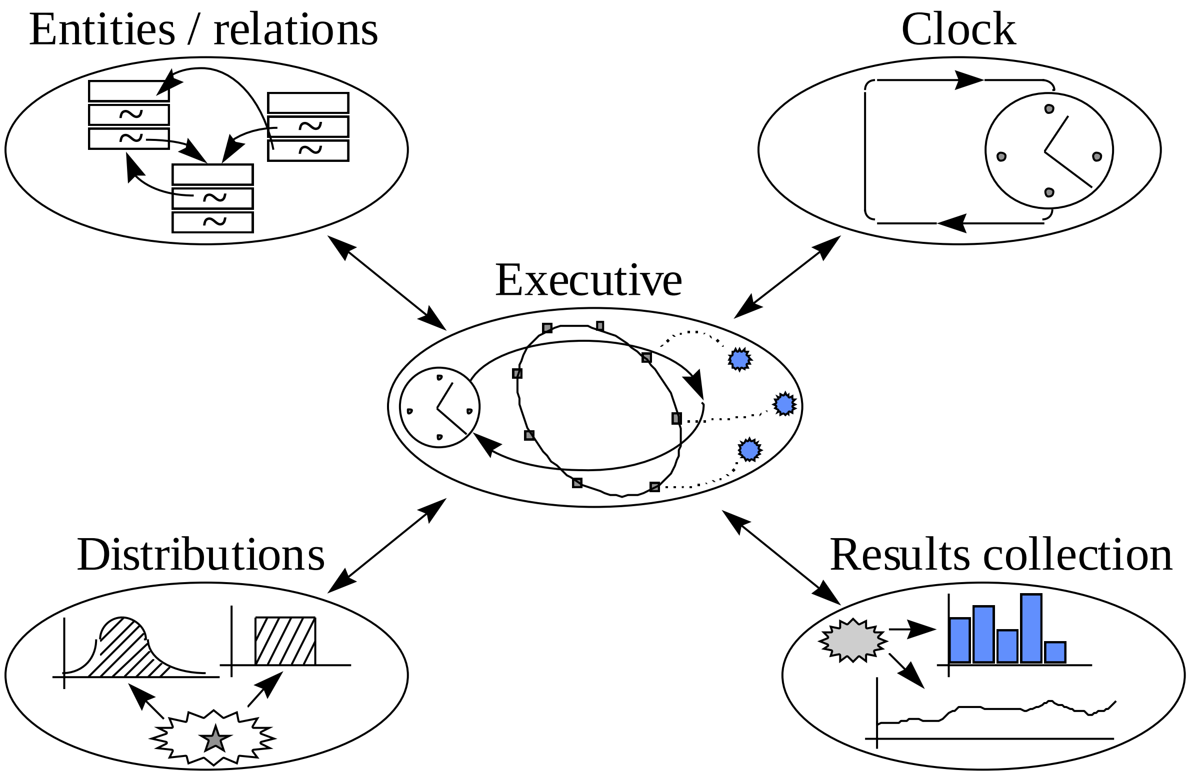
Systems which are designed by the human being, where underlying changes take place in term of discrete events are called Event oriented - Discrete Event System.





Rubber-metal vibration reducer

Flow simulation-system



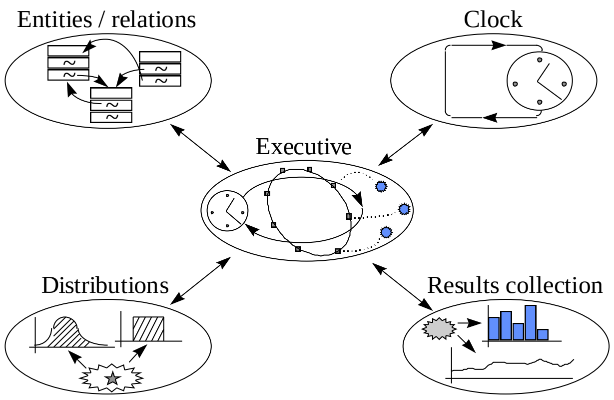
Flow simulation example

Clock time	*Event*	Machine 1	Buffer	Machine 2	Output
0	-	*idle*	-	*idle*	0
6	*1st part arrives*	**busy**	-	*idle*	0
11	*part to buffer*	*idle*	1	*idle*	0
11	*buffer to m/c2*	*idle*	-	**busy**	0
12	*2nd part arrives*	**busy**	-	**busy**	0
17	*part to buffer*	*idle*	1	**busy**	0
18	*3rd part arrives*	**busy**	1	**busy**	0
23	*part to buffer*	*idle*	2	**busy**	0
23	*part complete*	*idle*	2	*idle*	**1**
23	*buffer to m/c2*	*idle*	1	**busy**	1
24	*4th part arrives*	**busy**	1	**busy**	1

Code for this System?

Clock time	*Event*	Machine 1	Buffer	Machine 2	Output
0	-	*idle*	-	*idle*	0
6	*1st part arrives*	**busy**	-	*idle*	0
11	*part to buffer*	*idle*	1	*idle*	0
11	*buffer to m/c2*	*idle*	-	**busy**	0
12	*2nd part arrives*	**busy**	-	**busy**	0
17	*part to buffer*	*idle*	1	**busy**	0
18	*3rd part arrives*	**busy**	1	**busy**	0
23	*part to buffer*	*idle*	2	**busy**	0
23	*part complete*	*idle*	2	*idle*	**1**
23	*buffer to m/c2*	*idle*	1	**busy**	1
24	*4th part arrives*	**busy**	1	**busy**	1

Discrete Event Simulation



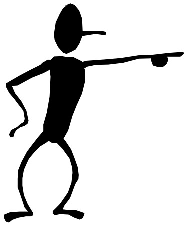
- Systems where the pattern of events cannot be predicted
    - Models of such systems contains stochastic variables
    - They adopt probability distributions
- DES-models are "run", not solved, with the result based on the interaction of system components
- When next event is time fixed, the clock jump to a given point in time
- Identifies which events going to happen next
- Perform the identified events in due sequence and order.

Discrete Event Simulation

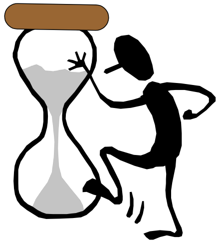
- ~~Deterministic~~ vs. Stochastic
- Dynamic vs. ~~Static~~
- Discrete vs. ~~Continuous~~
- ~~Change oriented~~ vs. Event oriented

Why Simulation?

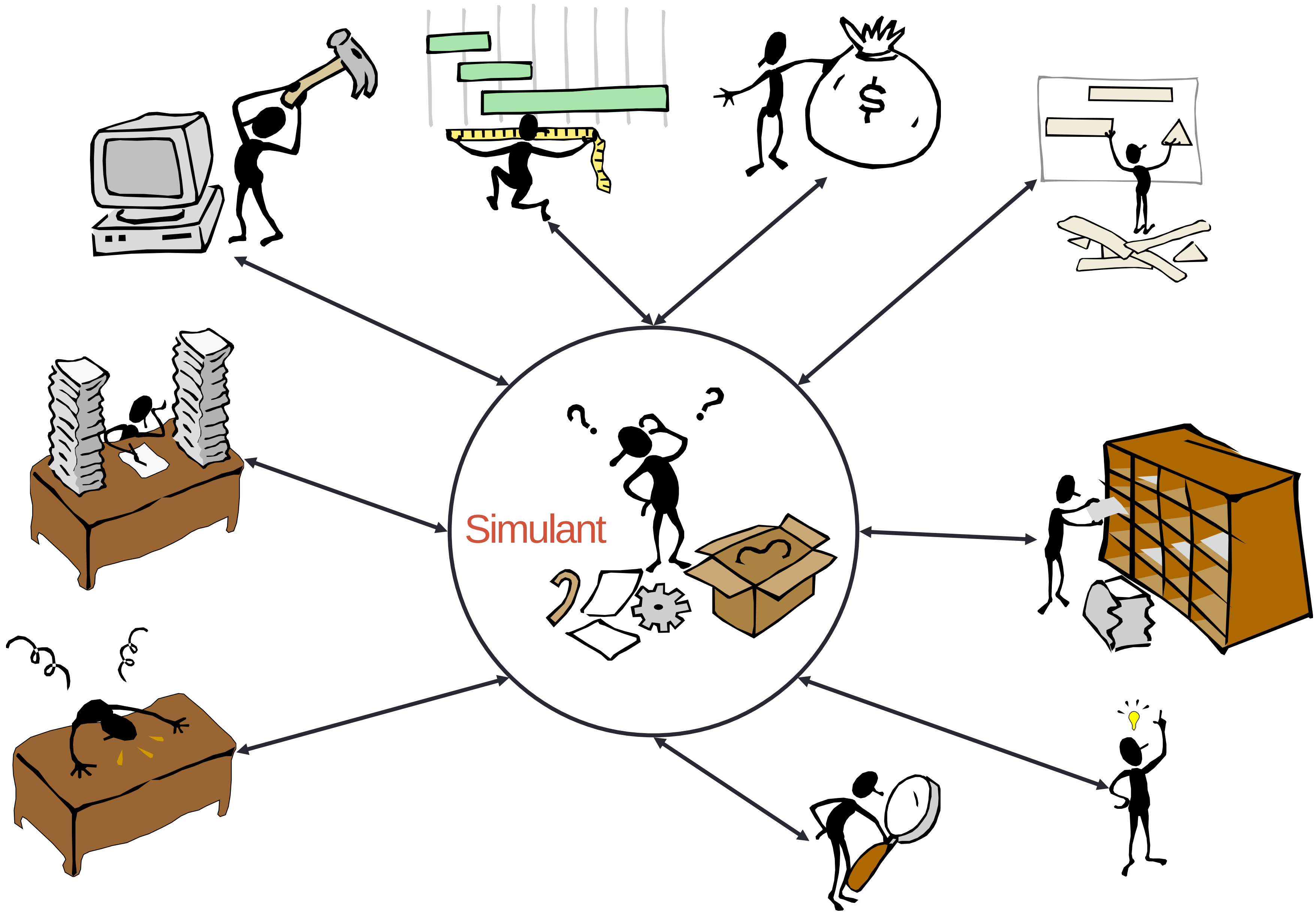
- Creates the need for order



- Points in the right direction



- Timesaver


Simulant

Advantages of Simulation

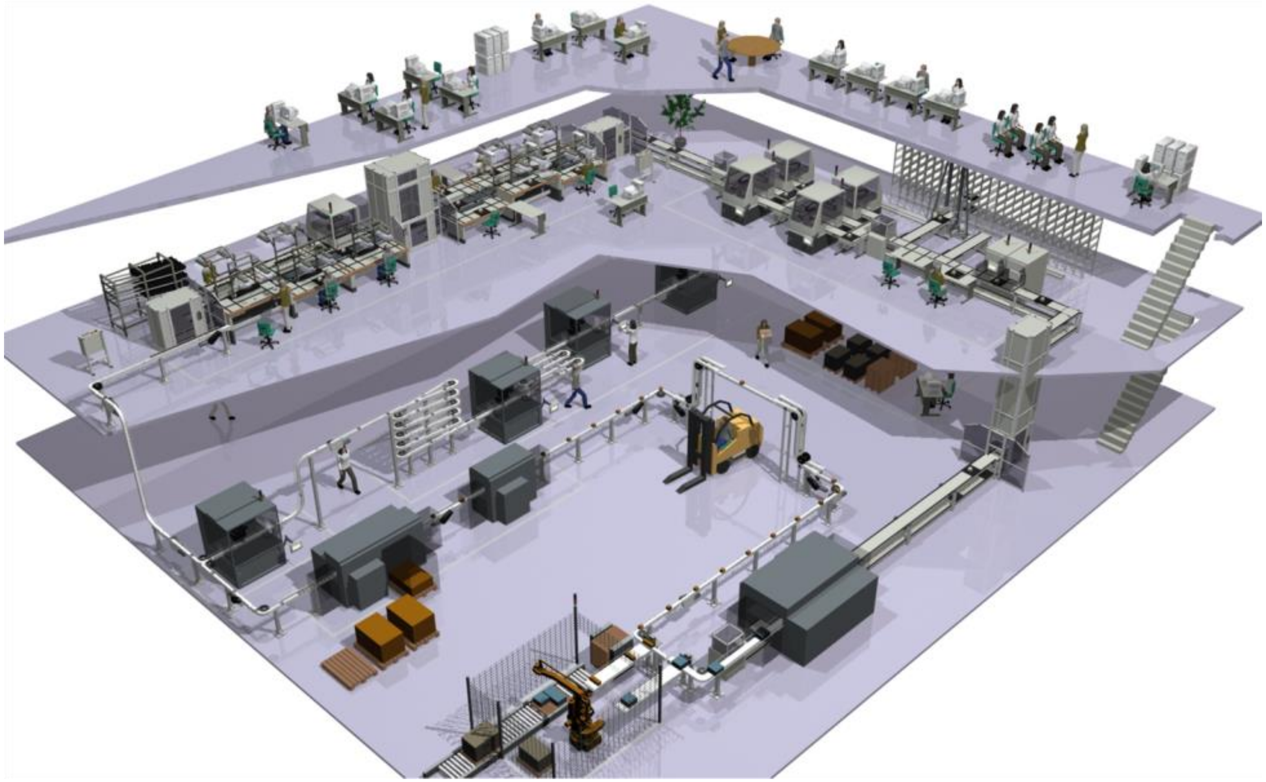
1. Making correct choices
2. Compressing and expanding time
3. Understanding “Why?”
4. Exploring possibilities
5. Diagnosing problems
6. Identifying constraints
7. Developing understanding
8. Visualizing the plan
9. Building consensus
10. Preparing for change
11. Making wise investments
12. Training the team
13. Specifying requirements

Disadvantages of Simulation

- Simulation takes time
- Simulation does only propose a solution
- Bad input data can seem to produce reliable output data
- It is hard to determine the level of detail for the model
- Creating a model is not what its all about, more skills are needed

Simulation is necessary when there are a large number of events and interactions in a system, which is true of most manufacturing problems!

Simulation Model building is an art



Examples in simulation

Water Bottling Industry

U.S. Consumption of Bottled Water in 2006:

- 31.2 billion liters of water
- 900,000 tons of polyethylene terephthalate (PET)

U.S. Manufacturing of Bottled Water in 2006:

- Required 17 million barrels of oil, not including energy for transportation
- Produced more than 2.5 million tons of carbon dioxide
- Took 3 liters of water to produce 1 liter of bottled water

Source: The Pacific Institute, 2006

Why is manufacturing's energy/ water use important

Manufacturing alone accounts for:

- 65% of the industrial sector's energy consumption
- 85% of the industrial sector's carbon dioxide emissions
    - 1,349 million metric tons of carbon dioxide in 2008
- 18,200 million gallons of water per day
    - 9% of the nations water withdrawals excluding thermoelectric power

Source: Energy Information Administration, 2008, and U.S. Geological Survey, 2005

Project Statement

To systematically study and model the combined sustainability performance of a bottled water facility

- Taking into account the sustainability performance of manufacturing operations
- Considering the environmental impacts of the building facility
- Analyzing utilization and processing of manufacturing unit processes

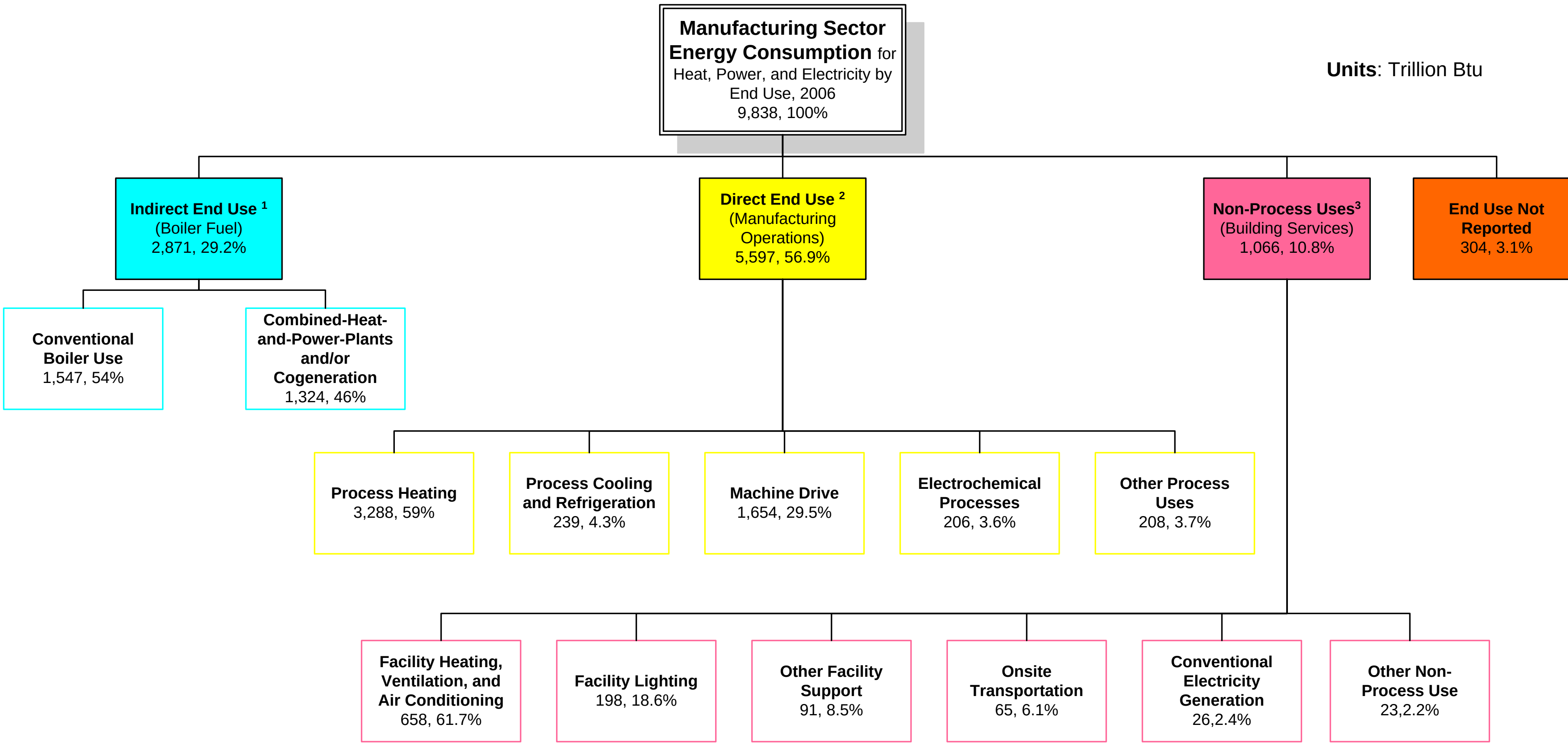
Methodology

Manufacturing Operations

Sustainability Performance

Building Services

Energy Implications in Manufacturing



Source: Energy Information Administration, 2006

Bottled Water Production Process

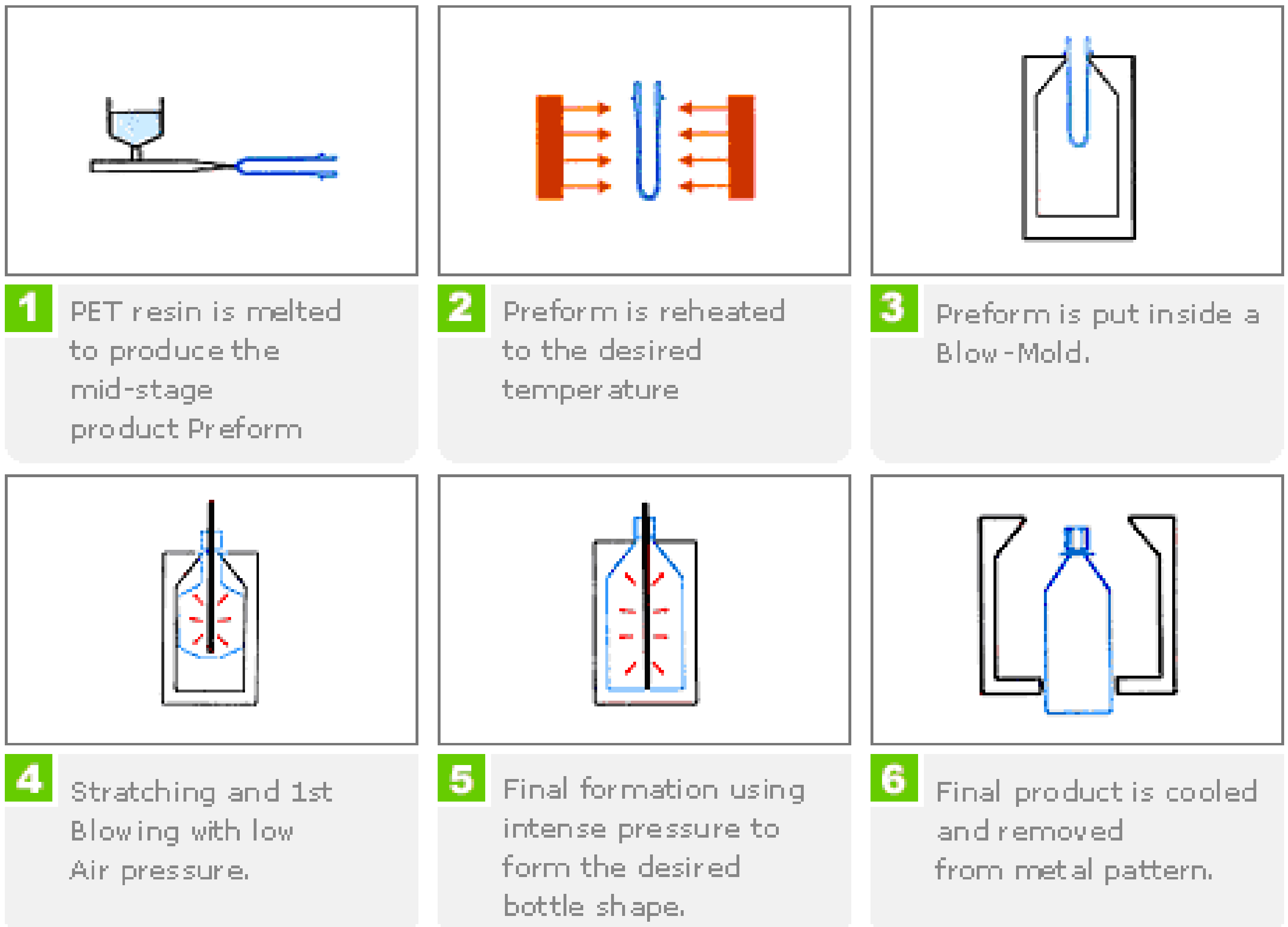
Bottled Water Production Process	Energy (MJ)
Container Production	11940.8
Packaging Production	1582.3
Bottling	941.9
Distribution	2202.5
Consumer Transport	245.5
End-of-Life	2.3
Total:	16915.3

Bottled Water Production Process	Water (Gallons)
Container & Packaging Production	175
Bottling	400.5
Power Production	716.2
Transportation	11.1
Total:	1302.8

Illustrative data

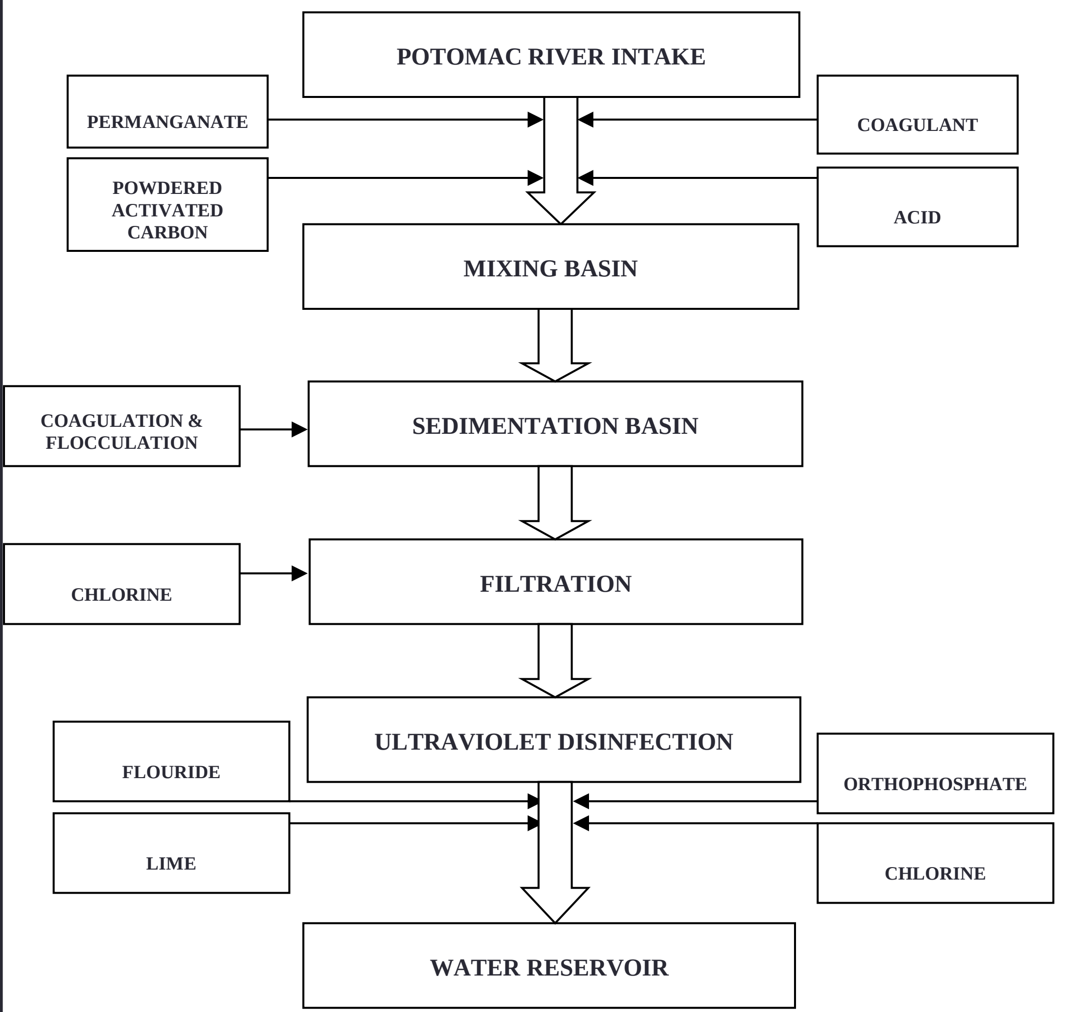
Source: Center for Sustainable Systems, 2006

Overview of Injection Stretch Blow Molding

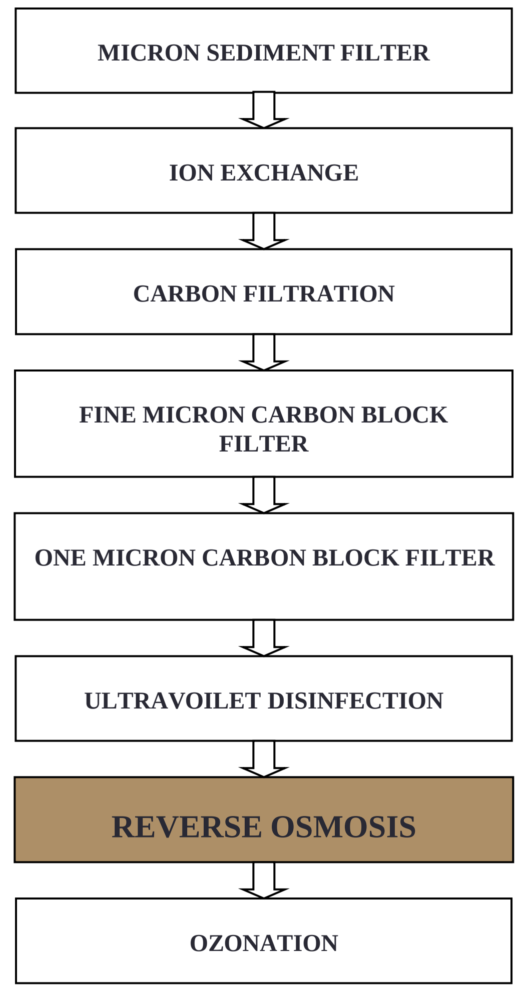


Water Purification

Washington Suburban Sanitary Commission (Tap Water) Purification Process

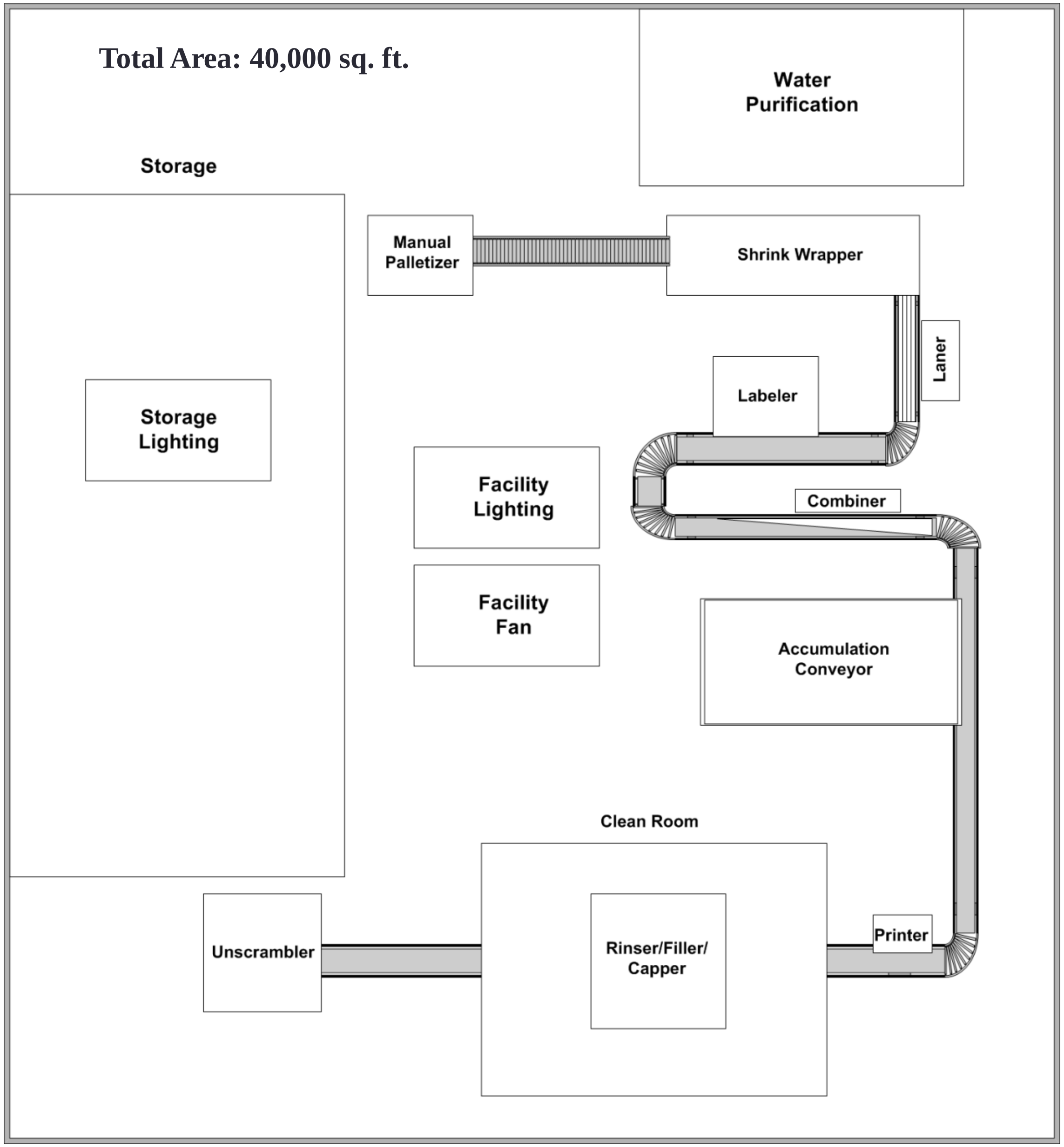


Water (Bottled Water) Purification Process

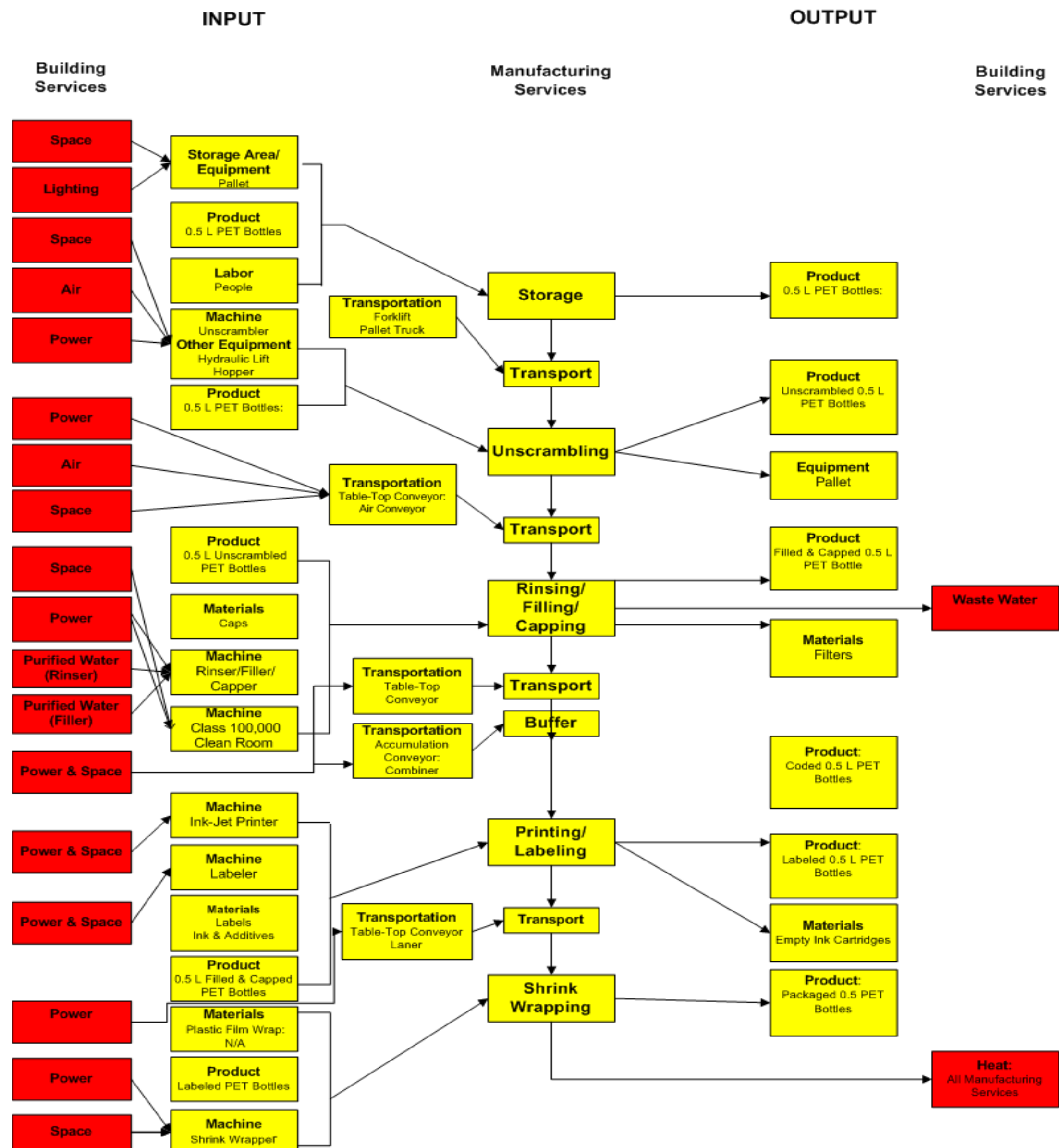


Water Bottling Plant

Water Facility Layout



Input-Output Diagram of Facility



Data Collected

	Manufacturing Operations				
	Unscrambler	Rinser/Filler/Capper & Clean Room	Date Coder	Labeler	Shrink Wrapper
Quantity	1	1	1	1	1
Energy (watt)					
Busy	2,640	6,824	300	1,000	13,000
Idle	1,760	1,824	100	500	8,000
Water (liter/bottle)					
Rinsing	0	0.05	0	0	0
Filling	0	0.5	0	0	0
Processing Time (sec)/Bottle					
Mode	0.3	0.26	0.26	0.3	0.25

	Building Services			
	Lighting (Storage)	Lighting (Busy Areas)	Fan (HVAC)	Reverse Osmosis
Quantity	59 (fixtures*)	35 (fixtures**)	1	1
Utilization (1 production day=9.5 hours)	30%	80%	100%	158%
Energy (watt)				
Busy	7,776	12,744	7,460	14,920
Idle	0	0	0	N/A
Water (1 production day=66237.5 liters)				
Purified Water	0	0	0	32,500
Waste Water)	0	0	0	17,500

***59 fixtures=6 lamp 32 watt T8 (216 watts/fixture)**
**** 9 fixtures=7 lamp 32 Watt T8 (240 watts/fixture), 26 fixtures=, 6 lamp 32 watt T8 (216 watts/fixture)**

Facility Model

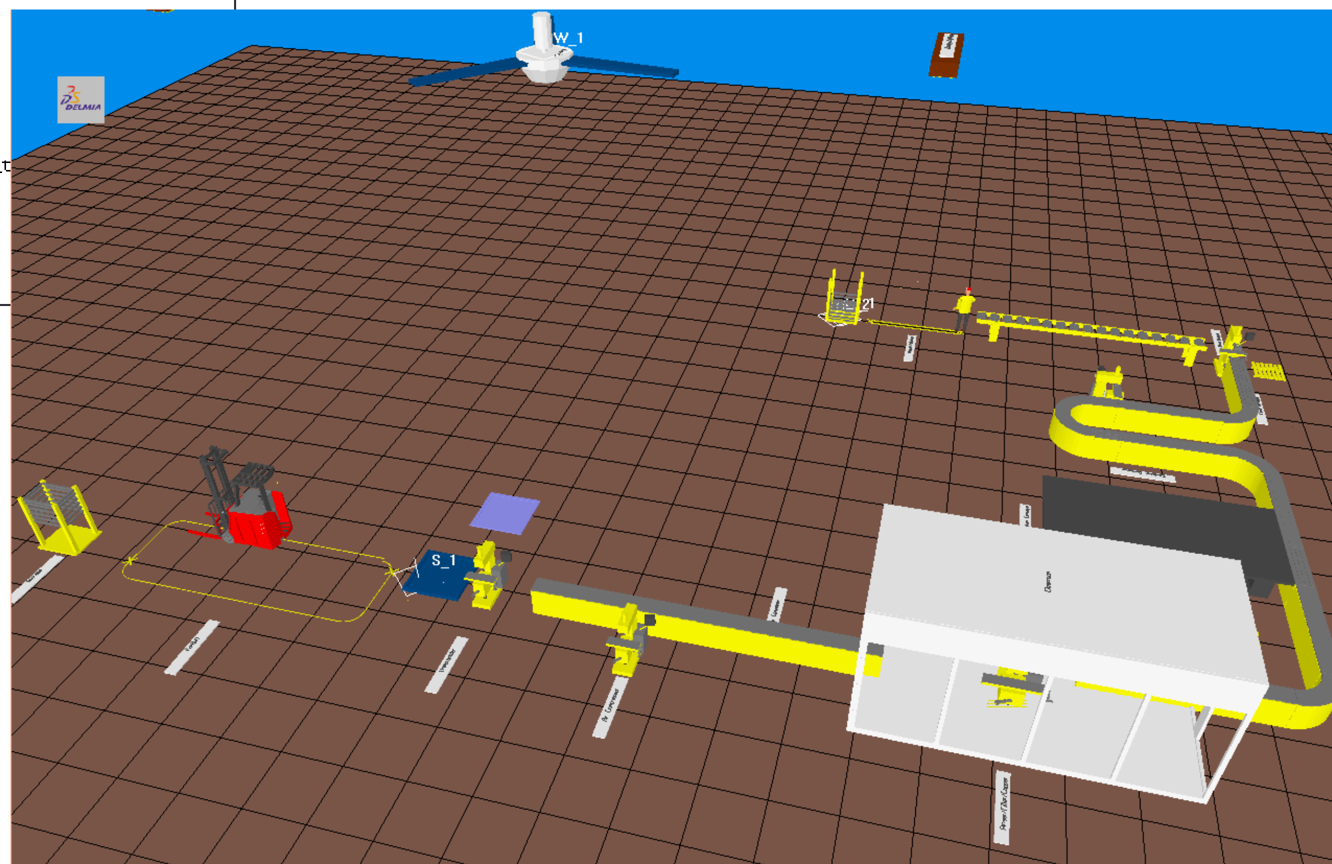
Delmia Quest Software

Simulation Control Language

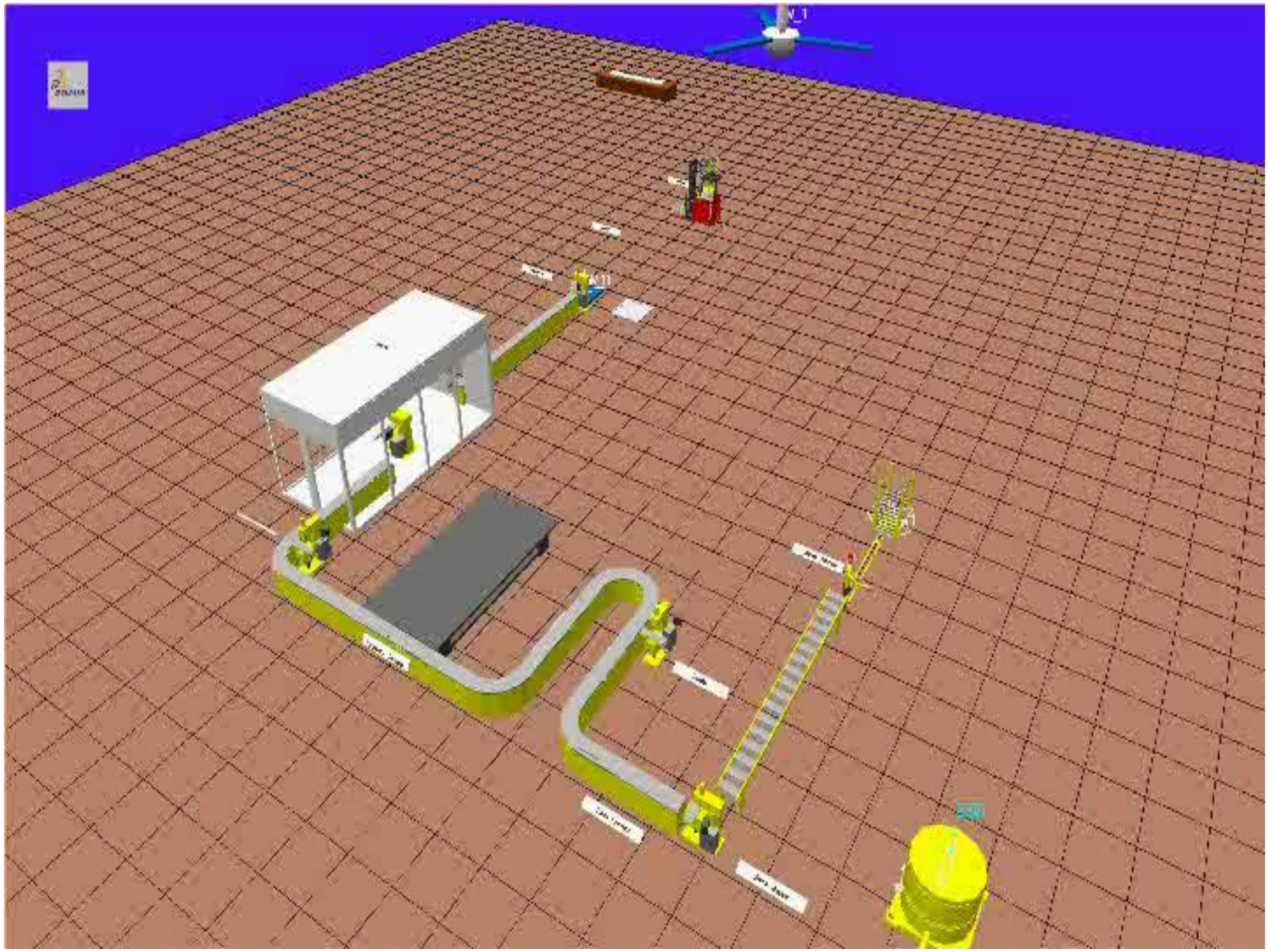
Busy_Time_Shrinker - Notepad

File Edit Format View Help

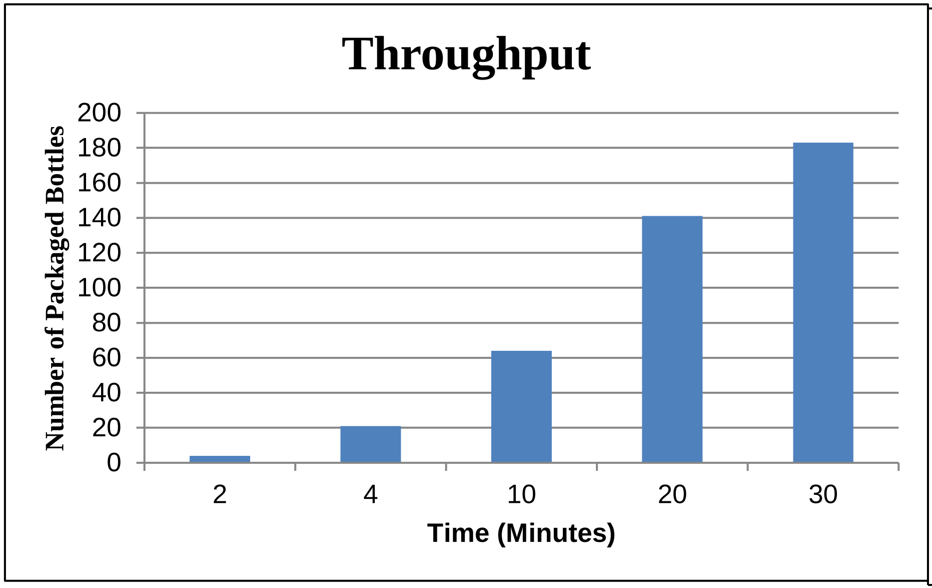
```
external
var
T2pa: Real
T1pa : Real
ITpa: Real
BTpa: Real


procedure energy5()

var
pid: Process
Begin
        pid=get_process('Process_16')
        require part ANY
--      write('T2pa from previous part = ',T2pa,'secs',CR)
        T1pa=sim_time
--      write('T1pa = ',sim_time,'secs',CR)
        if ((T1pa-T2pa) > 5) then
                ITpa=ITpa + (T1pa-T2pa)
--      write('ITpa = ',ITpa,'secs',CR)
        endif

        do_process(pid)

        T2pa=sim_time
--      write('T2pa for current part = ',sim_t

        BTpa=sim_time-ITpa
--      write('BTpa= ',BTpa,'secs',CR)
End
```

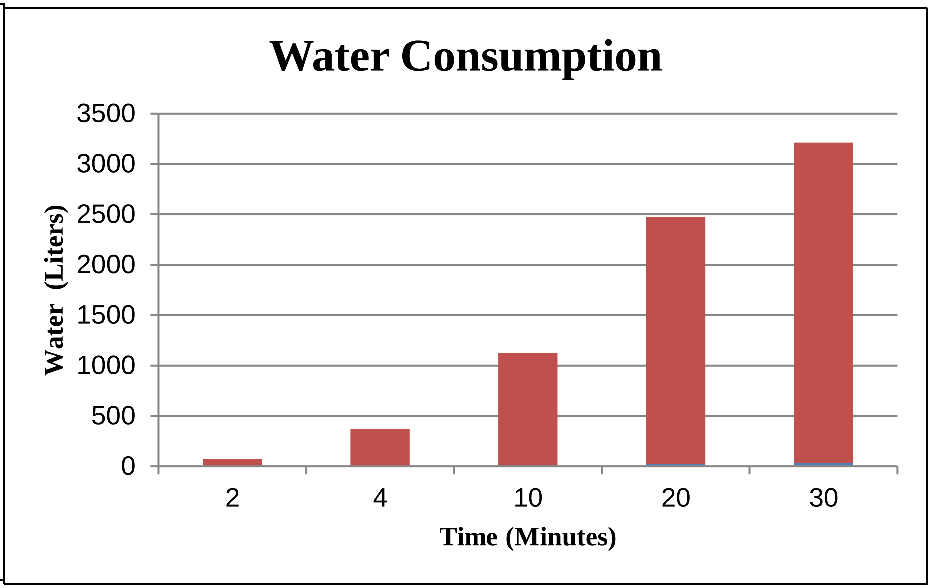


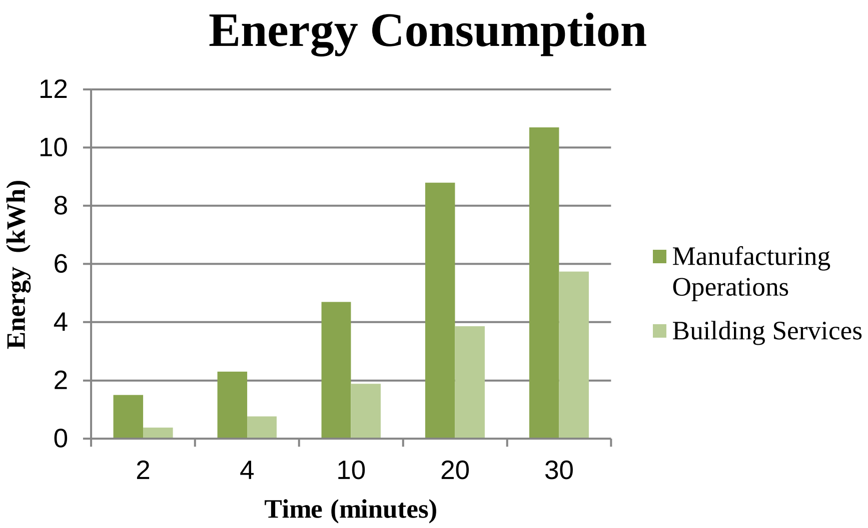
Simulation Video



Results



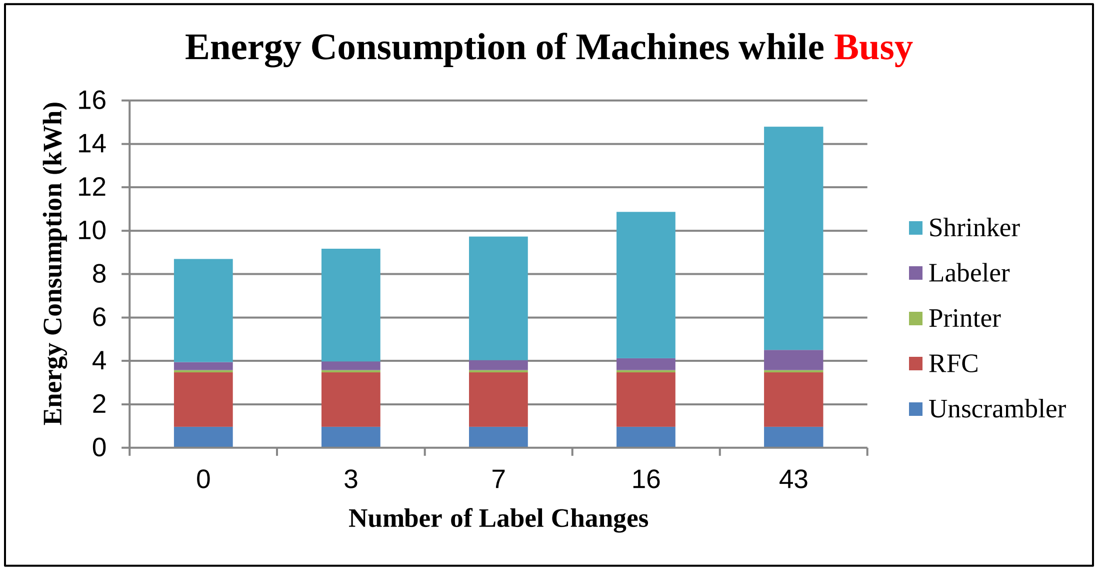


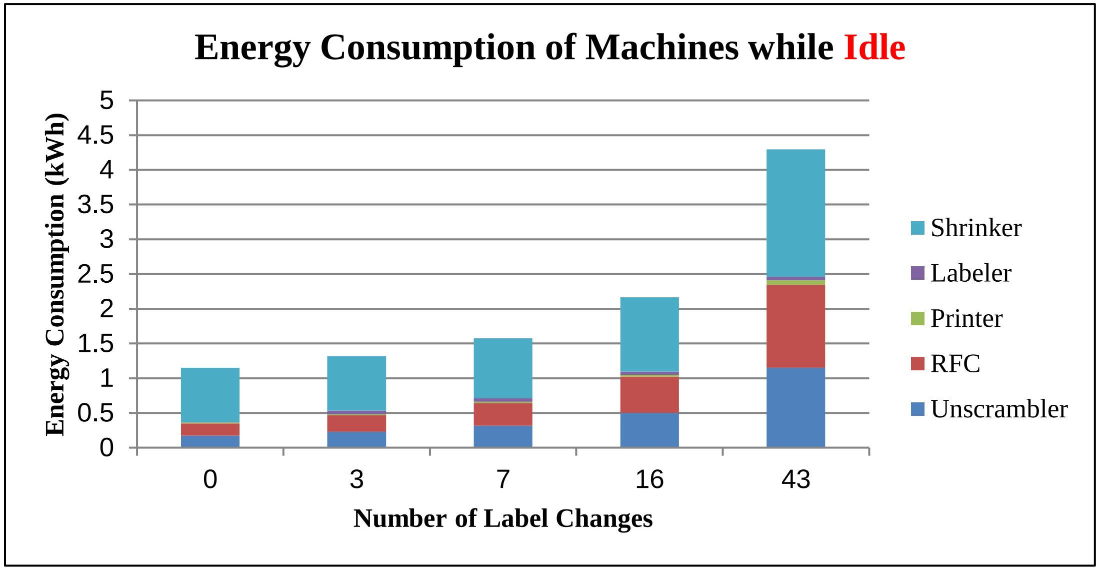


Additional Information:

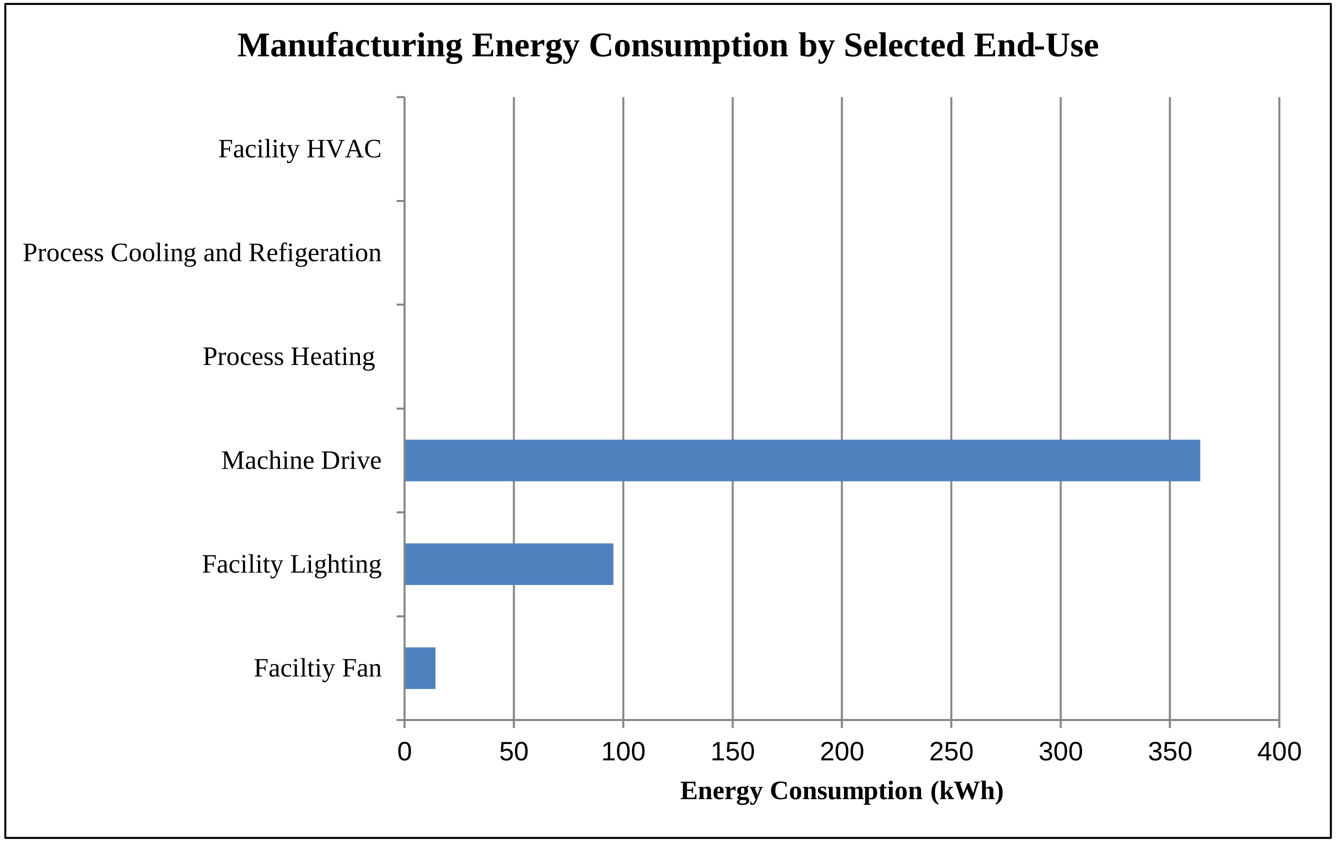
- •1 package of bottles = 24 bottles
- •Time: Does not include time to transport bottles from storage to unscrambler
- •Energy Consumption: Does not account for energy consumed in water purification process
- •Water Consumption: Does account for water consumed in water purification process

Energy Consumption, Bottleneck: Labeler





Manufacturing Operation vs. Building Services



Discussion

Discrete event simulation for the sustainable manufacture of golf balls

Motivation

- How best can Discrete Event Simulation (DES) and Life Cycle Assessment (LCA) help analyze the utilization and processing of manufacturing resources?
- Implications of such methods and evaluations to reduce the financial and environmental costs for energy intensive manufacturing processes

Project Statement

What-if scenarios in a simplified golf ball factory using as close to real-world data as possible to demonstrate DES and LCA's ability to facilitate decision-making and optimize energy intensive manufacturing processes (Injection Molding)

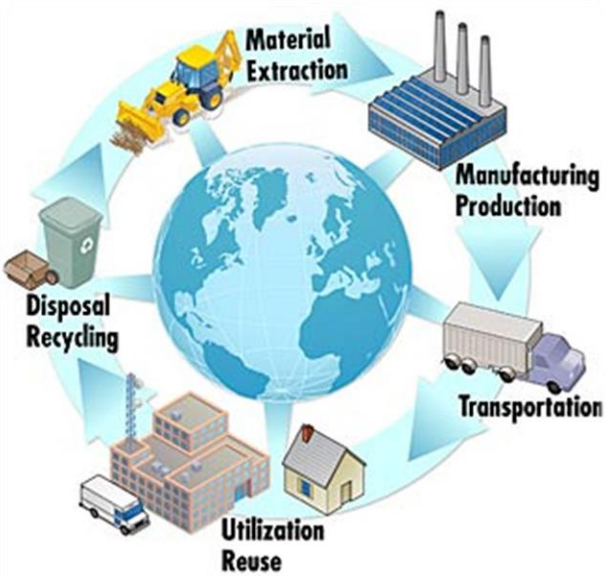
Discrete Event Simulation

- Computer simulation used to evaluate a system represented by a sequence of events
- Has typically been used to increase throughput and profitability of factories

Source: visualcomponents.com

Life Cycle Assessment

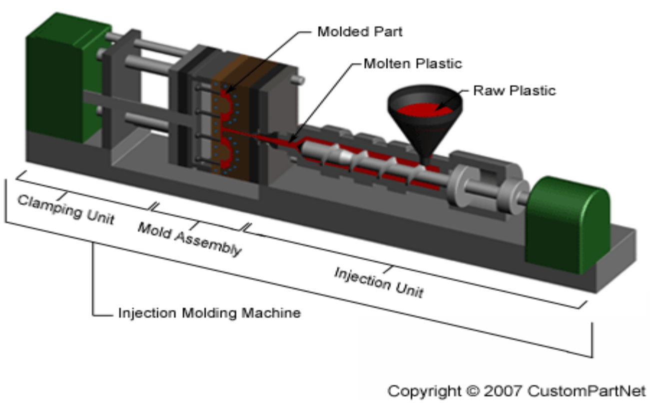
- LCA is an evaluation of a product's environmental impact during its full life cycle
- Only recently have been combined to promote sustainability

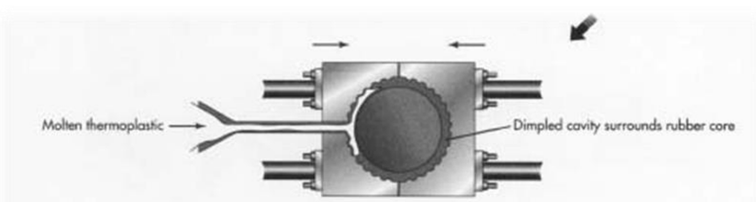


Source: nist.gov/mel/msid

Injection Molding

- Three different types of injection molding machines: **all-electric, hybrid, and hydraulic**
- Unlike hydraulic and hybrid, all-electric machines have very low idle energy consumptions, use servomotors instead of hydraulic pumps
- Hydraulic are a bit more precise, can produce larger clamping forces, but create hydraulic oil waste



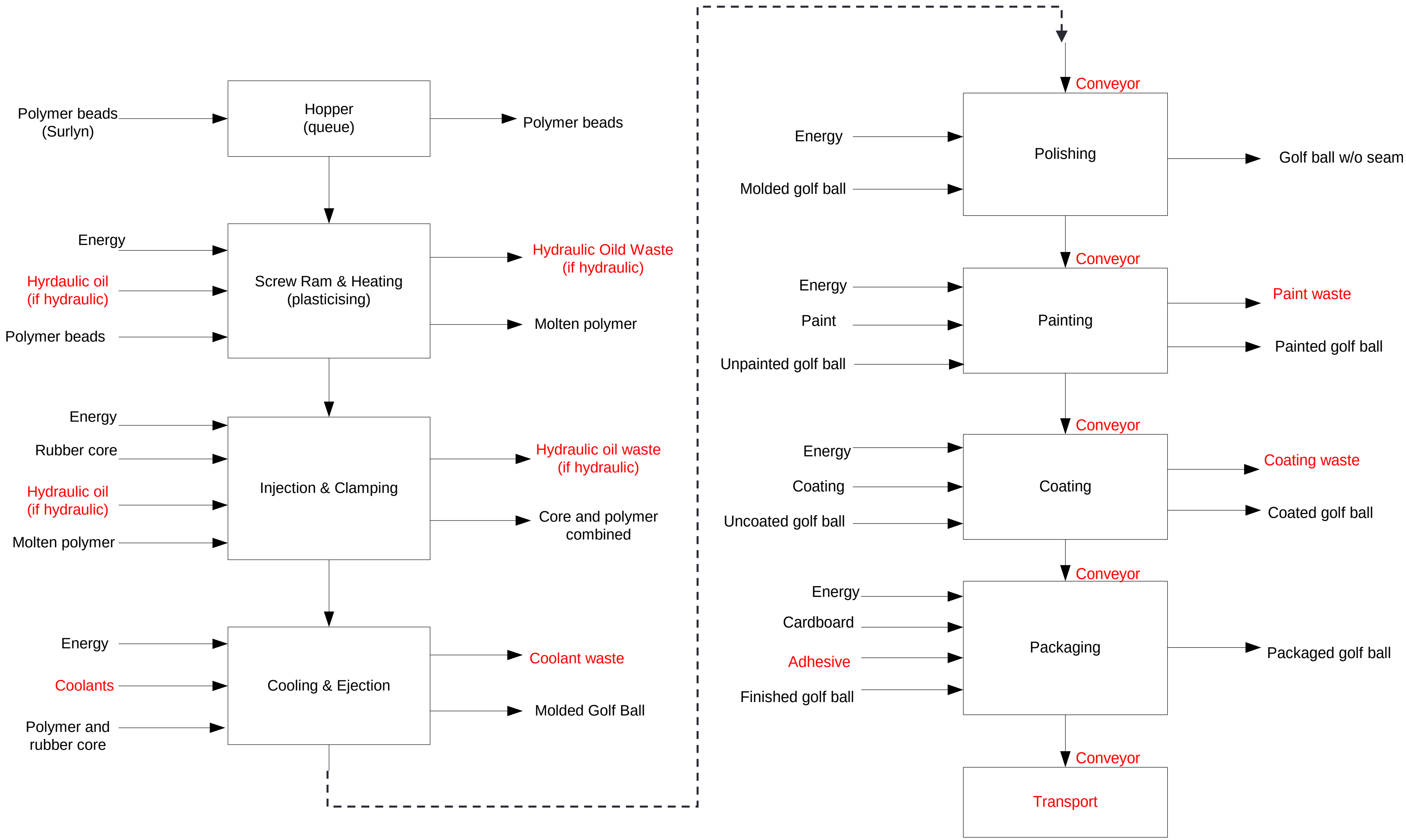


The cover is applied through injection or compression molding.

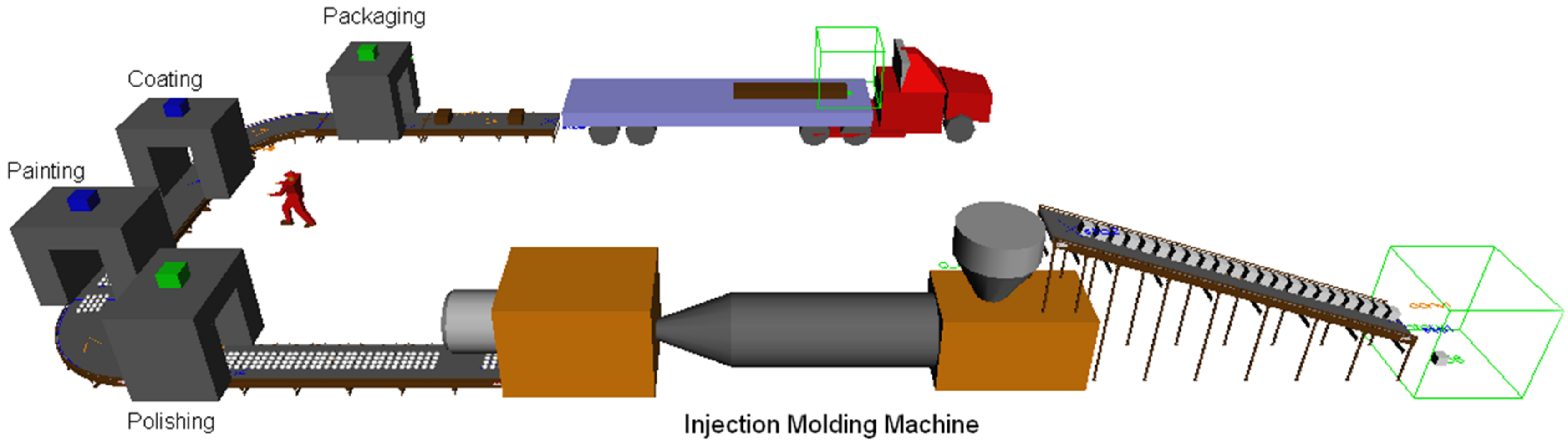
Case Study: Golf Ball Covers

- **About a billion golf balls manufactured per year**
- **Can be made using either injection or compression molding**
- **Two-piece vs. three-piece balls**
- **Rubber (compression molded) core and thermoplastic (injection molded) cover**
- **Core is held by retractable pins**
- **Surlyn by DuPont**

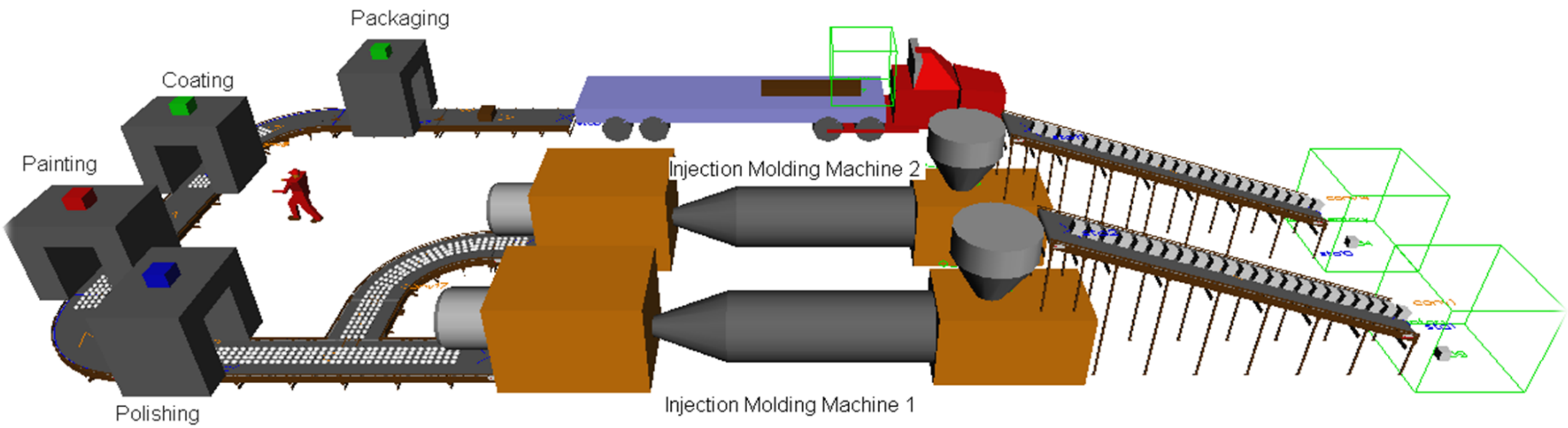
Input-Output Diagram of Model



AutoMod Factory Simulation



Simplified golf ball factory simulation with one injection molding machine



Golf ball factory simulation with injection molding machines in parallel

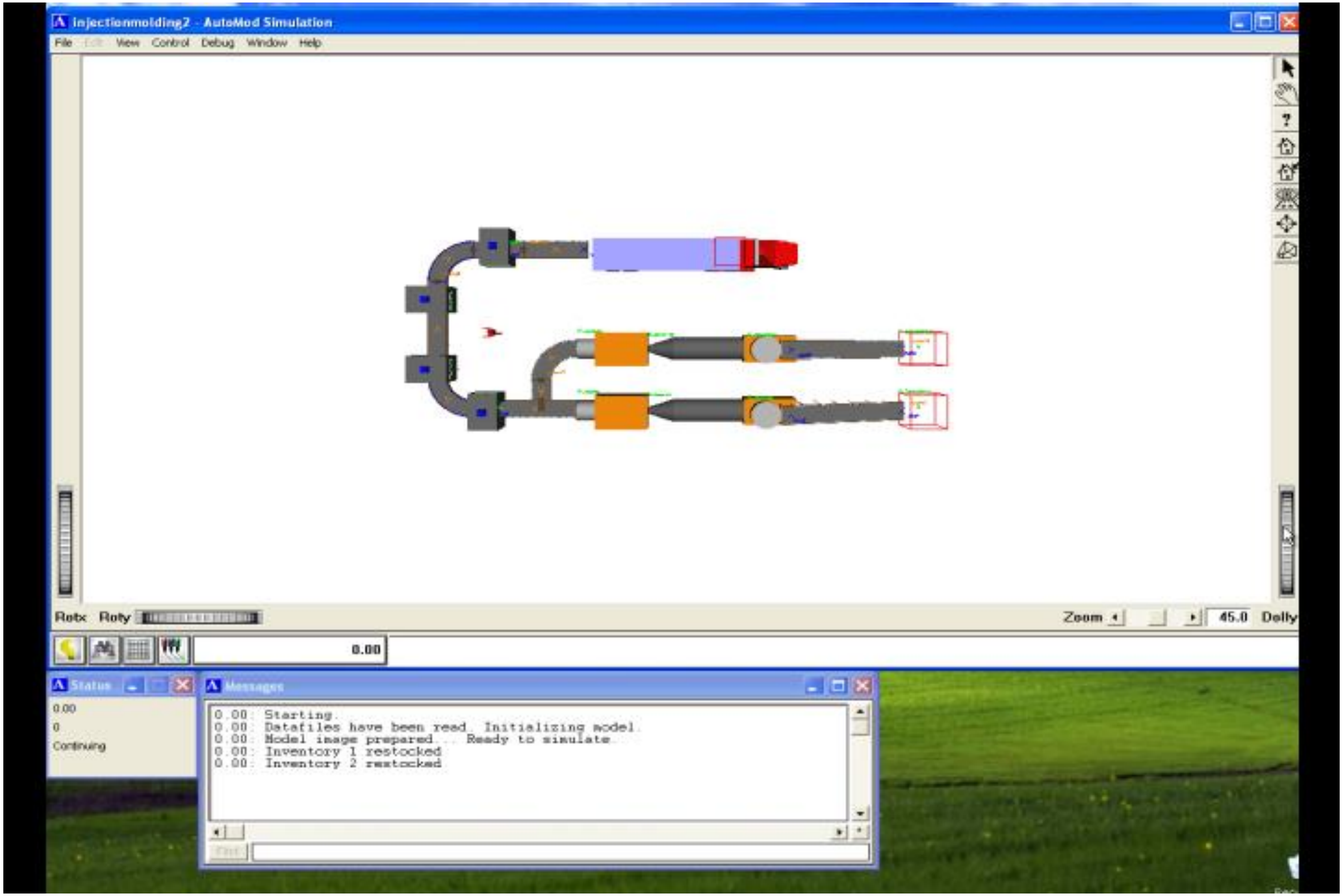
Input Data

- Injection molding cycle times and energy usage taken from real world data (*Thiriez*, 2006)
- Cycle times, energy usage for other resources were estimated
- Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) were chosen randomly
- Material usage estimated based on golf ball specifications

What-if Scenarios

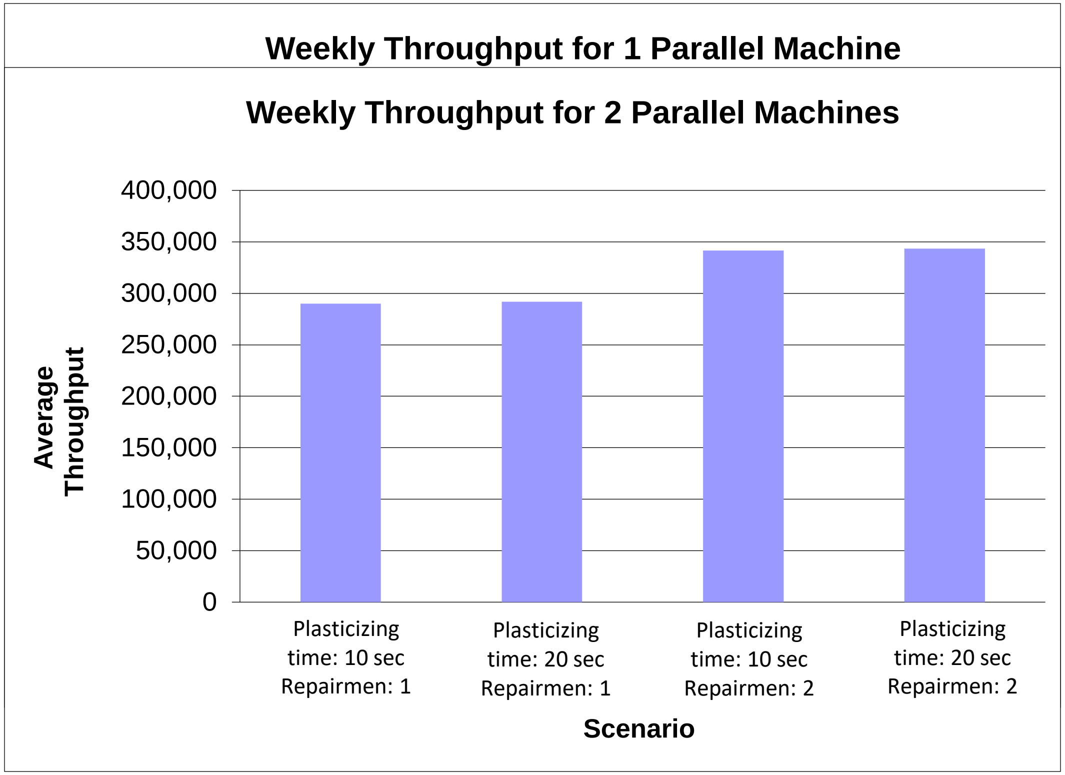
- Change type of injection molding machine (all-electric, hybrid, hydraulic)
- Increase number of injection molding machines in parallel (1 to 2)
- Increase number of repairmen (1 to 2)
- Change type of polymer processed
  - Surlyn 9320W - melting point: 70°C (10 sec plasticizing time)
  - Surlyn 8670 – melting point: 100°C (20 sec plasticizing time)

AutoMod Simulation Model



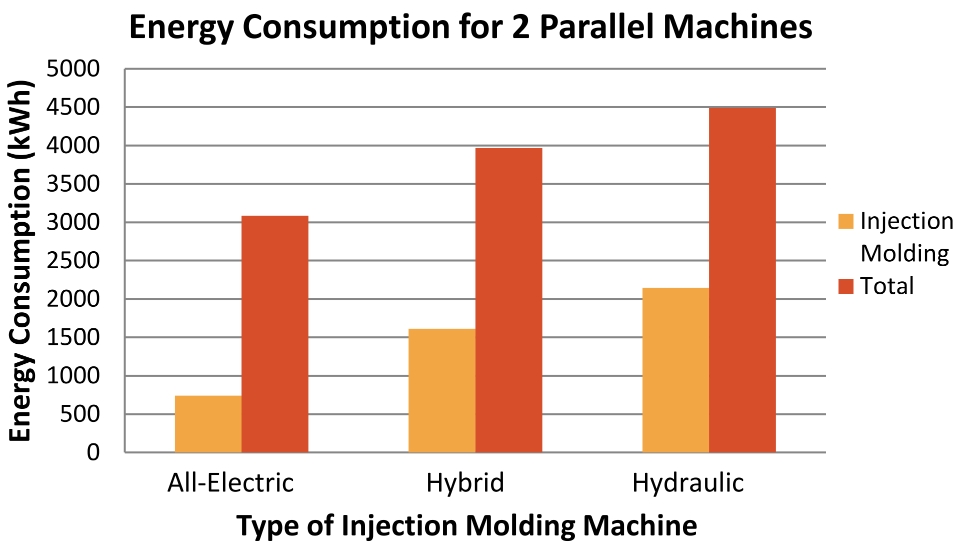
Results – Throughput

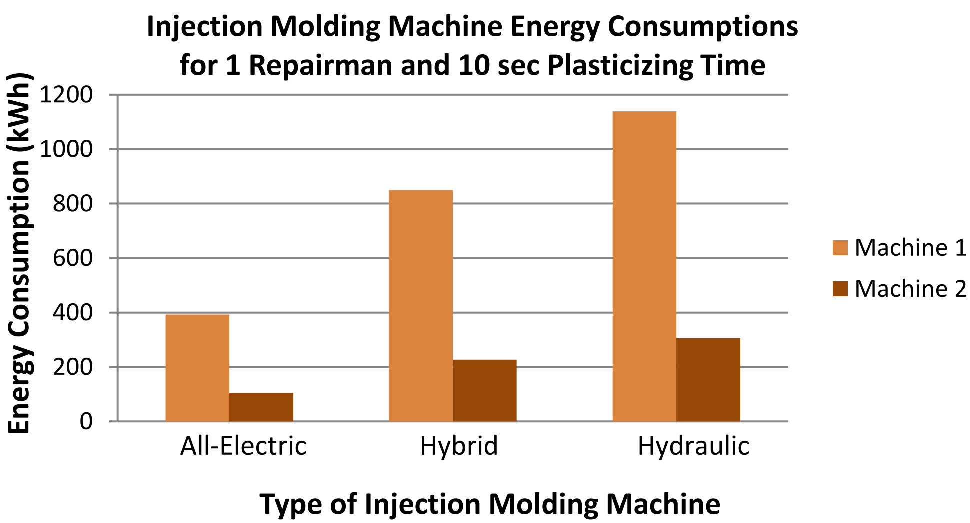
- With one injection molding machine, adding a repairman had little effect
- Both a second machine and a second repairman can increase throughput to over 300,000
- A second repairman is needed to make the investment worthwhile
- Plasticizing time had almost no effect for two machines



Results – Energy Consumption

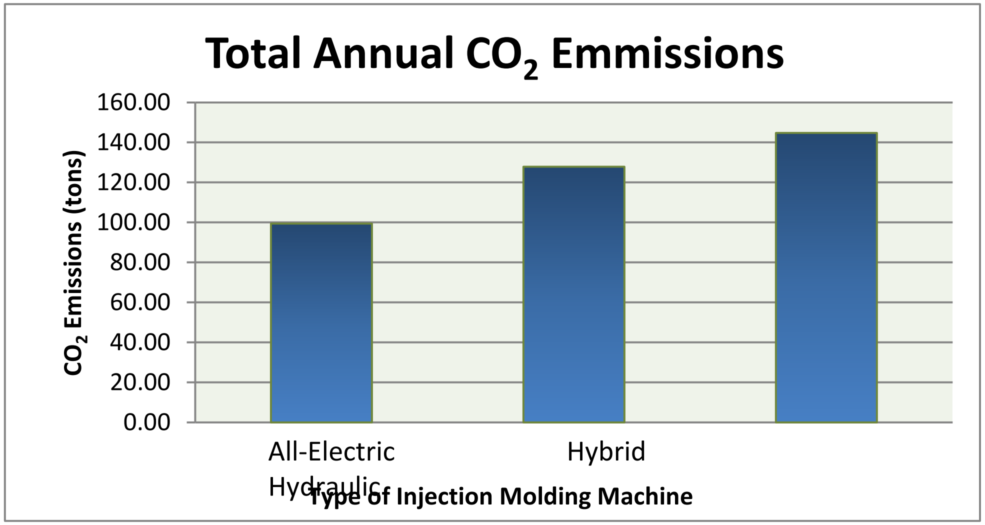
- Type of injection molding machine had significant impact on energy consumption
- Energy savings of 60-70% have led to trend towards adoption of all-electric machines
- For hydraulic machines, injection molding accounted for almost half of the total energy consumed
- For shorter plasticizing time and one repairman, second machine was hardly used





Results – Material Usage & CO_2 Emissions

- CO_2 emissions were calculated by multiplying energy consumption by an *f* factor for Maryland (*Department of Energy,* 2002)
- Modest estimates due to exclusion of HVAC, lighting, waste materials, transportation, etc.
- LCA would include environmental impacts of materials from extraction to disposal



- Potential use of Volatile Organic Compounds (VOCs)

Material Usage

Input parameters changed				Output data from simulation				
# of Injection Molding Machines	IM Type/ Power Draw (kW)	Plasticizing time (sec)	Repairmen	Rubber (kg)	Polymer (kg)	Paint (L)	Coating (L)	Cardboard (m^2)
1	Electric (6.3)	20	1	4879	2439.2	184.2	91.8	1829.2
2	Electric (6.3)	20	2	8582	4290.8	324.4	162	3218

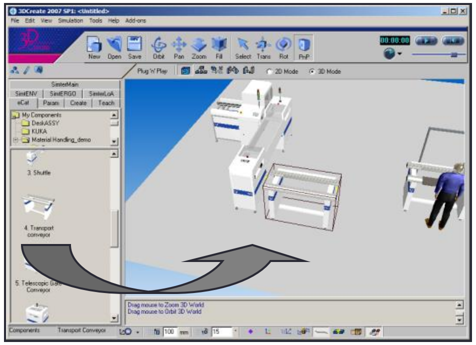
Discussion

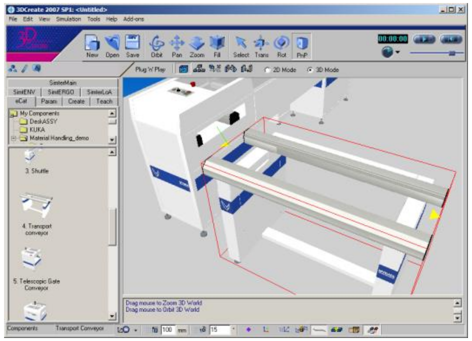
- Proof of concept of using DES with LCA for energy intensive manufacturing processes
- Adopting systems approach to problem solving
- Better incorporation of sustainability metrics in simulation software (interfaces in AutoMod)
- Comprehensive LCA on related materials
- Improve upon lack of LCI data on the unit processes

Muroyama, Alexander, Mahesh Mani, Kevin Lyons, and Bjorn Johansson. "Simulation and analysis for sustainability in manufacturing processes." In *ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. 935-941. American Society of Mechanical Engineers, 2011

Simulating Sustainable Enterprises: Factory Level

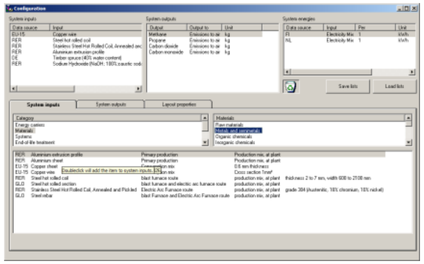
System Design



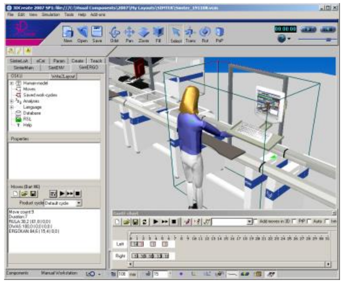


System Inputs

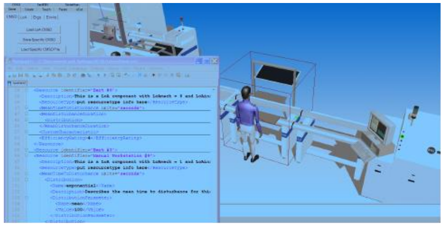
Environmental



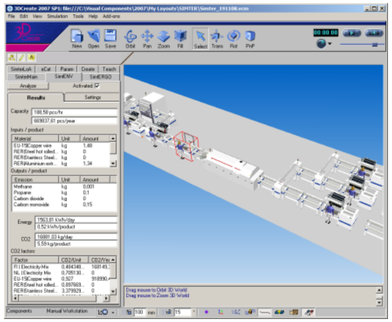
Ergonomics

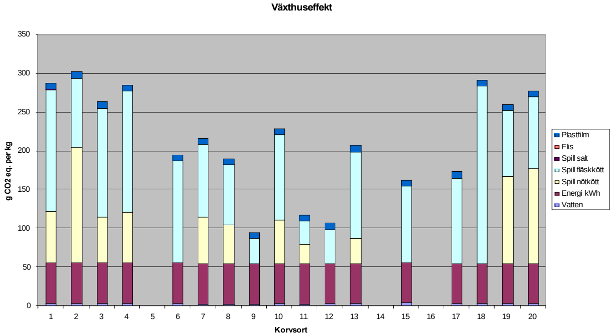


Level of Automation



System Analysis





Redesign

ARENA

https://www.youtube.com/watch?v=dlbW8WFen1s