Digital Supply Chain and the Human Element

John Wassick

January 23, 2025

Outline of Discussion

- The importance of a digital supply chain
- Observations about supply chains
- Observations about decision-making
- Ongoing research addressing human decision-making
- Important methods for a digital supply chain

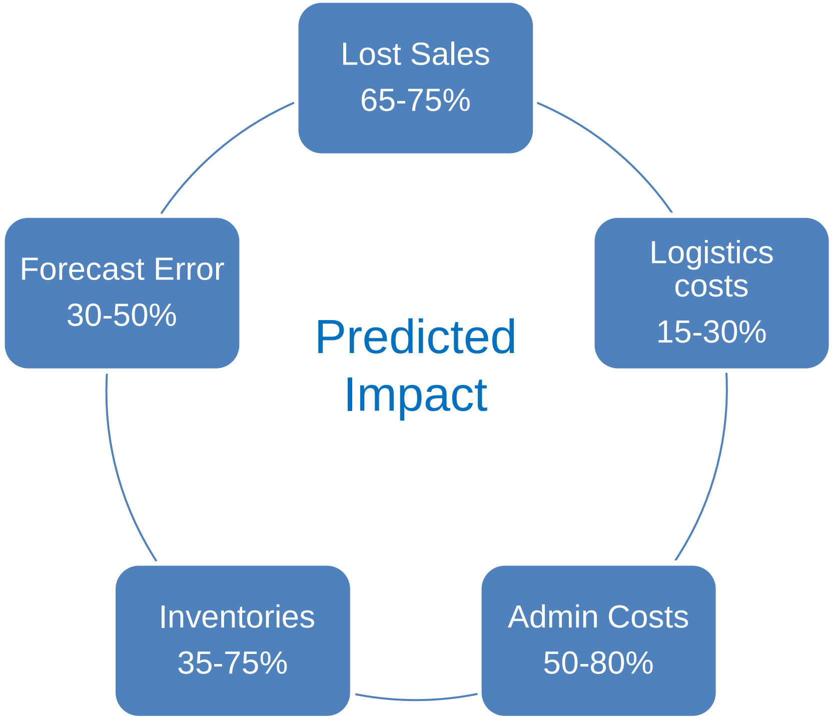
A digital supply chain is more than a collection of solutions

Digitalizing a supply chain: introducing digital technology and methods at various points in supply chain operations

Digital supply chain: a fully integrated and orchestrated end-to-end delivery system minimizing human intervention accomplished by digital technology

Expectations of a digital supply chain

- **Agility** to react speedily to sudden changes in demand and supply including disruptions in either
- **Adaptability** over time as market structures and strategies evolve
- **Aligned** interests of all participants in the value chain so that they optimize the overall performance when they maximize their interests



Supply Chain 4.0 – the next-Generation Digital Supply Chain | McKinsey.; 2016.

Expected cumulative impact ($B)
2016 to 2025

Sector	Society	Industry
Consumer	$5,439	$4,877
Automotive	$3,141	$667
Logistics	$2,393	$1,546
Electricity	$1,741	$1,360
Oil & Gas	$637	$940
Mining	$105	$321
Chemistry	$3	$302
Total	$13,459	$10,013

https://www.weforum.org/reports/digital-transformation-of-industries/

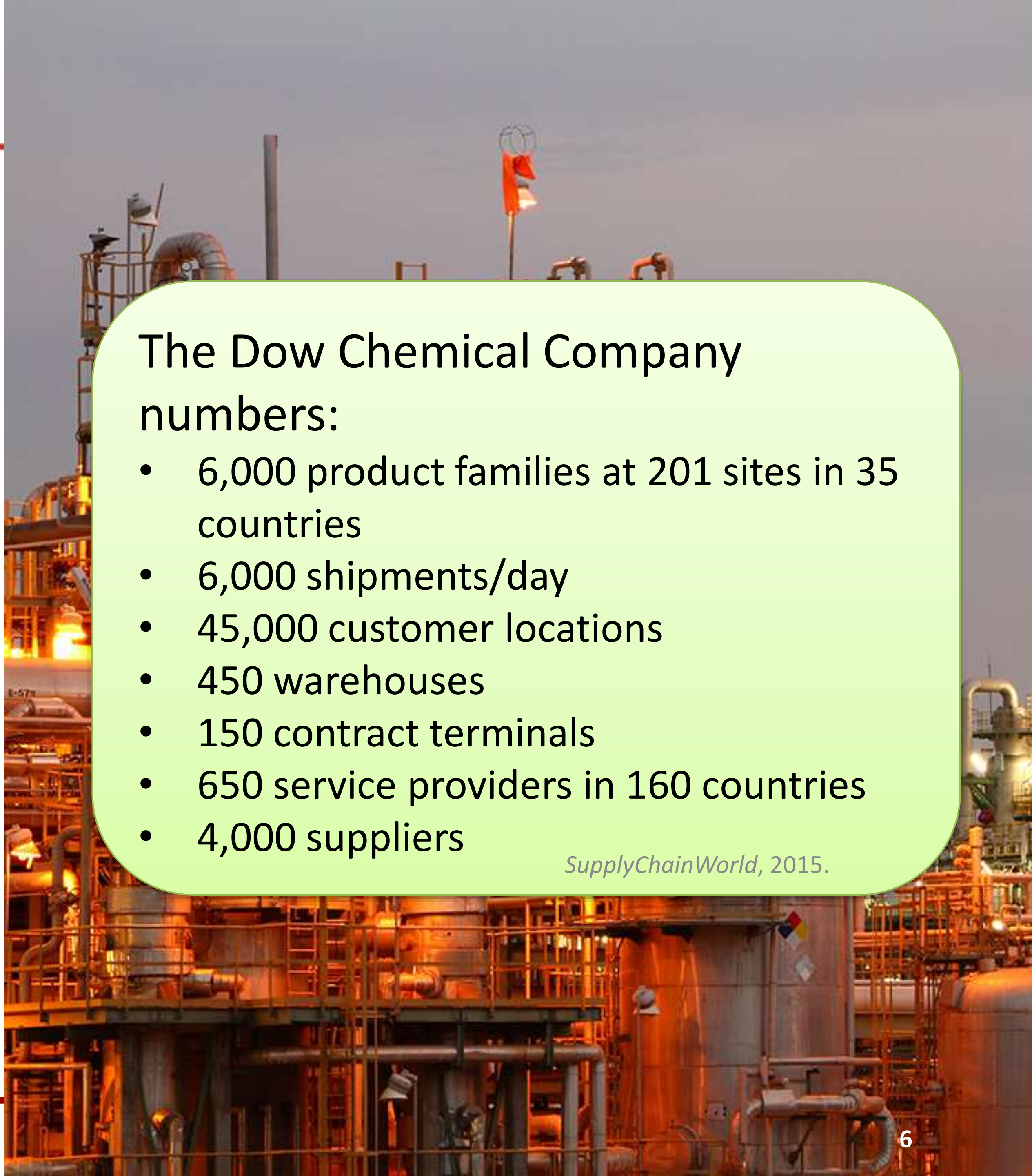
List by annual revenue the top ten Petro-Chemical companies that use the word "digital" on their website or in their annual report when discussing supply chain

1. **China Petroleum & Chemical Corp (Sinopec)** - $424.95 billion
   Context: Sinopec discusses its digital supply chain initiatives, focusing on integrating big data and AI to enhance supply chain efficiency and transparency
2. **PetroChina Co Ltd** - $405.33 billion
   Context: PetroChina highlights its use of digital technologies to optimize supply chain management, including real-time tracking and predictive analytics
3. **Saudi Arabian Oil Co (Saudi Aramco)** - $400.38 billion
   Context: Saudi Aramco emphasizes its digital supply chain strategy, leveraging IoT and blockchain to improve supply chain visibility and security.
4. **Exxon Mobil Corp** - $413.68 billion
   Context: ExxonMobil mentions its digital transformation efforts in supply chain management, focusing on automation and data analytics to streamline operations
5. **Royal Dutch Shell plc** - $386.20 billion
   Context: Shell discusses its digital supply chain initiatives, including the use of AI and machine learning to enhance supply chain resilience and efficiency
6. **BP plc** - $297.10 billion
   Context: BP highlights its digital supply chain projects, focusing on the use of advanced analytics and cloud computing to optimize logistics and inventory management
7. **TotalEnergies SE** - $184.63 billion
   Context: TotalEnergies focuses on its digital supply chain transformation, leveraging IoT and AI to improve supply chain agility and reduce costs
8. **Chevron Corp** - $162.47 billion
   Context: Chevron mentions its digital supply chain initiatives, including the use of blockchain and data analytics to enhance supply chain transparency and efficiency
9. **Lukoil Oil Co** - $128.09 billion
   Context: Lukoil discusses its digital supply chain efforts, focusing on automation and real-time data analytics to improve supply chain performance
10. **BASF SE** - $94.85 billion
    Context: BASF highlights its digital supply chain strategy, leveraging AI and digital twins to optimize supply chain processes and enhance sustainability

These companies are integrating digital technologies into their supply chain operations to improve efficiency, transparency, and resilience.

Process Industries

- Vertical integration: globally distributed manufacturing sites that work as internal supply chains.
- Value chains are intertwined and interdependent
- Complexity is not well understood by decision makers
- Raw material is supplied by a combination of internal and external sources.
- Business-to-business transactions.
- Long lead time orders of massive volumes.



The Dow Chemical Company numbers:

- 6,000 product families at 201 sites in 35 countries
- 6,000 shipments/day
- 45,000 customer locations
- 450 warehouses
- 150 contract terminals
- 650 service providers in 160 countries
- 4,000 suppliers

SupplyChainWorld, 2015.

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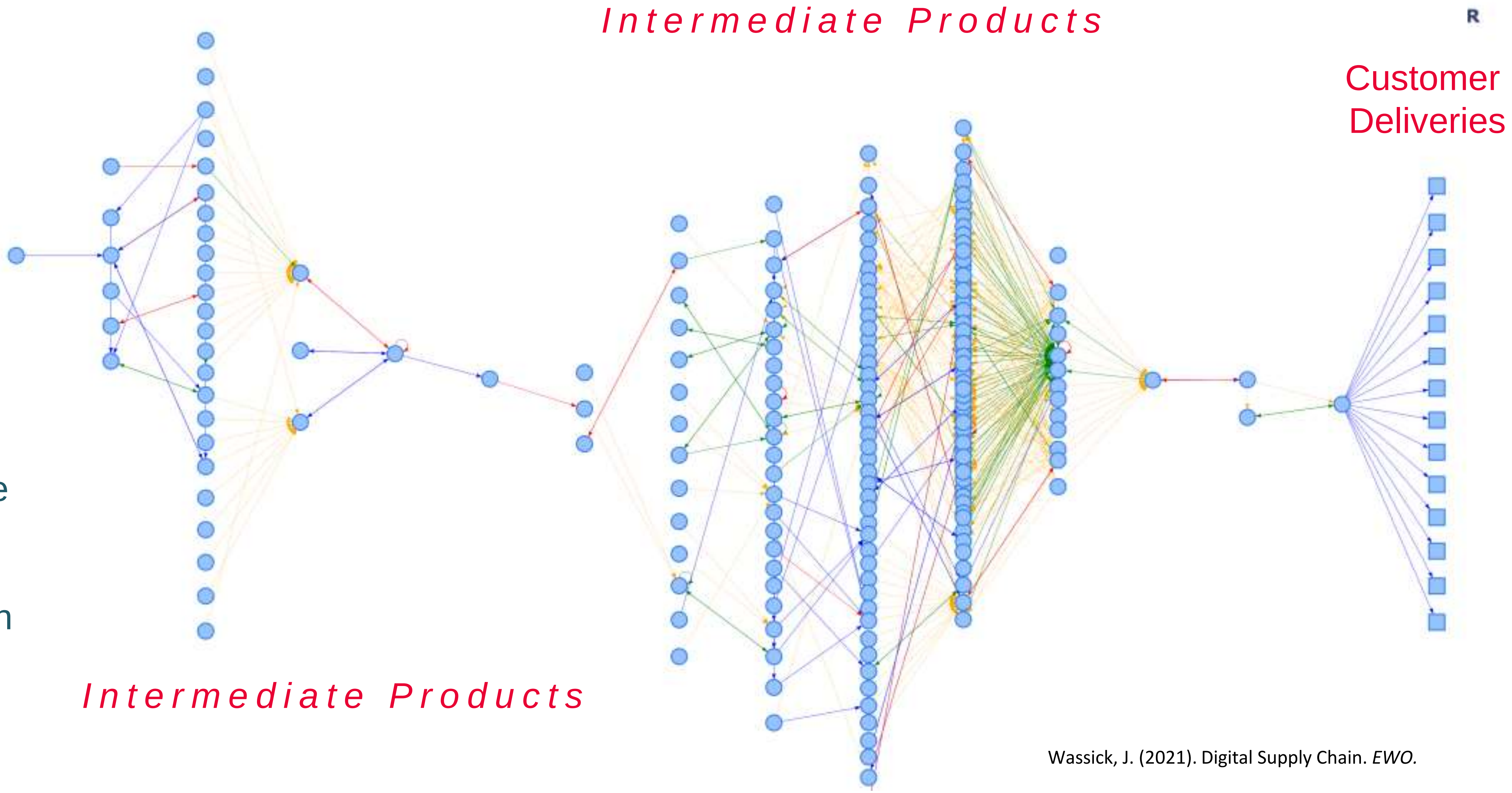
Typical internal value chains can be very complex

Nodes
a specific material at a geographic location

Arcs
- Physical move
- Unit ratio
- Inventory reclassification



Wassick, J. (2021). Digital Supply Chain. *EWO.*

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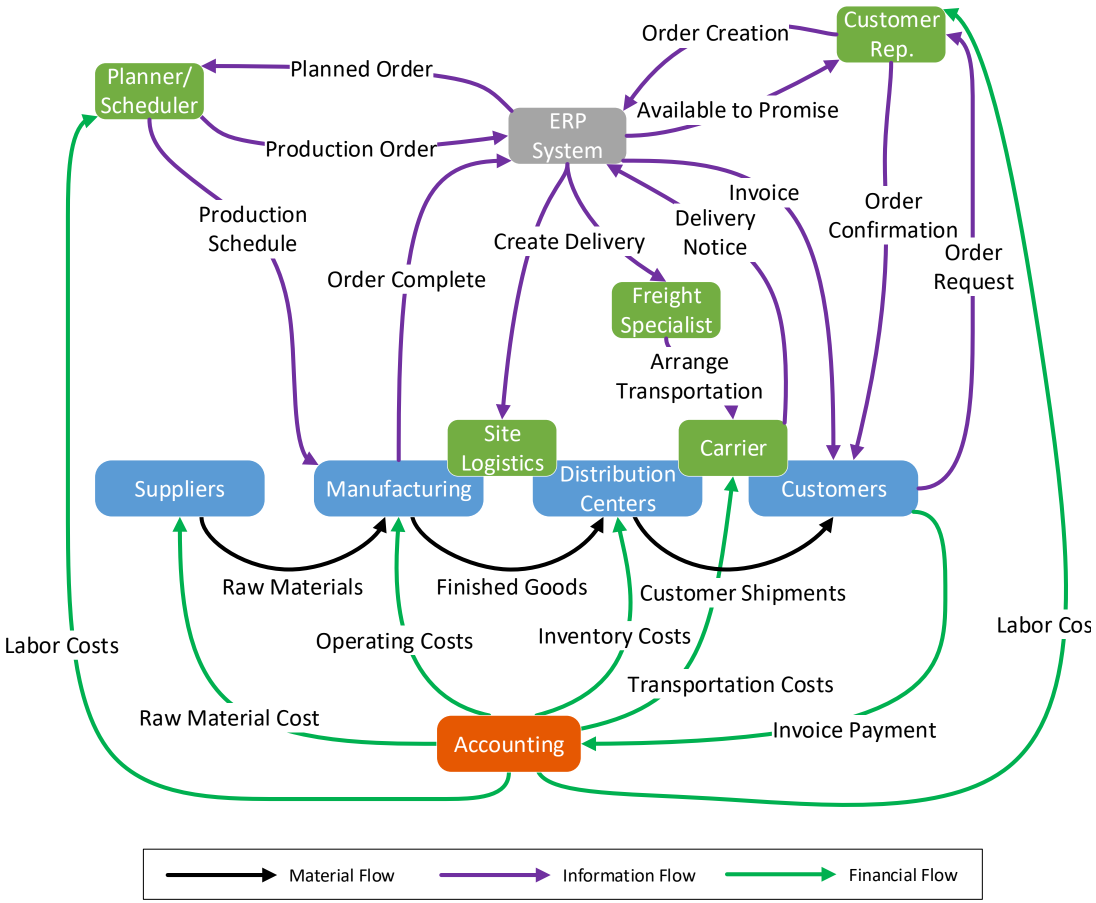
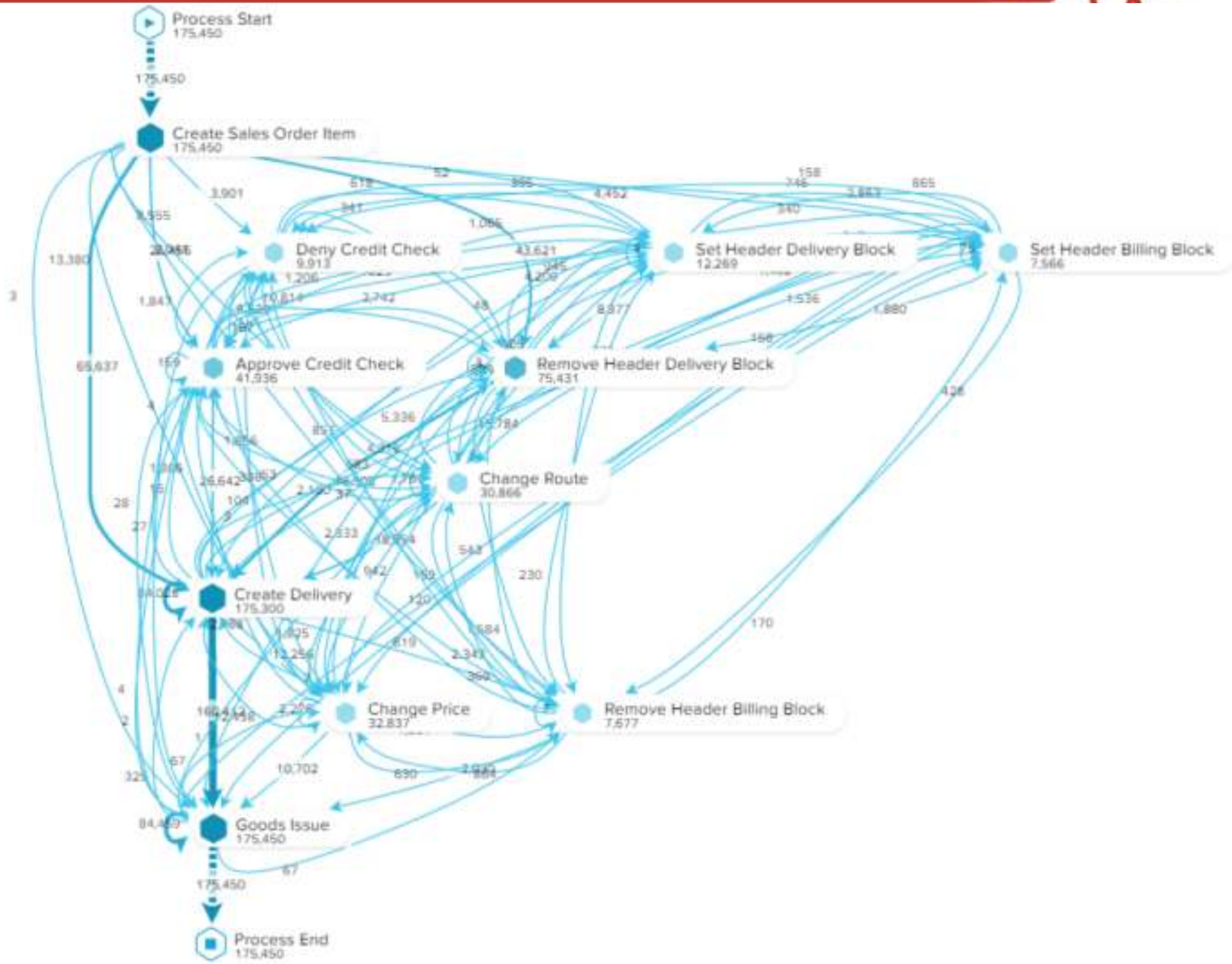
Complex business processes underpin supply chain operations





Wassick, J. (2021). Digital Supply Chain. *EWO.*

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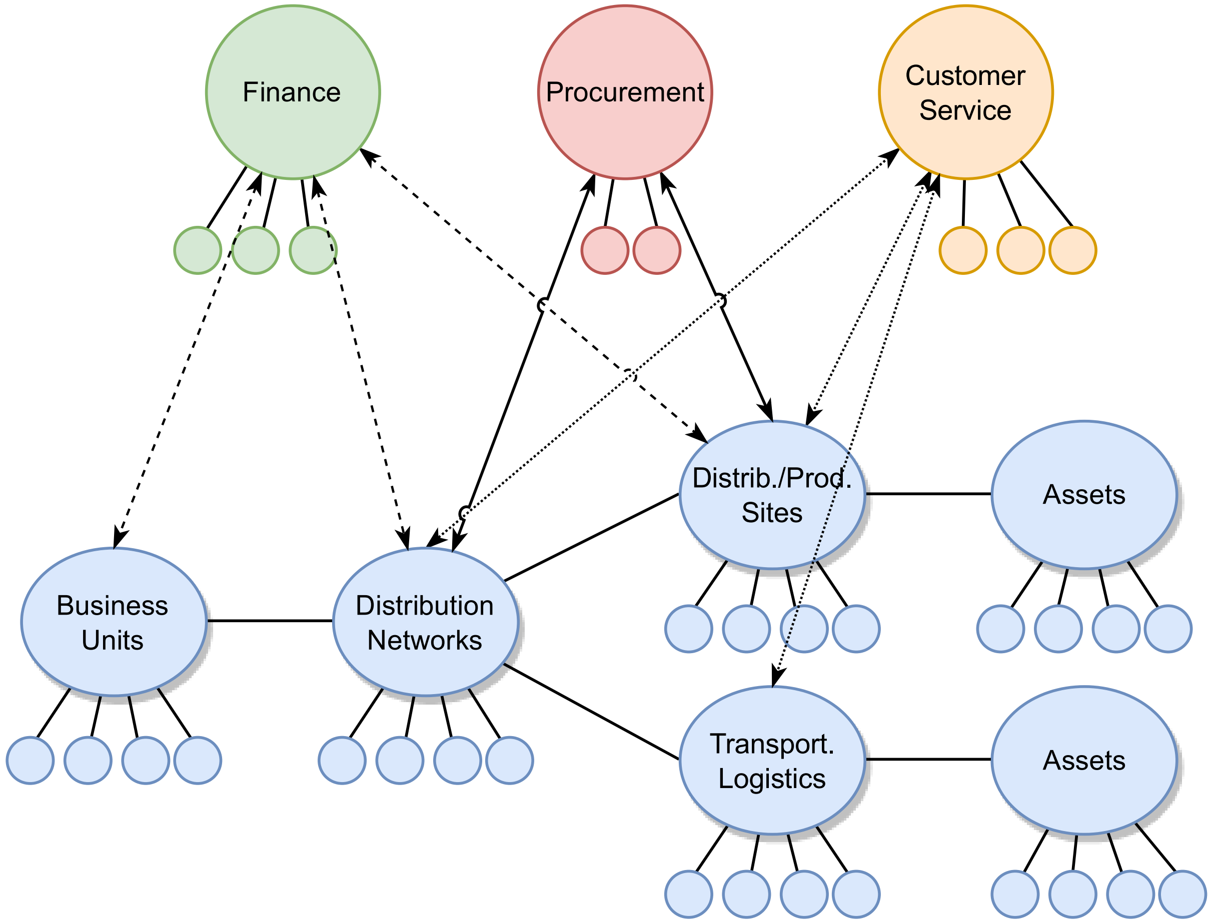
Supply Chains are a network of networks

Nodes:
decision-makers,
functional departments,
business units
whole enterprises



Attributes:
scope,
span of control,
geographic distribution,
decision time frame.

Widespread, daily disruptions

CAPD

- **Supplier**
  - Bankruptcy
  - Force Majeure
- **Corporation**
  - MA&D
  - LER
  - Working Capital
- **Weather**
  - **Hurricane**
  - Flood
  - **Winter storm**
  - Fog
  - Tsunami
  - Extreme Heat
- **Logistics**
  - **River closure**
  - Road closure
  - Rail disruption
  - Lock closure
  - **Port congestion**
  - Boarder congestion
  - **Driver Shortage**
- **Natural Disasters**
  - Earthquake
  - High water
  - Vulcanic eruption
  - Wildfire
  - **Pandemic**
- **Facilities**
  - Strike
  - Power outage
  - I/S outage
  - Evacuation
  - Unplanned outage
  - Short work week
- **Political and Social**
  - Political unrest
  - Embargo
  - Riot
  - Regulations
  - Legislation
  - ESG
    - Circular Economy
    - GHG
- **Customer**
  - Supply / Demand change
  - New Product Launch
  - Customer D[illegible]
- **Competitor**
  - UPE
  - Force Majeure

Human decision performance

Product supply reliability has become a key competitive differentiator

Supply chain resiliency requires orchestration across the enterprise

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Many open questions

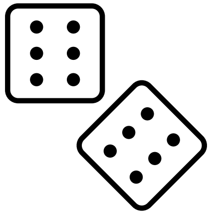
- How to coordinate decision making across multiple orgs, regions, and time scales?
- How to better align strategic, tactical and execution level decisions?
- How to create robust plans that are executable, and then execute as planned?
- How to ensure consistency of assumptions and inputs?

Some Observations of Supply Chain

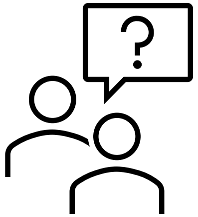
- Complexity reigns
- There are no solutions, only trade-offs
- Supply chain is a team sport
- Human decision-making is ubiquitous
- Employee time may be the scarcest resource

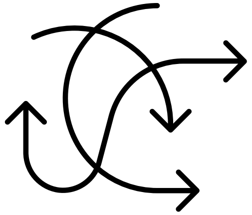
Decisions differ with respect to important dimensions

Operational Decisions — Tactical Decisions — Strategic Decisions



Analytical Decision Making	**Intuitive Decision Making**
Objectivity •Data driven •Reduceable to math	Subjectivity •Divergent interpretations •Competing interests
Uncertainty •Quantifiable probabilities •Inferable outcomes	Ambiguity •Situations lack precedent •Creativity drives actions





Decision domains with dominant dimensions

Operational Decisions — Tactical Decisions — Strategic Decisions

Analytical Decision Making	**Intuitive Decision Making**
Process Control/Automation •Defined by inputs/outputs •Driven by math and logic	ESG Policies •Many stakeholders •Balancing interests
Inventory Management •Demand uncertainty •Safety stock setting	New Product Authorization •Interpreting trends •Defining market niche

Sources of Intelligent Decisions

Analytical Methods
Optimization
Simulation
Statistical Regression
Machine Learning
Artificial Intelligence

Business Process	Workflows
Simple Policies	Spreadsheets
Dashboards	Control Towers

Human Decision Making
Individual human
Standing Team
Ad Hoc Team
Business Rules

Strengths of Analytical Methods and Humans

Analytical Methods	Human Decision Making
Rigorous	Common Sense
Consistent	Intuition
Handle many variables	Creativity
Handle Complexity	Socially Aware
Speed	Socially Engaged

Consequential aspects of Machine and Human Intelligence

Analytical Methods	Human Decision Making
Data hungry	Reluctance to Change
Defined scope	Biases
Reliance on assumptions	Response to incentives
Reliance on human intervention	Affinity for simple policies

Qualities of successful applications of machine intelligence

- User feels their job is improved
- Fits into the user's workflow
- User retains autonomy
- Run time not expected to be 100%
- Can tolerate uncertainty in parameter values
- Useful when results are not “proven optimal”
- Recognize value throughout the organization

Emerging methods for addressing the human element

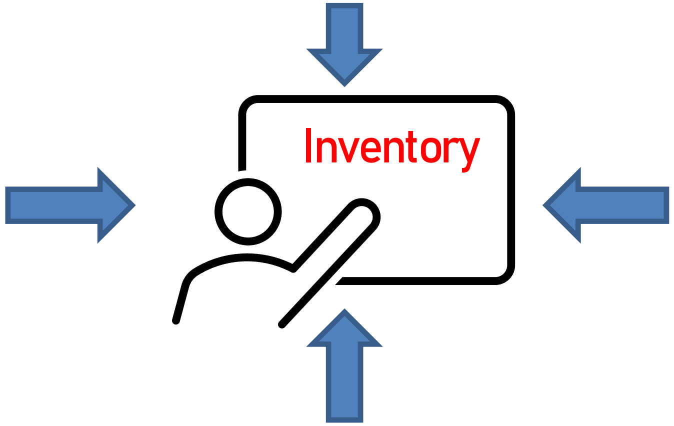
- Analytical methods that incorporate human intuition and judgement
- Design methods for model-based solutions that consider:
  - Human interaction/intervention
  - Operation within a larger workflow
  - Role of human decision-making
- Extracting policies from human decisions
- Use of virtual assistants

Dellermann D, Ebel P, Sollner M, Leimeister JM. Hybrid Intelligence. Bus Inf Syst Eng. 2019; 61(5):637–643

A production planner is a great example of the human element

Competing Objectives

Implicit Incentives



Operational deviates from Strategic

Feasible rather than Optimal

Learning Production Planners' Unknown Objectives via Inverse Optimization

Shivi Dixit[1], Rishabh Gupta[1], Adam Kelloway[2], John Wassick[3], and Qi Zhang[1]

[1] Department of Chemical Engineering and Materials Science, University of Minnesota
[2] Integrated Supply Chain, Dow, Inc. | [3] Department of Chemical Engineering, Carnegie Mellon University

Background and Motivation

Context: Production scheduling at Dow is commonly performed by human planners, who make operational decisions given the current demands and inventory levels.

Challenge: We often do not know exactly what factors the human planners consider in their decision-making.

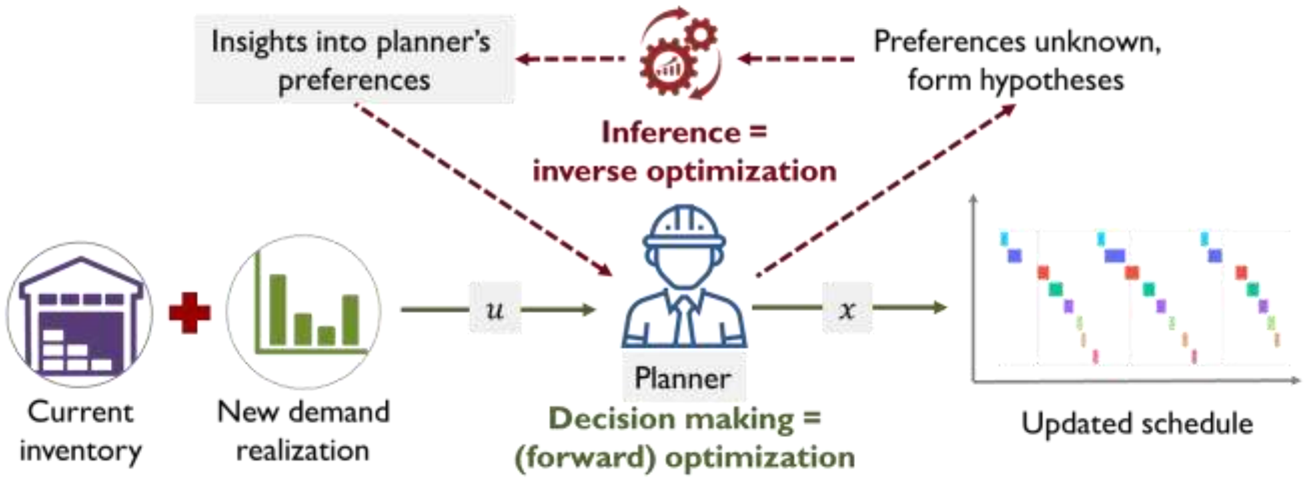
Opportunity: A better understanding of these factors can help answer important questions, such as:

- What decision rules do planners follow & how well do they follow them?
- What inherent preferences do planners have?
- Do these preferences align with the business objectives?
- What distinguishes different planners in their decision-making?

The Inverse Optimization (IO) Approach

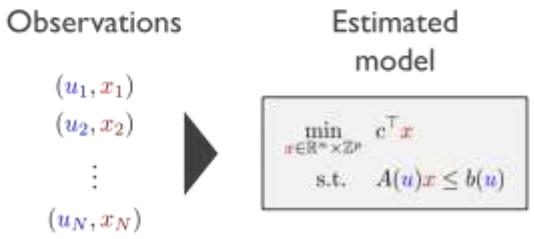
Main assumption: Planners make decisions in some optimal manner.

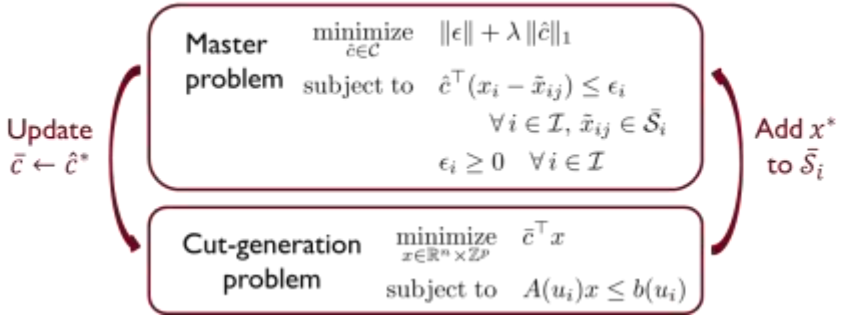
Approach: Assuming the planner solves a mental forward optimization problem (FOP), learn its unknown objective function from observed decisions.



Here, the FOP is an MILP.

We solve the IOP using a cutting-plane method.





The forward problem is formulated as a mixed-integer linear program

Scheduling decisions

- Timing & length campaigns
- Number of cycles
- Cycle lengths

Scheduling constraints

- Inventory and mass balances
- Produce one product at a time
- Product sequence

We hypothesize different decision factors as potential cost terms in the objective function.

- Keep inventory low → inventory holding costs
- Not too low → penalty on inventory level between S_U and S_L
- Not even lower → penalty on inventory level below S_L
- Not too high → penalty on inventory level between E_L and E_U
- Not even higher → penalty on inventory level above E_U
- Minimize plant downtime → penalty on gaps in production
- Be less sensitive to demand surges → penalty on cycle length deviations

Fit of detailed scheduling decisions

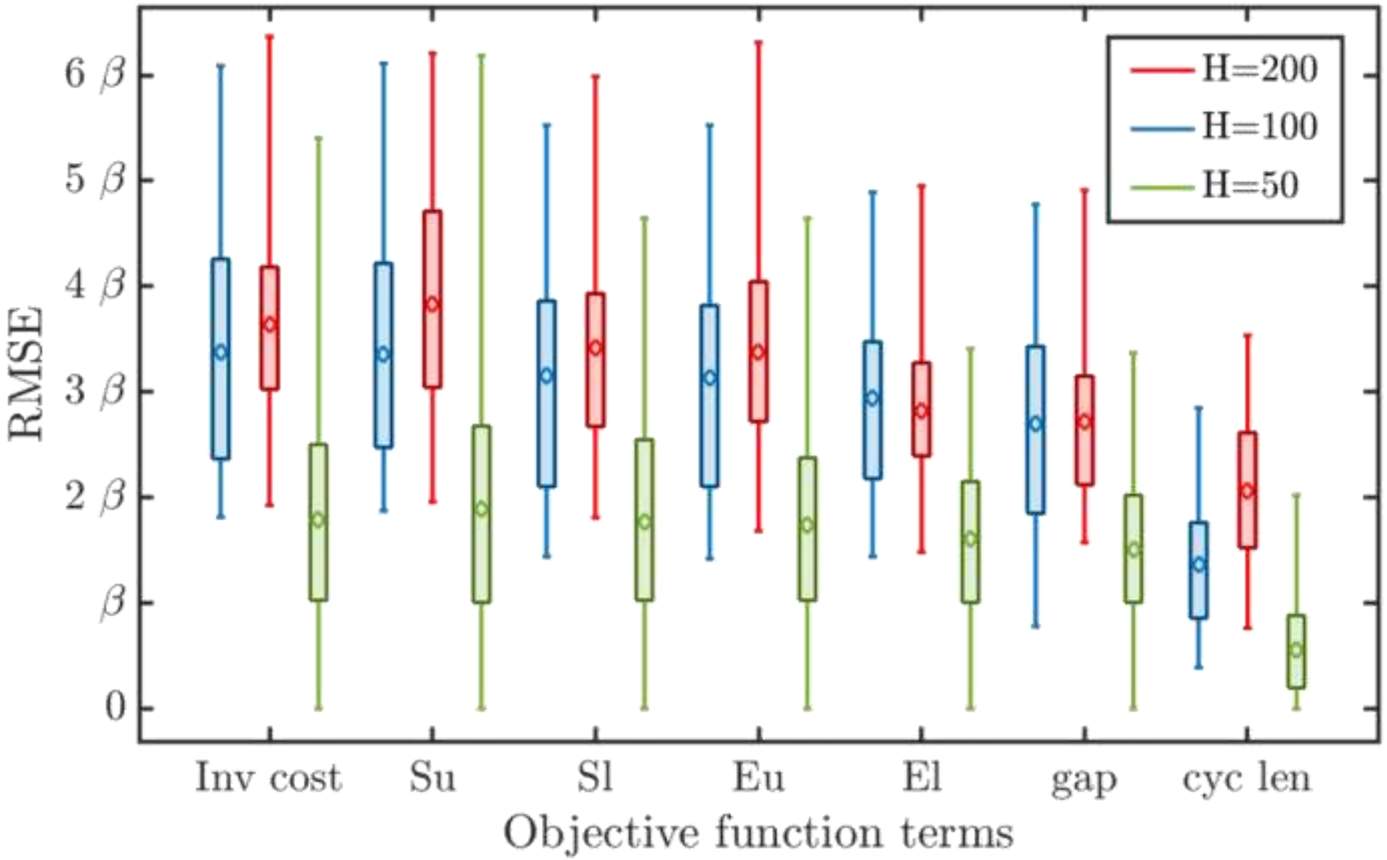
We used 10 observations for training and 10 observations for testing.
Each observation contains the planned scheduling decisions for up to the next 90 days

We evaluate the prediction accuracy for different horizon lengths (one time interval = 10 hours).

Rationale: Planners know that there is recourse in the decisions for later time periods.

Results indicate that the planner may focus more on the earlier time periods.

Accuracy increases with number of cost terms

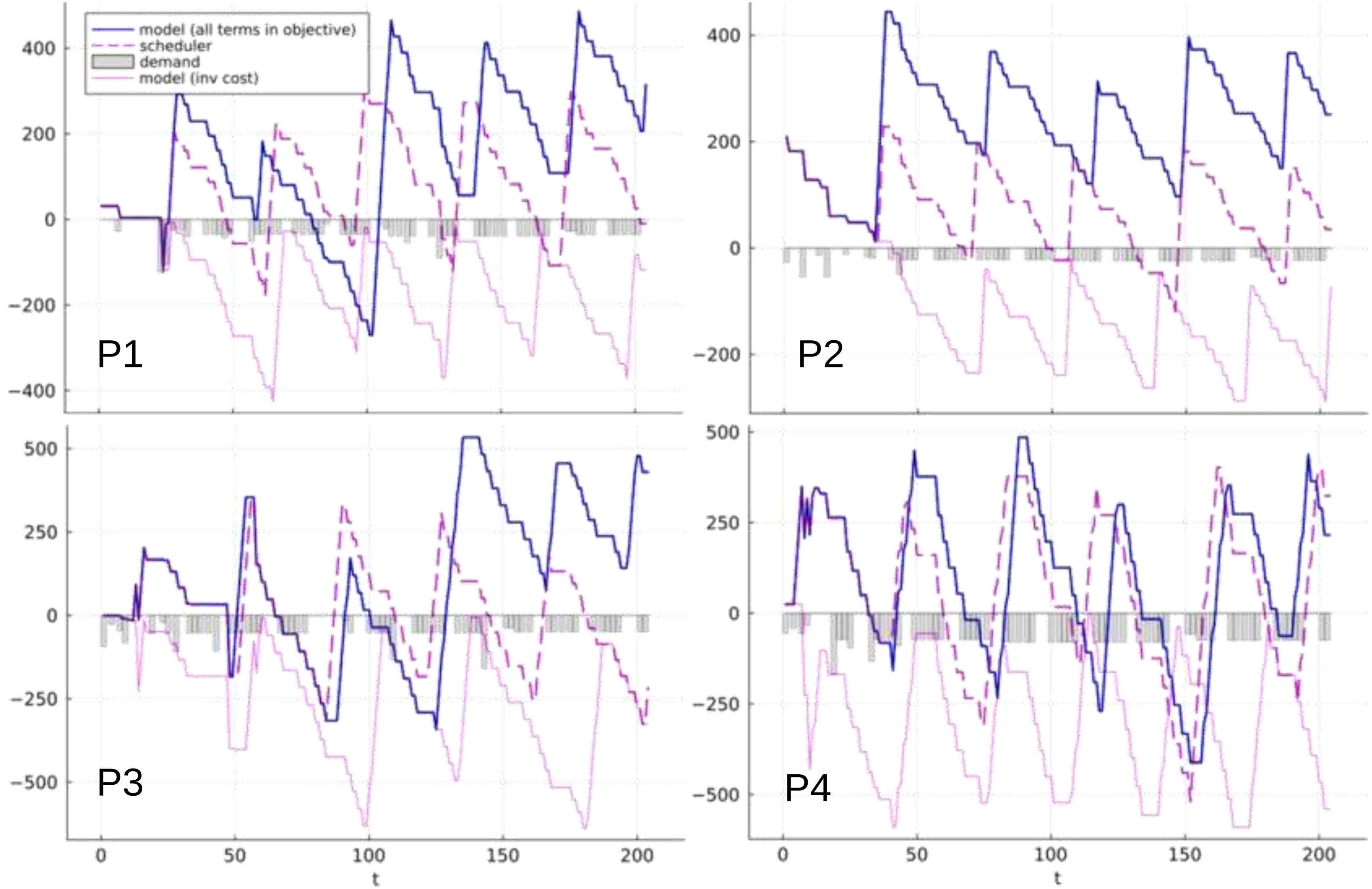


Results from IO are easily interpretable and provide insights into the planner's decision strategy.

Fit of detailed scheduling decisions

Real and predicted inventory profiles for four products in one specific test instance.

Varying prediction accuracy suggests product dependence in the planner's decision-making.



Google Maps provides an inspiring paradigm for a SC virtual assistant

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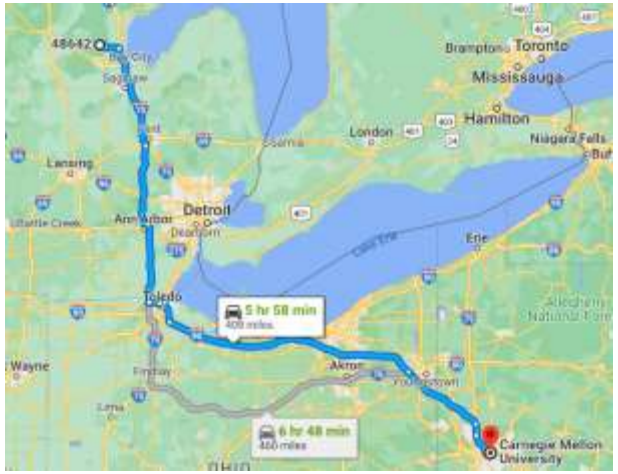
Strategic decision: route selection



https://www.google.com/maps/dir/Midland,+MI+48642/Carnegie+Mellon+University

Agility: alternative routes suggested in real time from current traffic.

Adaptability: recommended routes derived from traffic history.

Alignment: coordination with other drivers and road construction

Tactical decision: rerouting for traffic

https://trak.in/tags/business/2016/04/14/google-maps-navigation-traffic-alerts/

Operational decision: driving maneuvers

https://www.geowebguru.com/2017/07/01/relevance-of-web-mapping-applications/

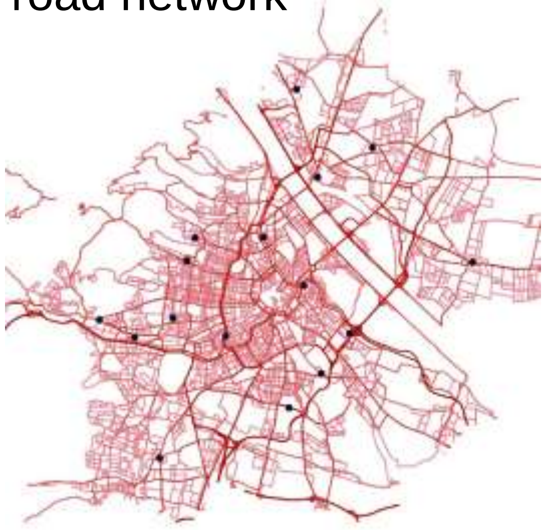
- *User feels their job is improved*
- *Fits into the user's workflow*
- *User retains autonomy*
- *Useful when results are not "proven optimal"*

Google Maps are a Cyber Physical System

GPS data gathered from smart phones and drivers providing crowd source information

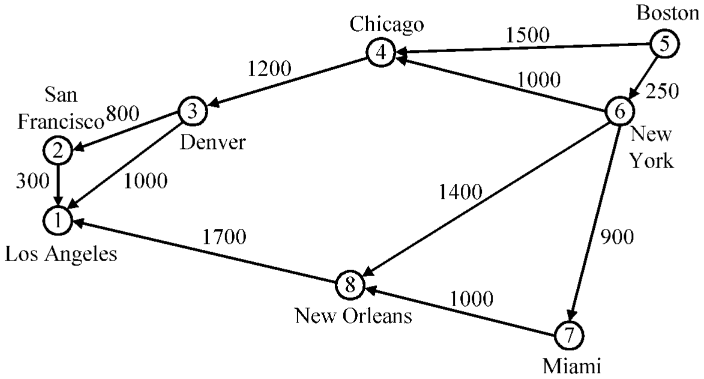
https://www.charlottestories.com/charlottes-first-toll-road-will-generate-half-much-income-initially-projected/

This data is used in a digital twin to provide the current state of the road network



European Journal of Operational Research 219(3):611-621

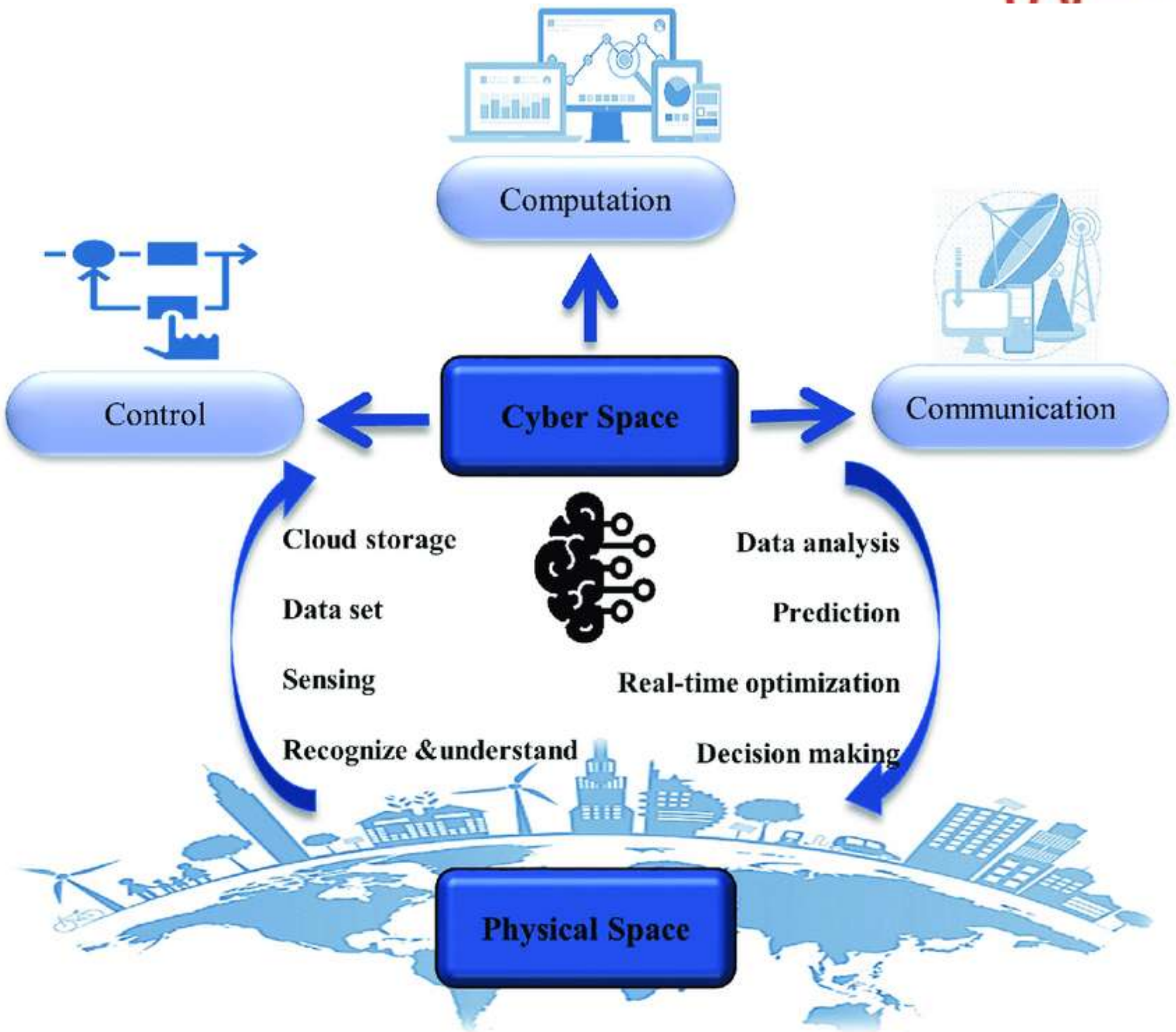
Optimization models find the fastest route; AI recognizes traffic jams to recommend rerouting



https://academyera.com/single-source-shortest-path

Supply chains can be viewed as a cyber-physical system

- Integrate devices, computation, people
- Interoperable to exchange information
- Modular for flexibility and responsiveness
- Autonomous to learn and adapt
- Decentralized to be resilient
- Cooperative to achieve organization goals



https://www.researchgate.net/publication/346524305_Robust_optimal_design_of_FOPID_controller_for_five_bar_linkage_robot_in_a_Cyber-Physical_System_A_new_simulation-optimization_approach/figures?lo=1

Napoleone A, Macchi M, Pozzetti A. A review on the characteristics of cyber-physical systems for the future smart factories. J Manuf Syst. 2020;54:305-335

Supply chains can be viewed as a cyber-physical system

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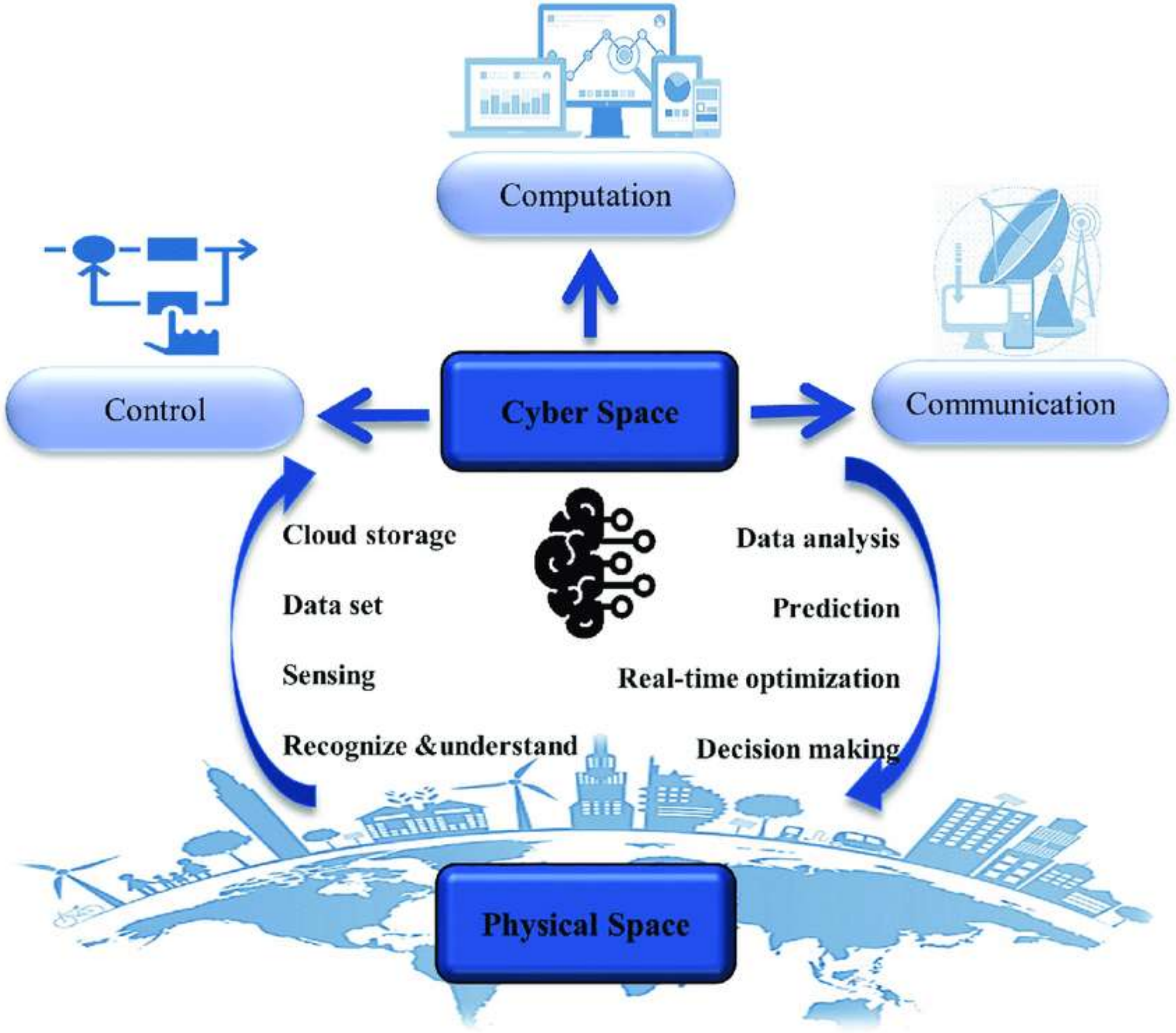
Cyberphysical systems (CPS) are engineered systems that link sensing, computation, and control to the physical world.

If orchestrated correctly, the economic and societal potential of CPS will transform broad domains such as transportation, critical infrastructure monitoring, healthcare, defense systems, manufacturing, smart buildings, and citywide energy optimization.

https://engineering.cmu.edu/research/cyberphysical-systems.html

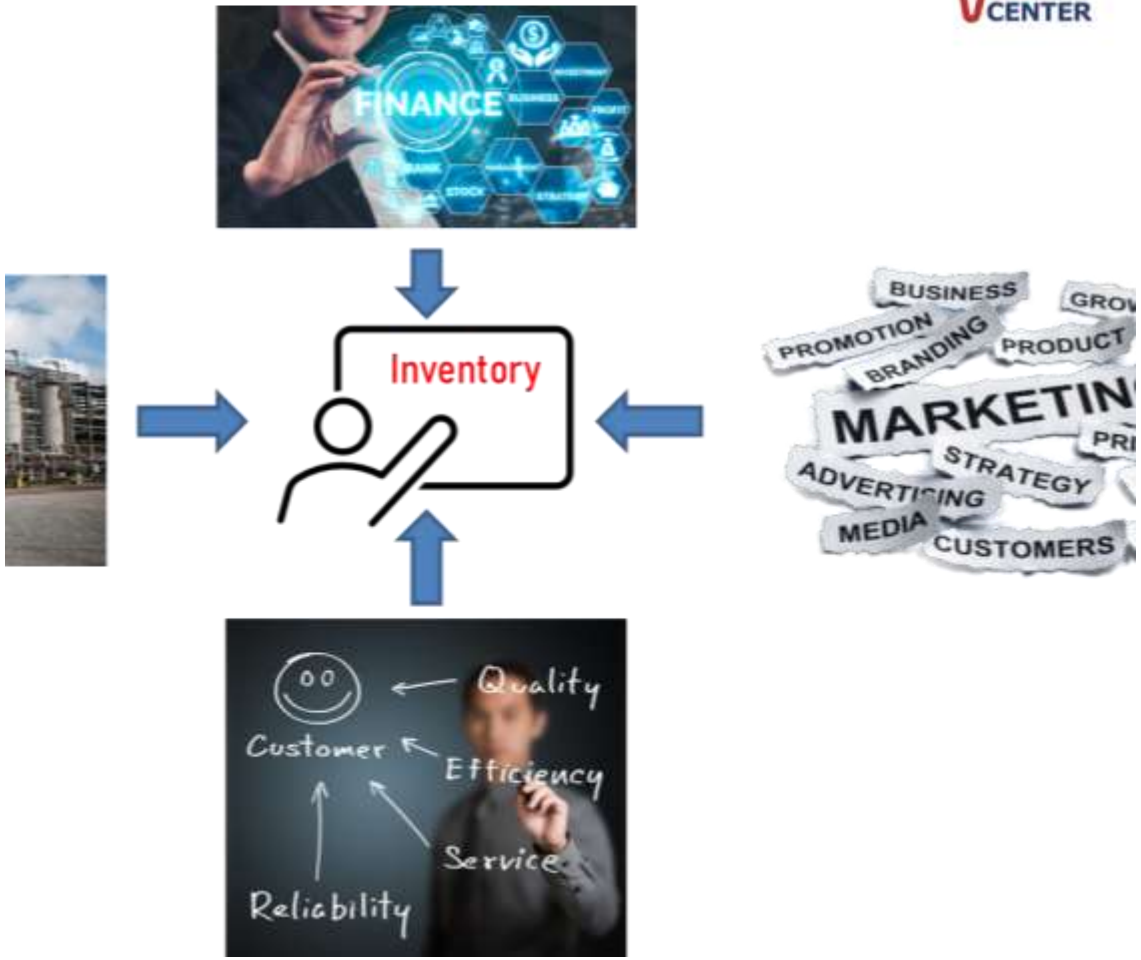


https://www.researchgate.net/publication/346524305_Robust_optimal_design_of_FOPID_controller_for_five_bar_linkage_robot_in_a_Cyber-Physical_System_A_new_simulation-optimization_approach/figures?lo=1

Multi-agent networks are an excellent paradigm for enterprise solutions

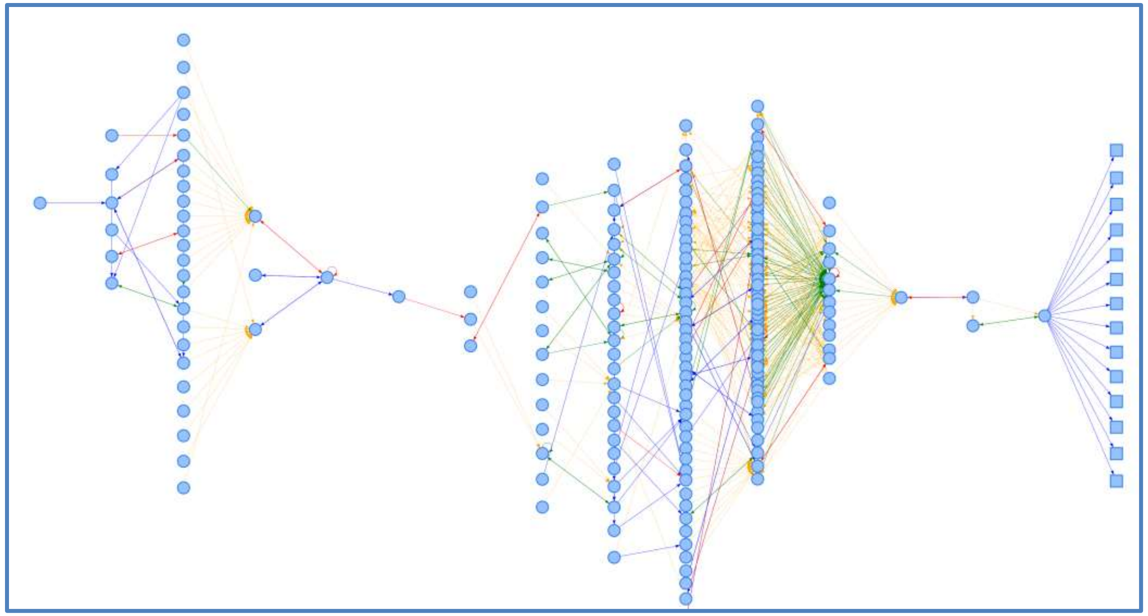
“A collection of multiple decision-making agents which interact in a shared environment to achieve common or conflicting goals”

- Advantages of distributed decision-making
  - Helps to provide resilience
  - Large problems become tractable in pieces
  - More agile than hierarchical methods
  - Human or artificial agents are accommodated
  - They can reflect organizational roles
  - Agent connections are flexible and dynamic to create solutions as needs arise
  - Commercial offerings deployed as agents



Dorri A, Kanhere SS, Jurdak R. Multi-Agent Systems: A Survey. IEEE Access. 2018;6:28573-28593. doi:10.1109/ACCESS.2018.2831228

Knowledge graphs are a great foundation for a digital supply chain



- Naturally capture the nature of supply chain networks
- Model the relationship between objects
- Objects and their relationships have attributes
- Powerful graph analytics are available
- Can be easily extended as new information becomes available

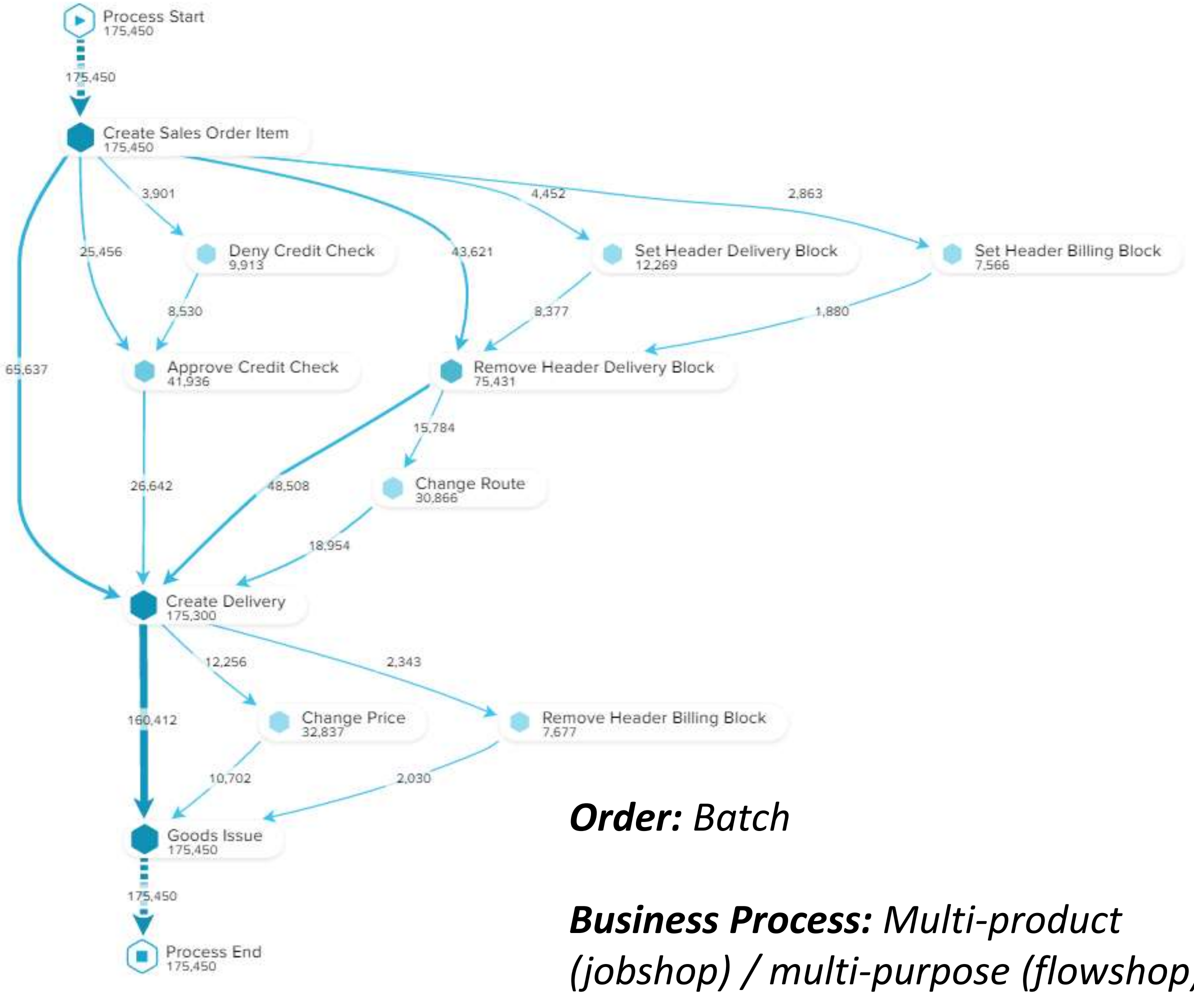
Integrated Optimization and Simulation of Extended Supply Chain Business Processes

Hector D. Perez

Advised by Ignacio E. Grossmann

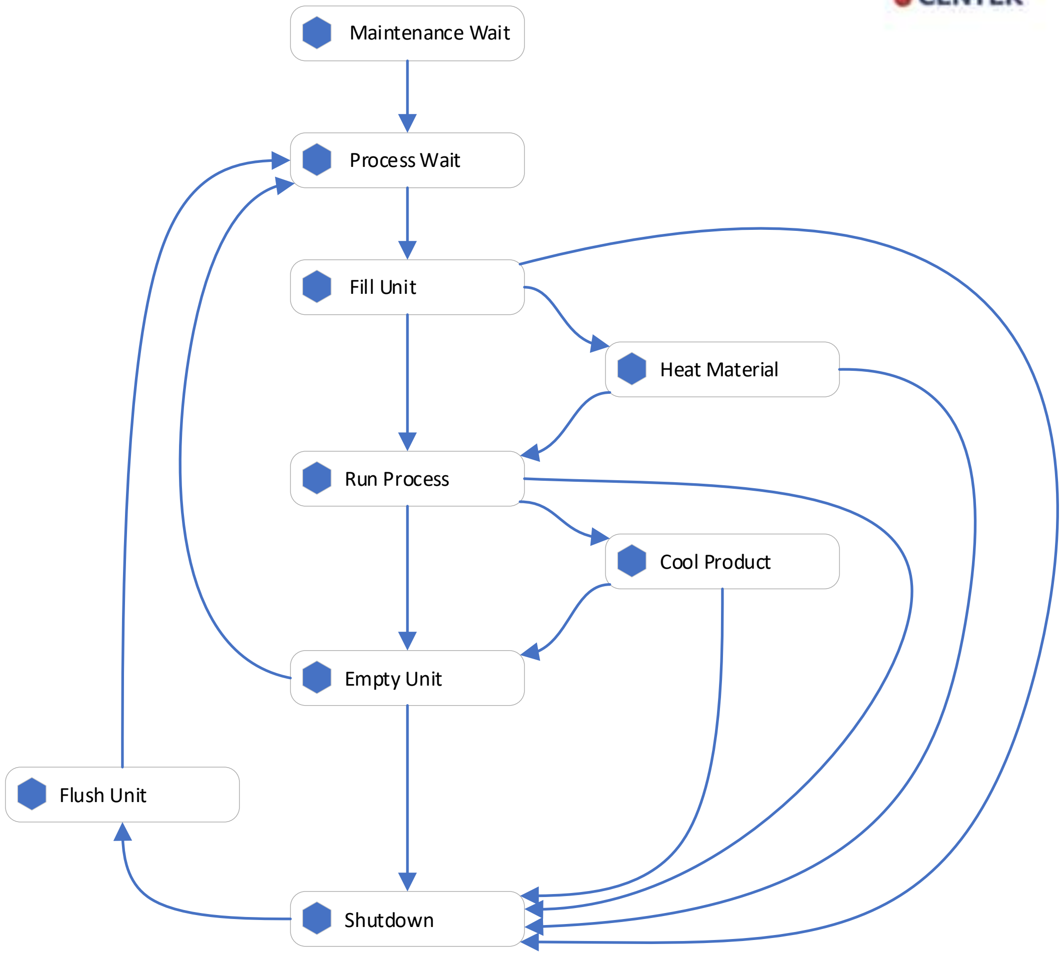
Ph. D. Proposal: December 11th, 2020

Business transactions have many features of chemical batch processing



Order: *Batch*

Business Process: *Multi-product (jobshop) / multi-purpose (flowshop) batch plant*



Wassick, J. (2016). Supply Chain Automation. *EWO.*

Integrated framework has been built using Julia Language

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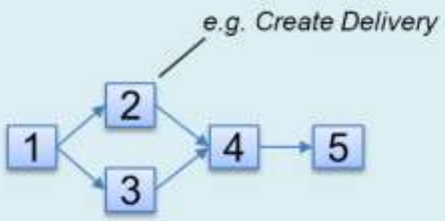
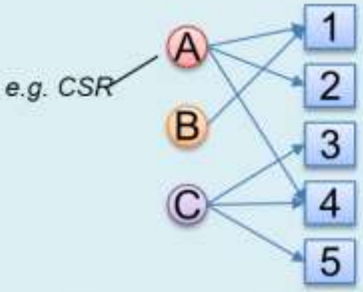
Business Process Module

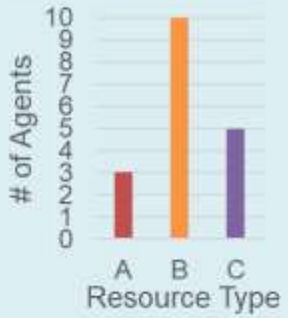
Task Graph



Resource Assignments



Resource Capacities



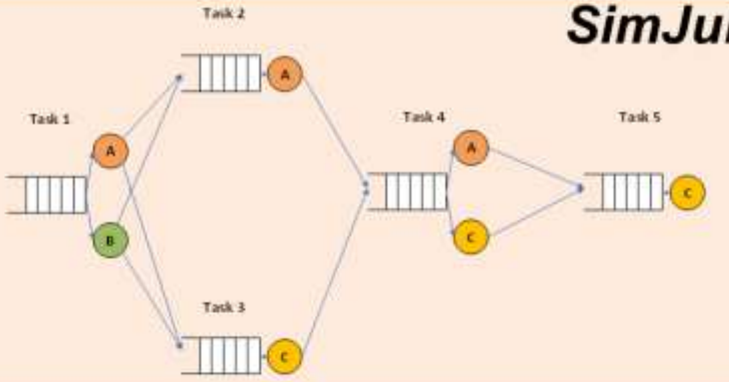
Processing Time Distributions: e.g., N(μ, σ)

	A	B	C
1	μ, σ	μ, σ	
2	μ, σ		
3			μ, σ
4	μ, σ		μ, σ
5			μ, σ

LightGraphs

Discrete Event Simulation Module

SimJulia



Optimization Module

Math Programming

- General Precedence
- State-Task Network
- Resource-Task Network

Heuristics

- Greedy

JUMP

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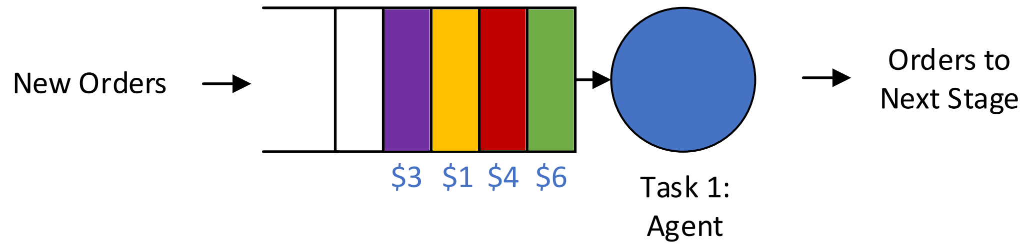
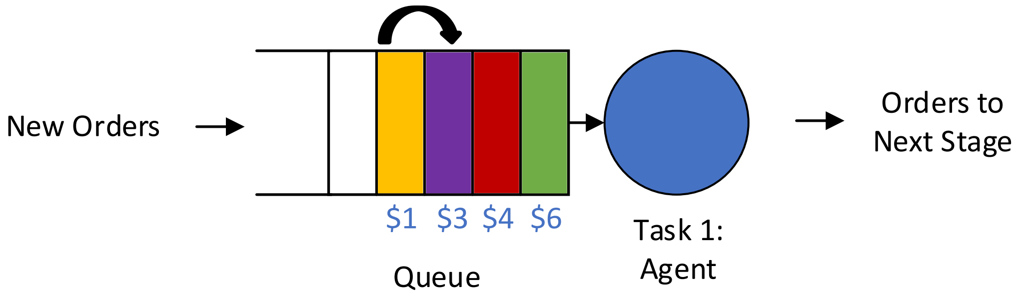
Two benchmarks to compare the models against

- First-in-first-out queueing network (un-optimized system)



- Greedy heuristic
  - Prioritize by order revenue
  - Select agent that can finish the transaction the soonest
    - Availability
    - Mean processing time



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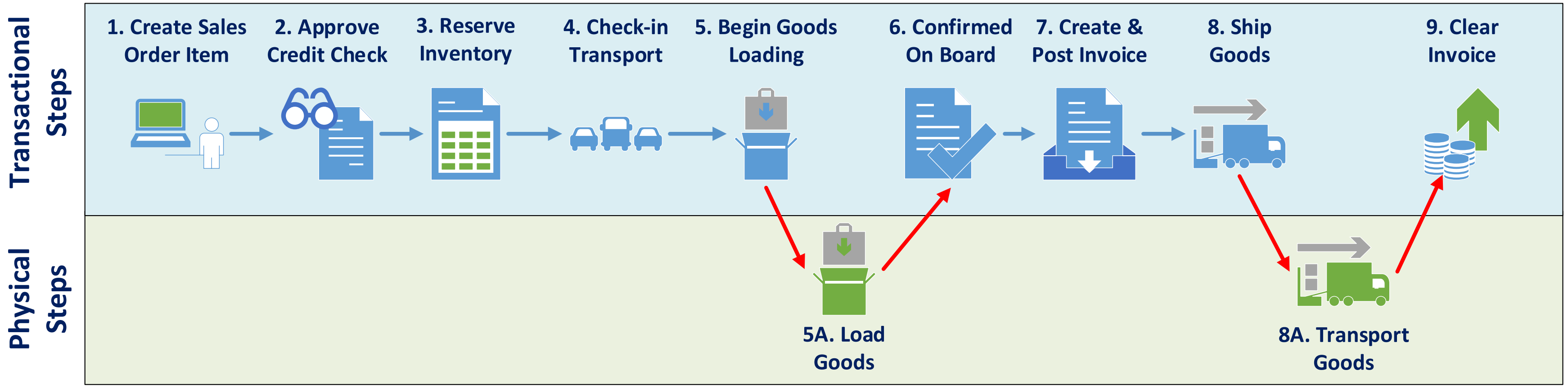
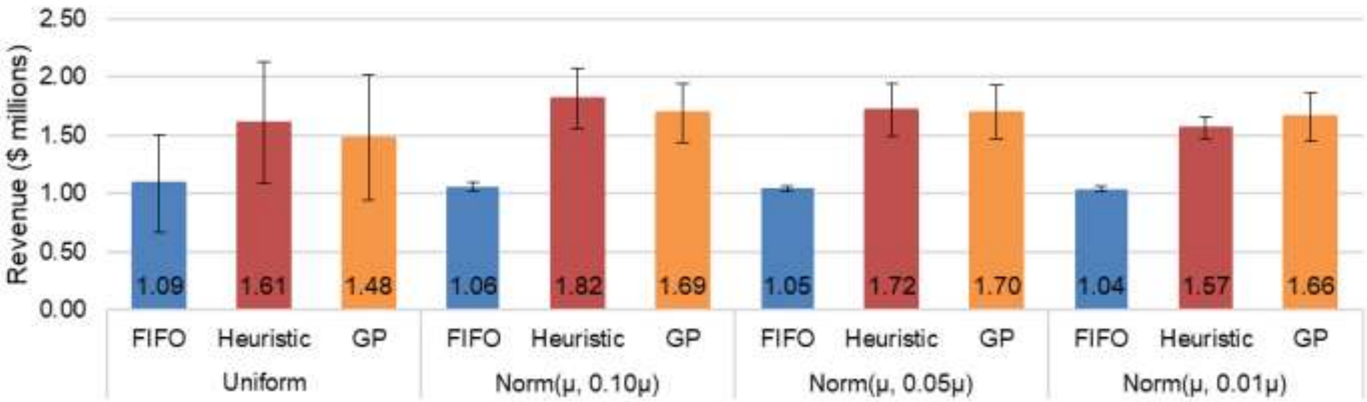
Optimization-simulation improves stochastic system performance



- 10 orders
- Random processing times
- Horizon: 50 h
- Time Limit: 10 min
- MIP Gap: ≤ 5%
- 100 simulations
- Optimize 1x/h



Step	Processing Time	Agents
Transactional	*15 - 30 min*	1
Loading	*1 - 2h*	1
Transportation	*8 - 24h*	3

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