NORTHEASTERN UNIVERSITY

School of Engineering

MECHANICAL & INDUSTRIAL ENGINEERING DEPARTMENT

IE7200 Supply Chain Engineering

2nd Partial Exam Project

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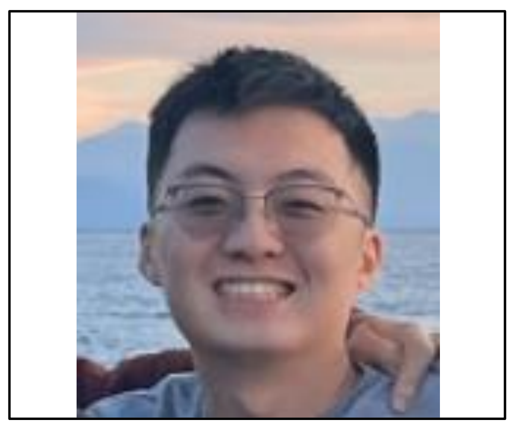

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I. Introduction to Supply Chain Management

Supply chain management (SCM) is a comprehensive approach to managing the flow of goods, information, and finances across the entire supply chain, from raw material sourcing to the delivery of finished products to end customers. It involves a series of interconnected activities and processes aimed at maximizing efficiency, reducing costs, and meeting customer demands effectively.

Here's a more elaborative breakdown of key components and processes within supply chain management:

1. **Planning and Forecasting**: SCM starts with demand forecasting and planning to anticipate customer needs and plan production and inventory levels accordingly. This involves analyzing historical data, market trends, and customer feedback to make accurate predictions.
2. **Sourcing and Procurement**: This involves identifying and selecting suppliers, negotiating contracts, and managing relationships to ensure a reliable supply of quality raw materials or components at competitive prices. Strategic sourcing decisions are made based on factors such as cost, quality, lead times, and supplier reliability.
3. **Production and Manufacturing**: Once raw materials are sourced, they undergo manufacturing processes to convert them into finished products. SCM focuses on optimizing production processes, improving productivity, and minimizing waste to meet demand efficiently while maintaining quality standards.
4. **Inventory Management**: Effective inventory management is crucial for balancing supply and demand while minimizing carrying costs and stockouts. SCM involves monitoring inventory levels, forecasting demand, implementing just-in-time (JIT) or lean inventory practices, and optimizing reorder points to ensure the right amount of inventory is available at the right time.
5. **Logistics and Transportation**: SCM encompasses the movement of goods from suppliers to manufacturers, warehouses, distribution centers, retailers, and ultimately, to customers. It involves selecting the best transportation modes, optimizing routes, managing freight costs, and ensuring timely delivery while minimizing transit times and disruptions.
6. **Warehousing and Distribution**: Warehouses and distribution centers play a vital role in storing inventory, fulfilling orders, and managing the flow of goods within the supply chain. SCM focuses on efficient warehouse layout and design, inventory storage, order picking, packing, and shipping processes to streamline operations and reduce costs.
7. **Information Technology and Integration**: Modern SCM relies heavily on technology and digital systems to enable real-time visibility, collaboration, and coordination across the supply chain. This includes the use of enterprise resource planning (ERP) systems, supply chain management software, electronic data interchange (EDI), and advanced analytics to track inventory, monitor performance, and optimize processes.
8. **Risk Management and Resilience**: SCM involves identifying and mitigating risks such as supply chain disruptions, supplier failures, natural disasters, geopolitical instability, and demand fluctuations. Strategies for risk management include diversifying suppliers, implementing contingency plans, building resilience, and leveraging data analytics to identify potential disruptions proactively.
9. **Sustainability and Ethical Practices**: Sustainable supply chain management focuses on reducing environmental impact, promoting ethical sourcing practices, and ensuring social responsibility throughout the supply chain. This includes initiatives to reduce carbon emissions, minimize waste, improve working conditions, and support fair labor practices.

Overall, effective supply chain management requires collaboration, communication, and coordination among various stakeholders, including suppliers, manufacturers, distributors, logistics providers, and customers, to optimize the flow of goods and information and deliver value to end users while maintaining a competitive edge in the marketplace.

II. Introduction to Facility Location

Supply chain network optimization and simulation using tools like anyLogistix involve a process of analyzing, designing, and managing the flow of goods, information, and resources across the entire supply chain. This process is aimed at maximizing efficiency and effectiveness, reducing costs, and improving customer satisfaction. Here's a brief overview of how anyLogistix can be used for supply chain network optimization and simulation:

1. <u>Data Collection and Analysis:</u> Gathering accurate and comprehensive data about the supply chain, including inventory levels, demand forecasts, transportation costs, manufacturing capacities, lead times, and more, is crucial for creating an accurate model of the supply chain.

2. <u>Building a Supply Chain Model:</u> A digital supply chain model is created using software such as anyLogistix, which includes suppliers, manufacturing facilities, distribution centers, and retail outlets.

3. <u>Optimization:</u> The purpose of the model is to determine the most effective and economical methods for supply chain management. Optimization can concentrate on different areas, such as cost reduction, lead time minimization, inventory level optimization, or service level improvement.

4. <u>Simulation:</u> Simulation is a critical part of testing how the supply chain will perform under different scenarios. This can include stress-testing the supply chain against potential disruptions, changes in demand, or variations in supply. Simulation helps in understanding the impacts of different decisions and identifying potential bottlenecks or vulnerabilities.

5. <u>Scenario Analysis:</u> Different scenarios are analyzed to understand the potential outcomes of various decisions, such as supplier selection, transportation modes, inventory policies, or expansion plans.

6. <u>Implementation and Continuous Improvement:</u> The optimization and simulation provide valuable insights that can be used to make informed decisions regarding the supply chain. Continuous improvement is an essential aspect of this process, where the supply chain model is updated regularly with new data and re-optimized to adapt to changing business environments and market conditions.

Using a tool like anyLogistix for supply chain network optimization and simulation provides a powerful platform for making data-driven decisions. It enables businesses to visualize their supply chain, predict the impacts of different strategies, and optimize their operations for better efficiency, resilience, and competitiveness.

III. Description of the Proposed Model

1. <u>Product:</u>

For our Supply chain model, we have chosen Semiconductors as our product, and below is the table for its cost. There are several reasons for choosing semiconductors :

1. **<u>Manufacturing Process:</u>** Semiconductors are produced in specialized fabrication plants known as fabs. The manufacturing process is a complex one, requiring advanced technology and expertise in intricate steps such as lithography, etching, doping, and packaging.

2. **<u>Global Supply Chain:</u>** The semiconductor industry boasts a complex global supply chain that entails multiple entities, such as raw material suppliers, equipment manufacturers, fabrication facilities, assembly and testing plants, and distributors. These entities operate across multiple borders, relying on interdependencies and collaborations to ensure seamless production and efficient distribution.

3. **<u>Electronic Devices:</u>** Semiconductors are the essential building blocks of electronic devices. They are made of materials like silicon and are used to create integrated circuits (ICs) which form the basis of electronic circuits. These ICs are then utilized in a wide range of products such as smartphones, computers, televisions, medical devices, and more.

4. **<u>Interconnectivity:</u>** Semiconductors allow for interconnecting devices and systems, driving the development of IoT, where everyday objects connect to the internet for data exchange and automation.

5. **<u>Automotive Industry:</u>** The automotive industry heavily depends on semiconductors for advanced features such as infotainment systems, driver assistance systems, and electric vehicle components. The increasing demand for electric vehicles (EVs) and autonomous driving technologies further highlights the significance of semiconductors in this sector.

6. **<u>Industrial Applications:</u>** Semiconductors are utilized in various industrial processes, such as industrial automation, robotics, manufacturing equipment, and control systems, to enhance efficiency, precision, and connectivity.

7. **<u>Supply Chain Disruptions:</u>** The semiconductor industry is vulnerable to supply chain interruptions caused by natural disasters, geopolitical tensions, and market fluctuations. These interruptions can result in shortages that affect the production of electronic devices, causing a ripple effect across various industries.

8. **<u>Technological Innovation:</u>** Advancements in semiconductor technology drive innovation, enabling higher performance, efficiency, and new functionalities in electronic devices. Emerging technologies such as AI, AR, and 5G networks rely on semiconductor components for implementation.

#	Name	Unit	Selling Price	Cost	Currency
	filter	filter	filter	filter	filter
1	Semiconductor	m^3	2,000	800	USD

Figure 1: Product Details with Cost and Selling Price

2. Distribution Centers (DCs):

Following the budget constraints, the vendor is permitted to construct a maximum of three distribution centers. These centers serve as pivotal hubs for efficiently routing goods before reaching the end customers.

1. Geographic Centrality and Accessibility:
   - Cincinnati: Centrally located in the U.S., The city offers great access to most of the country, particularly to eastern and midwestern cities like New York and Chicago. Its central location reduces transportation time and costs to these major markets.
   - Shawnee: Not a typical choice for a major distribution hub but offers strategic advantages in serving the southern region like Houston and Dallas.
   - Barstow: Another hub for the southwestern region that caters to the needs of cities like San Francisco and Phoenix.

2. Transportation Infrastructure:
   - Cincinnati is well-connected through major transportation networks, including highways, railroads, and air transport, which is crucial for efficient distribution.
   - Shawnee and Barstow, though smaller, might have access to key regional transport routes that are optimal for reaching certain areas.

3. Scalability: Both locations allow for scalable operations. As the demand grows, these distribution centers can expand their operations or act as a model for setting up additional centers in other strategic locations.

4. Cost Efficiency: Operating in cities like Cincinnati, Shawnee and Barstow might offer cost benefits in terms of lower land and operating costs compared to major metropolitan areas, while still maintaining effective distribution capabilities.

5. Risk Diversification: Having two geographically distinct distribution centers helps in diversifying risk. In case of disruptions (like weather events, or logistical challenges) in one area, the other center can help maintain the supply chain's continuity.

6. Regional Market Penetration: Each DC can focus on serving its regional market more effectively; understanding and catering to local demand patterns and distribution challenges.

7. Local Workforce and Resources: All three locations can provide access to local workforce and resources, potentially reducing labor costs and benefiting from local expertise.

In conclusion, the choice of Cincinnati, Shawnee and Barstow as distribution centers is likely based on their geographic advantages, transportation infrastructure, scalability potential, cost efficiency, risk diversification, and ability to effectively penetrate regional markets. This strategic placement ensures comprehensive coverage and efficient distribution to the selected customer base across the U.S.

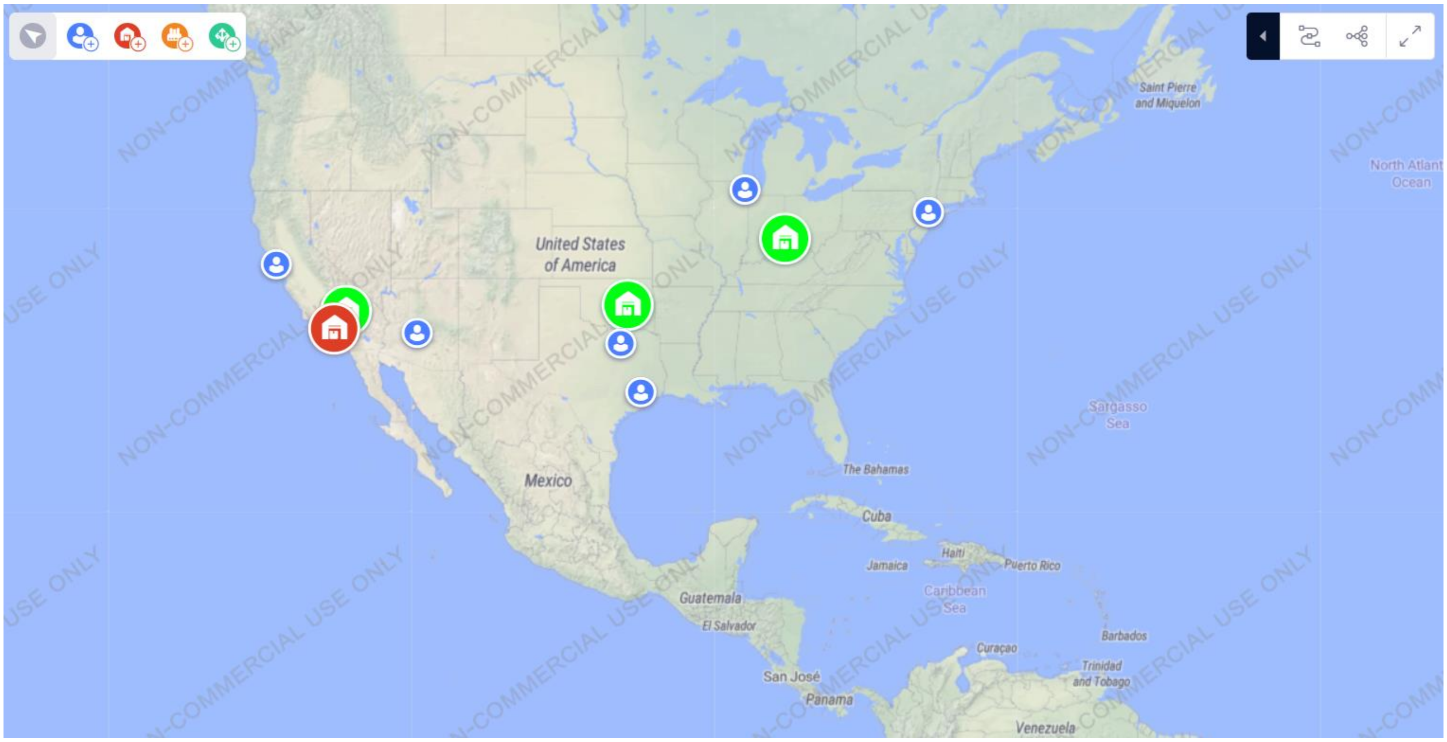

Figure 2: Illustration of Distribution Centers (Green), US Port of Entry(Red) and Customers(Blue)

3. <u>Port Selection:</u>

For the import of Semiconductor goods, Long Beach serves as the designated port, acting as the initial point of entry into the US supply chain. The following reasons are:

1. Busiest Port in the United States: The Port of Long Beach ranks as the second busiest port in the United States in terms of container traffic. Its strategic location on the West Coast makes it a gateway for goods entering the country from the Pacific Rim, including Asia and Oceania.

2. Infrastructure and Capacity: The Port of Long Beach is renowned for its extensive and advanced infrastructure, which comprises modern container terminals equipped with state-of-the-art handling equipment. Its exceptional capacity enables the efficient handling of a vast cargo volume, making it an ideal destination for large container ships.

3. Proximity to Major Markets: Long Beach is strategically located near major population centers and economic hubs within the United States, such as the Greater Los Angeles Area, Southern California, and other areas. This advantageous location provides a significant reduction in transit times and transportation costs for goods destined for these markets, thereby enhancing the efficiency and competitiveness of businesses operating in the region.

4. Intermodal Connectivity: The Port of Long Beach boasts a robust intermodal connectivity that enables effortless transportation of goods to diverse locations across the country. With access to an extensive network of highways, railways, and distribution centers, the port ensures seamless and efficient cargo movement, making it an ideal hub for businesses engaged in trade and logistics.

5. Customs and Border Protection (CBP) Facilities: The port is equipped with state-of-the-art customs and border protection facilities, which play a crucial role in expediting the clearance process for imported goods. In addition to ensuring timely delivery of goods to their final destinations, efficient customs clearance also helps minimize delays and associated costs.

6. Strategic Partnerships and Initiatives: The Port of Long Beach engages in collaborative efforts with industry stakeholders, government agencies, and logistics providers to implement innovative initiatives that are geared towards enhancing operational efficiency, promoting sustainability, and ensuring security throughout the supply chain.

7. Sustainability Efforts: The Port of Long Beach has made a firm commitment to environmental sustainability by implementing a range of initiatives aimed at reducing emissions, conserving energy, and promoting eco-friendly practices. These efforts are in line with the industry's prevailing trends and regulatory requirements, which make the Port an appealing choice for businesses that prioritize environmental consciousness.

4. <u>Transportation:</u>

Below are the different kinds of transportation options we have for our design network,

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
	filter	filter	filter		filter
1	Plane	876	m^3	656	mile/h
2	Rail	400	m^3	40	mile/h
3	class 8	90	m^3	60	mile/h
4	truck	20	m^3	80	mile/h

Figure 3: Types of transportation

For the first scenario, we are using Rail and Class 8 trucks and the second scenario includes Airplanes.

1. <u>Plane (Boeing 747-8F):</u>
   - Provides the fastest transportation option for urgent deliveries or high-value goods where speed is critical to maintaining a competitive advantage or for just-in-time delivery models.
2. <u>Rail:</u>
   - Offers a balance between cost and speed for inland transportation over long distances. It is more environmentally friendly than road transport and is suitable for large shipments that do not require the speed of air transport.
3. <u>Class 8 Truck:</u>
   - Suitable for medium to large shipments over regional distances. They are flexible for point-to-point deliveries and can access areas not served by rail or air.
   - Suitable for medium to large shipments over regional distances. They are flexible for point-to-point deliveries and can access areas not served by rail or air.

5. Facility Expenses:

#	Facility	Expense Type	Value	Currency	Time Unit
	filter	filter	filter	filter	filter
1	DC1	Other costs	30,000	USD	day
2	[US Ports]	Other costs	8,000	USD	day
3	DC2	Other costs	30,000	USD	day
4	DC3	Other costs	30,000	USD	day

#	Facility	Expense Type	Value	Currency	Time Unit
	filter	filter	filter	filter	filter
1	DC2	Other costs	30,000	USD	day
2	[US Ports]	Other costs	8,000	USD	day
3	DC3	Other costs	30,000	USD	day

Figure 4: Cost for the facilities in Scenario 1 and 2 respectively

6. Groups Created:

#	Name	Description	Customers	Sites	Suppliers	Groups
	filter	filter	filter	filter	filter	filter
1	US Ports			Long Beach Port		
2	US, DC			DC3 Shawnee, OK, DC1 Cinci...		
3	US, Customers		Customer San Francisco, CA,...			

Figure 5

Customers of Shawnee, OK:

#	Name	Type	Location	Inclusion Type	Additional Parameters	Icon
	filter	filter	filter	filter		
1	Customer San Francisco, CA	Customer	Customer San Francisco, CA	Exclude	Additional parameters	
2	Customer Phoenix, AZ	Customer	Customer Phoenix, AZ Locat	Exclude	Additional parameters	
3	Customer Chicago, IL	Customer	Customer Chicago, IL Locati	Exclude	Additional parameters	
4	Customer Dallas, TX	Customer	Customer Dallas, TX Locatio	Include	Additional parameters	
5	Customer NYC, NY	Customer	Customer NYC, NY Location	Exclude	Additional parameters	
6	Customer Houston, TX	Customer	Customer Houston, TX Loca	Include	Additional parameters	

Figure 6

Customers of Barstow, CA:

#	Name	Type	Location	Inclusion Type	Additional Parameters	Icon
	filter	filter	filter	filter		
1	Customer San Francisco, CA	Customer	Customer San Francisco, CA	Include	Additional parameters	
2	Customer Phoenix, AZ	Customer	Customer Phoenix, AZ Locat	Include	Additional parameters	
3	Customer Chicago, IL	Customer	Customer Chicago, IL Locati	Exclude	Additional parameters	
4	Customer Dallas, TX	Customer	Customer Dallas, TX Locatio	Exclude	Additional parameters	
5	Customer NYC, NY	Customer	Customer NYC, NY Location	Exclude	Additional parameters	
6	Customer Houston, TX	Customer	Customer Houston, TX Loca	Exclude	Additional parameters	

Figure 7

Customers of Cincinnati, OH:

#	Name	Type	Location	Inclusion Type	Additional Parameters	Icon
	filter	filter	filter	filter		
1	Customer San Francisco, CA	Customer	Customer San Francisco, CA	Exclude	Additional parameters	
2	Customer Phoenix, AZ	Customer	Customer Phoenix, AZ Locat	Exclude	Additional parameters	
3	Customer Dallas, TX	Customer	Customer Dallas, TX Locatio	Exclude	Additional parameters	
4	Customer Houston, TX	Customer	Customer Houston, TX Loca	Exclude	Additional parameters	
5	Customer Chicago, IL	Customer	Customer Chicago, IL Locati	Include	Additional parameters	
6	Customer NYC, NY	Customer	Customer NYC, NY Location	Include	Additional parameters	

Figure 8

IV. Description of the Scenarios to be Analyzed

Green Field Analysis

Customer List:

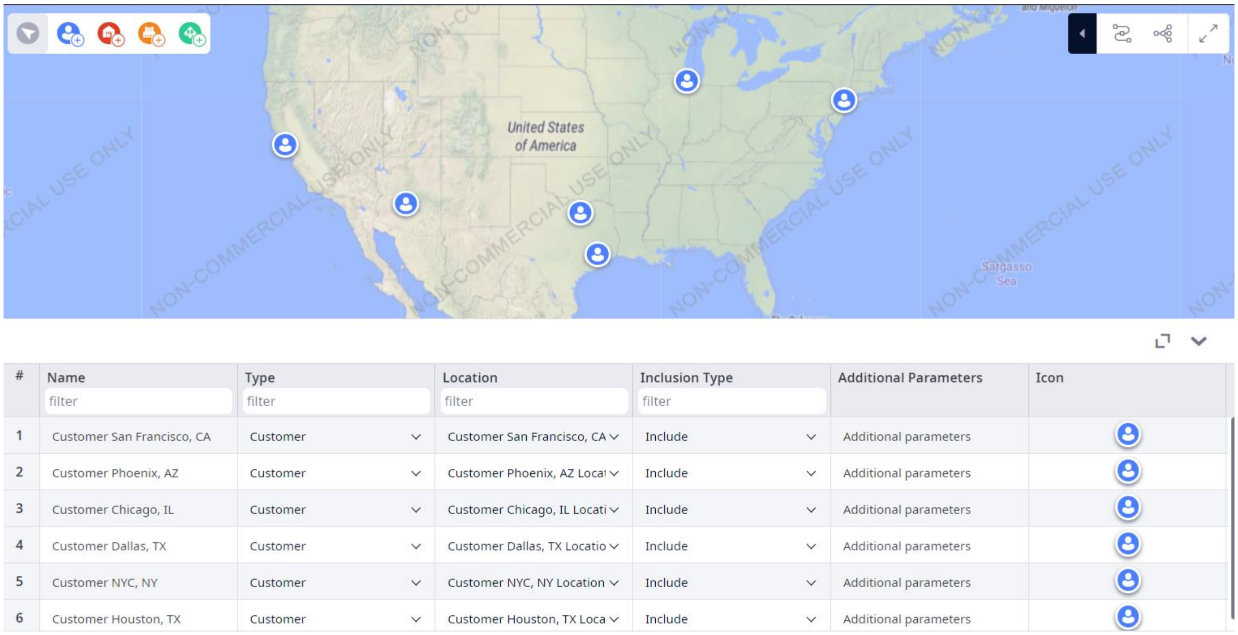

Figure 9: Customer List

As shown in the illustration, we have customers spread out across the United States with demands towards various industries like automotive and electronics.

Customer Distribution:

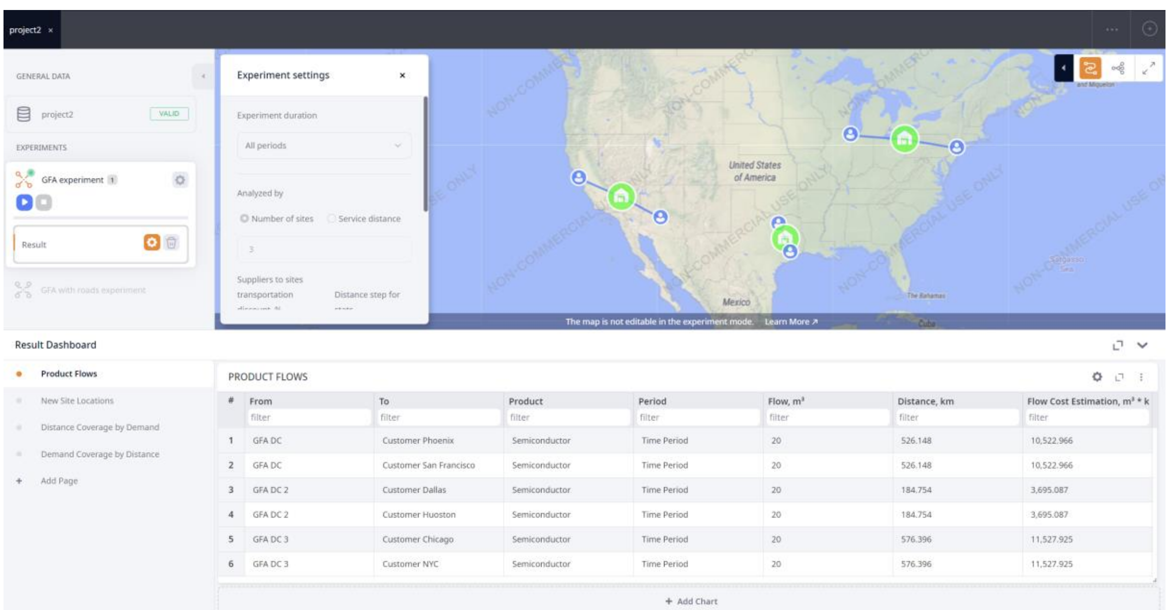

Figure 10: Customer Distribution

Given the allowance for three sites, an optimal allocation for the placement of distribution centers needs to be computed to ensure effective coverage and service to the customer base.

We now convert the green field analysis into a SIM scenario.

V. Analysis of the Scenarios

Scenario 1: Profit ($35 million)

In the first scenario, we include DCs in Cincinnati, Oklahoma and California which easily provide an efficient way of reaching customers.

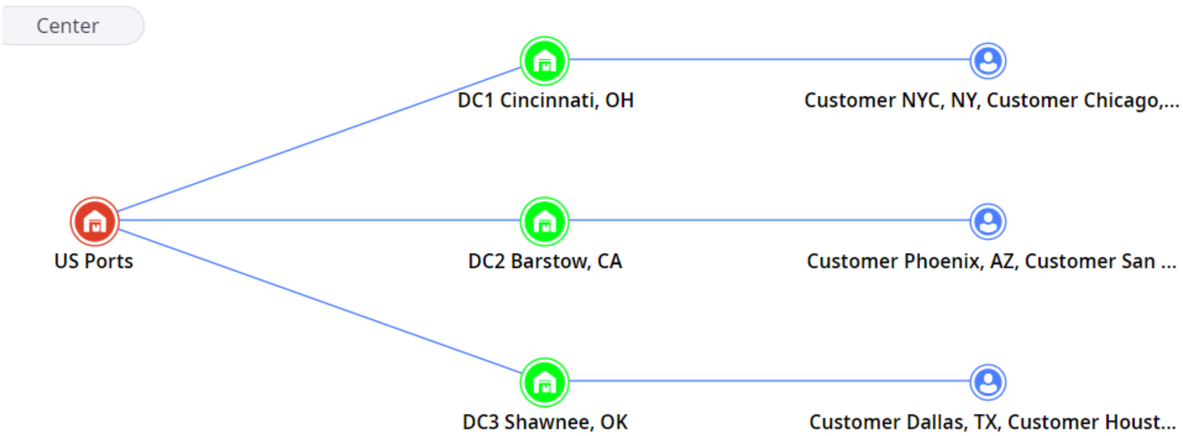

Figure 11: Sourcing Route

Shipping Method:

In this scenario, we are using railways and roadways for transporting goods. It is mostly the easiest way to get goods across the country given its cost.

#	Sources	Destinations	Product	Vehicle Type
	filter	filter	filter	filter
1	[US Ports]	[US, DC]	(All products)	Rail
2	DC1	Selected 2	(All products)	class 8
3	DC2	Selected 2	(All products)	class 8
4	DC3	Selected 2	(All products)	class 8

Figure 12: Shipping Options for Scenario 1

Simulation Result:

Profits of about $35 million are generated with this network design however lead time increases. The simulation result above gives us a better understanding of the network design.

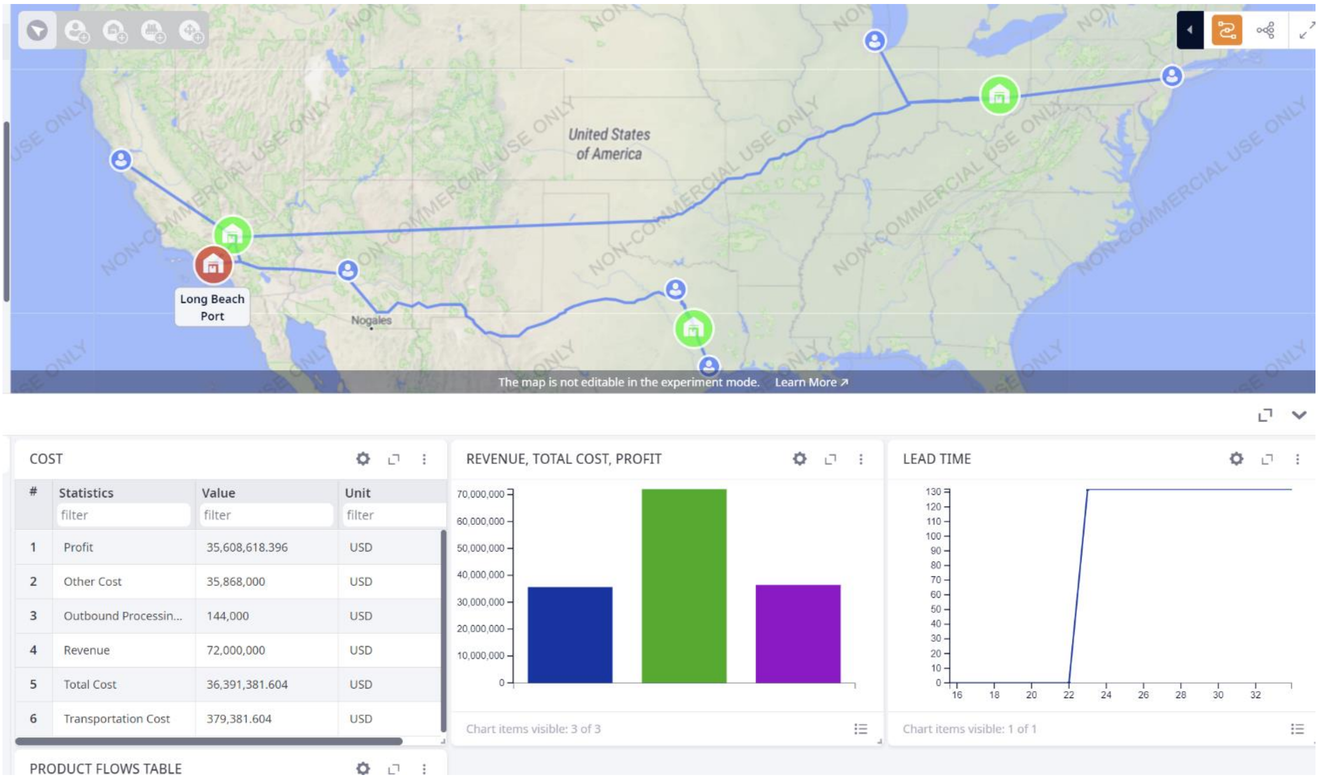

Figure 13: Scenario 1

PRODUCT FLOWS TABLE

#	Product	Destination	Period	Amount
	filter	filter	filter	filter
1	Semiconductor	Customer Phoenix	Time Period	120
2	Semiconductor	Customer San Francisco	Time Period	120
3	Semiconductor	Customer Dallas	Time Period	120
4	Semiconductor	Customer Huoston	Time Period	120
5	Semiconductor	Customer Chicago	Time Period	120
6	Semiconductor	Customer NYC	Time Period	120

Figure 13-2: Product Flow Table

Scenario 2: Profit ($31 Million)

A strategic adjustment has been proposed to address the financial implications of facility expenses and extended lead times experienced by East Coast customers. This adjustment involves the elimination of DC1(Cincinnati, OH) and a modification in the shipping method for Chicago and NYC from Class 8 to air transportation.

Although air transportation usually incurs higher costs compared to railway and Class 8 shipping, we are confident that the removal of DC1(Cincinnati, OH) will offset these expenses. Furthermore, this change will significantly reduce lead times for East Coast customers. We are certain that this strategy will be feasible and cost-effective, and a simulation will validate it.

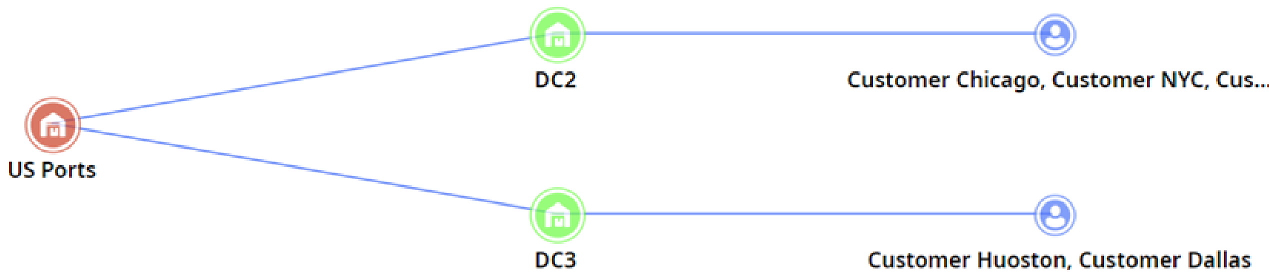

Figure 14: Sourcing Route change after removing DC1(Cincinnati, OH)

Shipping Method:

#	Sources	Destinations	Product	Vehicle Type	Type	Parameters	Priority
	filter	filter	filter	filter	filter		filter
1	[US Ports]	[US, DC]	(All products)	Plane	LTL	Partial delivery	FIFO
2	[US Ports]	Selected 2	(All products)	Plane	LTL	Partial delivery	FIFO
3	DC2 Barstow,CA	Selected 2	(All products)	class 8	LTL	Partial delivery	FIFO
4	DC3 Shawnee,OK	Selected 2	(All products)	class 8	LTL	Partial delivery	FIFO

Figure 15: Using Airplanes for customers in NYC and Chicago

Simulation Result:

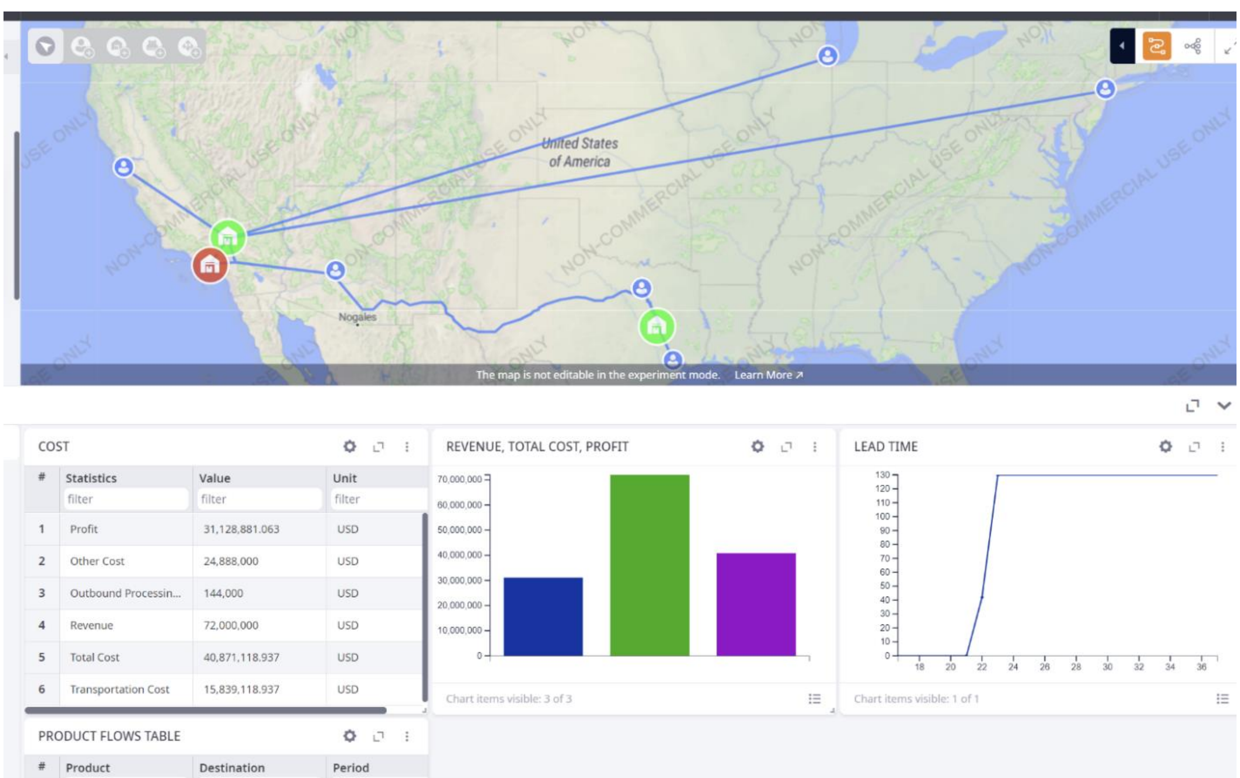

Figure 14: Scenario 2 Simulation Result

Given the substantial negative impact on profitability and minimal improvement in lead times observed in Scenario 2, it is evident that a different strategy is imperative. Strengthening the demand forecasting capabilities for Distribution Center 1 emerges as a viable alternative to enhance operational efficiency and mitigate financial losses.

PRODUCT FLOWS TABLE

#	Product	Destination	Period	Amount
	filter	filter	filter	filter
1	Semiconductor	Customer Phoenix	Time Period	120
2	Semiconductor	Customer San Francisco	Time Period	120
3	Semiconductor	Customer Dallas	Time Period	120
4	Semiconductor	Customer Huoston	Time Period	120
5	Semiconductor	Customer Chicago	Time Period	120
6	Semiconductor	Customer NYC	Time Period	120

Figure 14-2: Product Flow Table

VI. Proposed Recommendations

Strengthening Demand Forecasting for Distribution Center 1

1. **Advanced Forecasting Techniques Implementation:** By utilizing predictive analytics, statistical models, and machine learning algorithms, advanced forecasting methodologies can be deployed to analyze historical sales data, market trends, and customer behavior patterns. This implementation will enable more accurate predictions of future demand for semiconductor products.

2. **Collaborative Demand Planning:** Foster collaborative partnerships with semiconductor suppliers, customers, and key stakeholders to gather insights and intelligence on market demand dynamics, product preferences, and upcoming trends. Engaging in collaborative demand planning facilitates proactive decision-making and ensures alignment with customer requirements.

3. **Data Integration and Automation:** It's crucial to centralize various data sources and implement automation tools and software solutions to streamline processing, analysis, and forecasting tasks. Doing so will significantly enhance accuracy and efficiency, making it imperative to take action immediately.

4. **Continuous Improvement and Learning:** It's crucial that we establish a culture of continuous improvement and learning within Distribution Center 1. We need to encourage ongoing refinement of our forecasting methodologies and processes. Therefore, we must regularly review our forecast accuracy metrics, conduct root cause analysis of forecast errors, and incorporate the learnings to enhance forecasting accuracy over time. It's time to take action and ensure we're working at our best.

5. **Sensitivity Analysis and Risk Management:** To determine the impact of external factors, such as changes in the market, supply chain disruptions, and macroeconomic shifts, on demand forecasts, it is recommended to conduct sensitivity analysis and scenario planning. By doing this, you can develop risk mitigation strategies and contingency plans to address potential uncertainties and minimize their adverse effects on operations.

To enhance overall operational efficiency, it is important to strengthen the demand forecasting capabilities for Distribution Center 1. By doing so, the supply chain can better anticipate and respond to market demand fluctuations, optimize inventory management, and ensure customer satisfaction while mitigating risks. This alternative strategy aligns with the intention to maximize profitability.

VII. References

1. The Semiconductor Supply Chain by Jacob Teer, December 10, 2021, https://storymaps.arcgis.com/stories/1070e9c4aaec4e69ae3317b1d50cffbd

2. The Semiconductor Supply Chain: From Silicon to CPU, by Chris Borges https://www.iar-gwu.org/blog/iar-web/the-semiconductor-supply

VIII. Take Home Problem

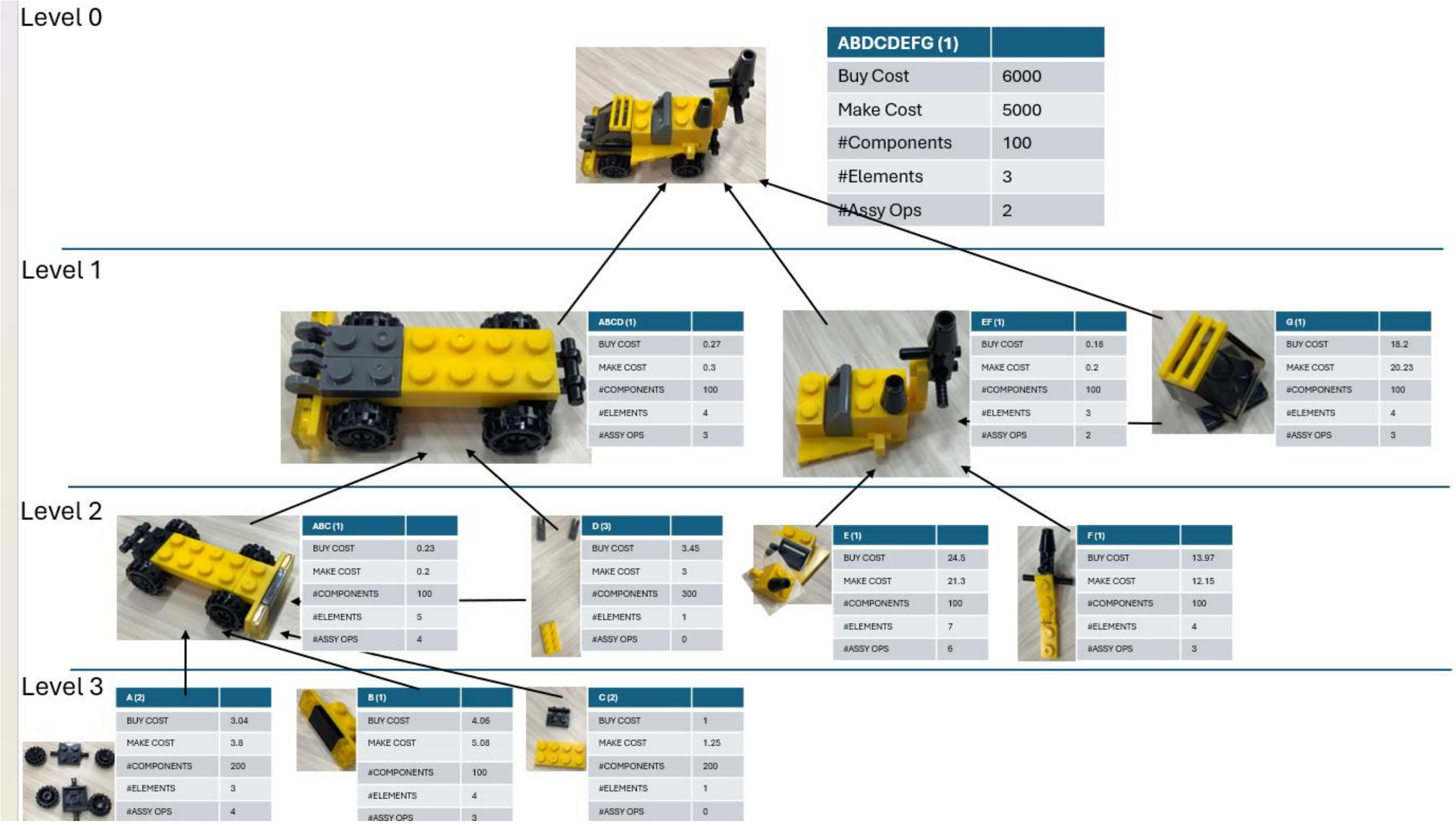

Figure 15: Tree BOM

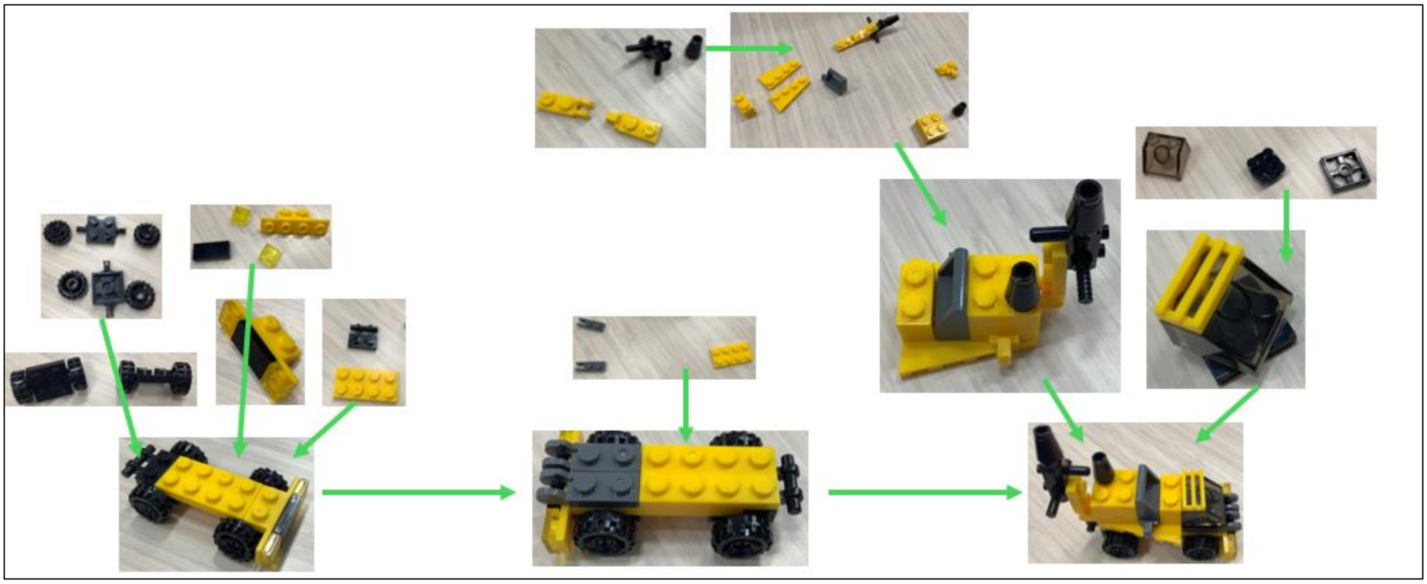

Figure 16: Production Line BOM

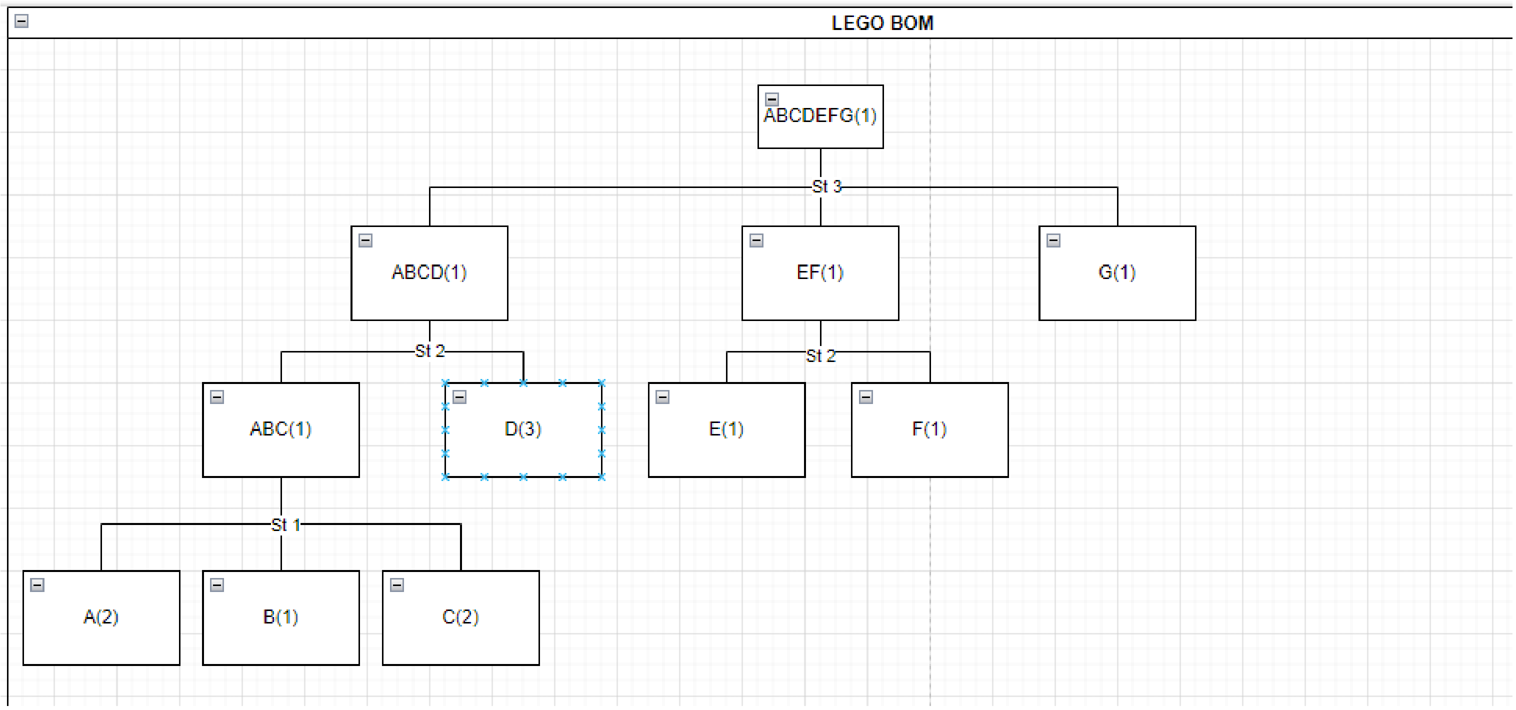

Figure 17: MRP Structure for LEGO

An LP formulation is:

```
MODEL:
      SETS:
            !The preceding commented line is the original code.;
            !TYPES/U, R, T/:M, B, MP, BP, NEED;
            LVL0/ABCDEFG/:M, B, MP, BP, NEED; !1 end-product;
            !MATERIALS/S, W, C/:MM, MB, MMP, MBP;
            LVL1/ABCD, EF, G/:MM, MB, MMP, MBP; !3 total;
            !SUBMATS/H, P, L/:SMM, SMB, SMP, SBP;
            LVL2/ABC, D, E, F/:SMM, SMB, SMP, SBP; !4 total;
            LVL3/A, B, C/:TMM, TMB, TMP, TBP; !3 total, this is the additional line for LVL3 operations;

            !The following lines initialize the component requirements (i.e., X many parts for the next sub-assembly);
            !The bicycle problem had 3 levels and 2 matrices, and we have 4 levels, therefore 3 matrices;
            !REQ(TYPES, MATERIALS): MATREQ;
            REQ(LVL0, LVL1): MATREQ; !first matrix;
            !MREQ(MATERIALS, SUBMATS): SMATREQ;
            MREQ(LVL1, LVL2): SMATREQ; !second matrix;
            2REQ(LVL2, LVL3): SMATREQ2; !third matrix;
      ENDSETS
      DATA:
            NEED  =     100; !Demand level;
            MP    =     122; !LVL0 make price;
            BP    =     60; !LVL0 buy price;
            MMP   =     32    78    42.5; !LVL1 make price;
            MBP   =     20.25 13.5  38.25; !LVL1 buy price;
            SMP   =     46    3     51    27; !LVL2 make price;
            SBP   =     23    3.45  58.65 31.05; !LVL2 buy price;
            TMP   =     8.75  12.5  1.25; !LVL3 make price;
            TBP   =     7     10    1; !LVL3 buy price;
            MATREQ=     1     1     1;
            SMATREQ=    1     3     0     0
                        0     0     1     1
                        0     0     0     0;
            SMATREQ2=   2     1     2
                        0     0     0
                        0     0     0
                        0     0     0;

      ENDDATA
      !MIN = @SUM(TYPES : M * MP + B * BP)
            + @SUM(MATERIALS: MM * MMP + MB * MBP)
            + @SUM(SUBMATS: SMM * SMP + SMB * SBP);
      ! OBJ Function: ;
      MIN = @SUM(LVL0: M * MP + B * BP)
            + @SUM(LVL1: MM * MMP + MB * MBP)
            + @SUM(LVL2: SMM * SMP + SMB * SBP)
            + @SUM(LVL3: TMM * TMP + TMB * TBP);

      !@FOR(TYPES: M + B = NEED);
      @FOR(LVL0: M + B = NEED); !Demand constraint;

      !Material requirement contraints;
      !@FOR(MATERIALS(I): MM(I) + MB(I) =
            @SUM(TYPES(J): M(J) * MATREQ(J, I)));
      @FOR(LVL1(I): MM(I) + MB(I) =
            @SUM(LVL0(J): M(J) * MATREQ(J, I)));
      !@FOR(SUBMATS(I): SMM(I) + SMB(I) =
            @SUM(MATERIALS(J): MM(J) * SMATREQ(J, I)));
      @FOR(LVL2(I): SMM(I) + SMB(I) =
            @SUM(LVL1(J): MM(J) * SMATREQ(J, I)));
      @FOR(LVL3(I): TMM(I) + TMB(I) =
            @SUM(LVL2(J): SMM(J) * SMATREQ2(J, I)));
END
```

The solution is: LINGO/EXCEL

```
Global optimal solution found.
Objective value:                              6000.000
Infeasibilities:                              0.000000
Total solver iterations:                             0
Elapsed runtime seconds:                          0.09

Model Class:                                        LP

Total variables:                     22
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                   12
Nonlinear constraints:                0

Total nonzeros:                      54
Nonlinear nonzeros:                   0
```

```
          Variable           Value        Reduced Cost
      M( ABCDEFG)         0.000000            0.000000
      B( ABCDEFG)         100.0000            0.000000
     MP( ABCDEFG)         122.0000            0.000000
     BP( ABCDEFG)         60.00000            0.000000
   NEED( ABCDEFG)         100.0000            0.000000
         MM( ABCD)        0.000000            177.7500
           MM( EF)        0.000000            142.5000
            MM( G)        0.000000            4.250000
         MB( ABCD)        0.000000            134.0000
           MB( EF)        0.000000            0.000000
            MB( G)        0.000000            0.000000
         SMM( ABC)        0.000000            49.00000
           SMM( D)        0.000000            0.000000
           SMM( E)        0.000000            0.000000
           SMM( F)        0.000000            0.000000
         SMB( ABC)        0.000000            0.000000
           SMB( D)        0.000000            0.4500000
           SMB( E)        0.000000            7.650000
           SMB( F)        0.000000            4.050000
           TMM( A)        0.000000            1.750000
           TMM( B)        0.000000            2.500000
           TMM( C)        0.000000            0.2500000
           TMB( A)        0.000000            0.000000
           TMB( B)        0.000000            0.000000
           TMB( C)        0.000000            0.000000
```

	Demand	100								
			Buy		Make					
	Component	Qty.	Cost	Total	Cost	Total	Minimum	Decision		
Level 3	A	200	3.04	608.00	3.80	760.00	608.00	Buy		
Buy Cost	B	100	4.06	406.00	5.08	507.50	406.00	Buy	1214.00	==> ABC
0.8	C	200	1.00	200.00	1.25	250.00	200.00	Buy		
			Buy		Make					
	Component		Cost	Total	Cost	Total	Minimum	Decision		
Level 2	ABC	100	0.23	23.00	0.20	1234.00	23.00	Buy		
Buy Cost	D	300	3.45	1035.00	3.00	900.00	900.00	Make		==> ABCD
1.15	E	100	24.50	2449.50	21.30	2130.00	2130.00	Make		EF
	F	100	13.97	1397.25	12.15	1215.00	1215.00	Make		
			Buy		Make					
	Component		Cost	Total	Cost	Total	Minimum	Decision		
Level 1	ABCD	100	0.27	27.00	0.30	923.00	27.00	Buy		
Buy Cost	EF	100	0.18	18.00	0.20	3345.00	18.00	Buy	1865.25	==> ABCDEFG
0.9	G	100	18.20	1820.25	20.23	2022.50	1820.25	Buy		
			Buy		Make					
	Component		Cost	Total	Cost	Total	Minimum	Decision		
Level 0	ABCDEFG	100	6000.00	6000.00	5000.00	6865.25	6000.00	Buy		
Buy Cost										
1.2										

Both the LP model from LINGO and the Excel model return a solution of buying all 100 completed vehicles. The cost of this is $6000.00, (in green highlighter) whereas the cost of manufacturing them is $6865.25. This is supported by the LP decision variables (DV) values for make/buy for all components and subcomponents, which are zero.

Some of these zero DV values hold a positive reduced cost value, meaning that there would be a penalty to the objective function if we pursued this action. Others show a reduced cost of zero, meaning there is no penalty.

IX. In-Class Problems

Problem #1

1. Production Plan

Quarter	**1**	**2**	**3**	**4**	**Total**
Agg. Forecast	**220**	**300**	**200**	**200**	**920**
Production Plan	**200**	**200**	**200**	**200**	**800**
Agg. Inventory	**250**	**150**	**150**	**150**	**700**

Given that,

Opening Inventory = 270 units

Ending Inventory = 150 units

Total Production = Forecast Sales + Ending Inventory – Opening Inventory

= 920 +150 -270 = 800 units

Average Total Production = 800/4 = 200 units

Quarterly Production = 200 units

Master Schedule (When referring to individual items)

Quarter	1	2	3	4
Mailbox A	0	200	200	0
Mailbox B	200	0	0	200
Total Planned	200	200	200	200

For each Mailbox, it is given that the lot size is 200 units

Mailbox A

Quarter	1	2	3	4	Total
Forecast Demand	120	180	100	120	520
Inventory	0	20	120	0	140
Master Production Schedule	0	200	200	0	400

Inventory = Open Inventory + MPS – Forecast Demand

Q1 = 120 + 0 -120=0

Q2 = 0 + 200 – 180 = 20

Q3 = 20 + 200 - 100 = 120

Q4 = 120 + 0 – 120 = 0

- As per the Master Production Schedule, production should run in two quarters (q2 and q3), each with 200 units in order to meet the demand.
- Mailbox A will have no units left at the end of the last quarter.

Mailbox B

Quarter	1	2	3	4	Total
Forecast Demand	100	120	100	80	400
Inventory	250	130	30	150	360
Master Production Schedule	200	0	0	200	400

Inventory = Open Inventory + MPS – Forecast Demand

Q1 = 150 + 200 -100 =250

Q2 = 250 + 0 – 120 = 130

Q3 = 130 + 0 - 100 = 30

Q4 = 30 + 200 – 80 = 150

- As per the Master Production Schedule, production should run in two quarters (Q2 and Q4), each with 200 units in order to meet the demand.
- Mailbox B will have 150 units left at the end of the last quarter.

Problem #2

Level Production with Overtime and Inventory

Step 1: Calculate the production quantity level for each month by dividing the total forecasted demand for the production period by the total number of periods.

Production Per Day = Forecasted / Total periods= 19100 / 300 = 63.66 unit per day

Step 2: Calculate the inventory and overtime for each period

Step 3: Calculate the total cost for the strategy.

Days	Forecast	Regular	Overtime	Subcontract	Inventory		Production per day	63.66
25	500	1591.5			1091.5			
20	300	1273.2			2064.7			
27	200	1718.82			3583.52			
25	1500	1591.5			3675.02			
28	2500	1782.48			2957.5			
30	3500	1909.8			1367.3			
30	4500	1909.8	1222.9		0			
30	2500	1909.8	590.2		0			
20	500	1273.2			773.2			
25	300	1591.5			2064.7			
20	300	1273.2			3037.9			
20	2500	1273.2	2		1811.1			
300	19100	19100	1815.1	0	22426.44			
		$15	$25		$0.50			
		$286,500	$45,378	$0	$11,213		Total	$343,091

Cost=$286500+$45378+$11213= $343,091

Level Production with Subcontracting

Step 1: Calculate the minimum daily requirements for each month by dividing the forecast by the number of days.

Step 2: Determine the minimum for all months, which is 7.407407407 per day

Step 3: Calculate the regular production for each period by multiplying the days.

Step 4: Calculate the total cost for the strategy.

Month	Days	Min daily requirement	Forecast	Regular	Subcontract			
Jan	25	20	500	185.18519	314.8148148			
Feb	20	15	300	148.14815	151.8518519			
Mar	27	7.407407407	200	200	0			
Apr	25	60	1500	185.18519	1314.814815			
May	28	89.28571429	2500	207.40741	2292.592593			
Jun	30	116.6666667	3500	222.22222	3277.777778			
July	30	150	4500	222.22222	4277.777778			
August	30	83.33333333	2500	222.22222	2277.777778			
Septembe	20	25	500	148.14815	351.8518519			
October	25	12	300	185.18519	114.8148148			
Novembe	20	15	300	148.14815	151.8518519			
Decembe	20	125	2500	148.14815	2351.851852			
Total			19100	2222.2222	16877.77778			
Rate				$15	$30			
				$33,333.33	$506,333.33		Total	$539,666.67

Cost= $539,666

Chase Production Strategy (Hiring /Firing Workers)

Step 1: Determine the production per period.

Production per period = demand per period

Step 2: Calculate the production per day

2600 units /20 days= 130 units per day with 8 workers

Hence, 16.25 units per employee per day

Step 3: Calculate the change in worker (increase/decrease) between periods. The beginning workforce is 8 workers.

Step 4: Calculate the total cost for the strategy.

A	B	C	D	E	F	G	H	I	J
Month	Forecast	Regular	# of Workers	Hired	Fired			production rate / worker	16.25
Jan	500	500	30.76923077	22.769231					
Feb	300	300	18.46153846		12.30769231				
Mar	200	200	12.30769231						
Apr	1500	1500	92.30769231	80					
May	2500	2500	153.8461538	61.538462					
Jun	3500	3500	215.3846154	61.538462					
July	4500	4500	276.9230769	61.538462					
August	2500	2500	153.8461538		123.0769231				
September	500	500	30.76923077		123.0769231				
October	300	300	18.46153846		12.30769231				
November	300	300	18.46153846						
December	2500	2500	153.8461538	135.38462					
Total	19100	19100	1175.384615	422.76923	270.7692308				
Rate		$15		$100	$200				
		$286,500.00	$0.00	$42,276.92	$54,153.85		Total	$382,930.77	

Cost= $382,930.77

Decision: Pick the alternative with the lowest cost. Recommend a **Level Production with Overtime and Inventory**

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Problem 3

DV	Value	Reduced Cost	Meaning
W1	0.4034848	0.000000	Workers in Period 1
W2	0.000000	0.000000	Workers in Period 2
W3	0.000000	0.000000	Workers in Period 3
H1	0.000000	6060.000	Hires in Period 1
F1	199.5965	0.000000	Fired in Period 1 (everyone got fired)
O1	0.000000	14.00000	Overtime Period 1
H2	0.000000	4425.000	Hires in Period 2
F2	0.4034848	0.000000	Fired in Period 2
O2	0.000000	99.50000	Overtime Period 2
H3	0.000000	3750.000	Hires in Period 3
F3	0.000000	0.000000	Fired Period 3
O3	0.000000	84.50000	Overtime Period 3
I11	234.0000	0.000000	Inventory Product 1, Period 1
I12	0.000000	2.250000	Inventory Product 1, Period 2

I13	**0.000000**	**2.000000**	**Inventory Product 1, Period 3**
I21	**725.0000**	**0.000000**	**Inventory Product 2, Period 1**
I22	**40.00000**	**0.000000**	**Inventory Product 2, Period 2**
I23	**0.000000**	**3.750000**	**Inventory Product 3, Period 3**
I31	**367.7000**	**0.000000**	**Inventory Product 3, Period 1**
I32	**0.000000**	**1.250000**	**Inventory Product 3, Period 2**
I33	**0.000000**	**0.5000000**	**Inventory Product 3, Period 3**
I41	**1234.000**	**0.000000**	**Inventory Product 3, Period 1**
I42	**0.000000**	**1.000000**	**Inventory Product 3, Period 2**
I43	**0.000000**	**0.5000000**	**Inventory Product 3, Period 3**

Total variables: 85
Total constraints: 32
Objective value: 504138.5

LP Model

```
MIN 4620W1 + 3780W2 + 4200W3
+ 1250H1 + 2500F1 + 42O1
+ 1250H2 + 2500F2 + 42O2
+ 1250H3 + 2500F3 + 42O3
+ 0.5I11 + 2.25I12 + 2I13
+ 1I21 + 2I22 + 3.75I23
+ 2I31 + 3.75I32 + 0.5I33
+ 0.5I41 + 2I42 + 0.5I43

ST
0.1X111 + 0.3X211 + 0.25X311 + 0.1X411 - W1pr1 <= 0
0.1X112 + 0.3X212 + 0.25X312 + 0.1X412 - W2pr1 <= 0
0.1X113 + 0.3X213 + 0.25X313 + 0.1X413 - W3pr1 <= 0

0.1X121 + 0.3X221 + 0.25X321 + 0.1X421 - W1pr2 <= 0
0.1X122 + 0.3X222 + 0.25X322 + 0.1X422 - W2pr2 <= 0
0.1X123 + 0.3X223 + 0.25X323 + 0.1X423 - W3pr2 <= 0
```

$0.1X131 + 0.3X231 + 0.25X331 + 0.1X431 - W1pr3 <= 0$
$0.1X132 + 0.3X232 + 0.25X332 + 0.1X432 - W1pr3 <= 0$
$0.1X133 + 0.3X233 + 0.25X333 + 0.1X433 - W1pr3 <= 0$

$W1pr1 + W1pr2 + W1pr3 - 165W1 - O1 + 82.5H1 <= 0$
$W2pr1 + W2pr2 + W2pr3 - 135W2 - O2 + 67.5H2 <= 0$
$W3pr1 + W3pr2 + W3pr3 - 150W3 - O3 + 75H3 <= 0$

$I11 - I10 + X111 + X121 + X131 - X141 = 234$
$I12 - I11 + X112 + X122 + X132 - X142 = -323$
$I13 - I12 + X113 + X123 + X133 - X143 = -380$

$I21 - I20 + X211 + X221 + X231 - X241 = 725$
$I22 - I21 + X212 + X222 + X232 - X242 = -685$
$I23 - I22 + X213 + X223 + X233 - X243 = -642$

$I31 - I30 + X311 + X321 + X331 - X341 = 634$
$I32 - I31 + X312 + X322 + X332 - X342 = -323$
$I33 - I32 + X313 + X323 + X333 - X343 = -280$

$I41 - I40 + X411 + X421 + X431 - X441 = 1234$
$I42 - I41 + X412 + X422 + X432 - X442 = -680$
$I43 - I42 + X413 + X423 + X433 - X443 = -285$

$2X111 + 1X211 + 1.5X311 + 0.5X411 <= 800$

$W1 - H1 + F1 = 200$
$W2 - H2 + F2 - W1 = 0$
$W3 - H3 + F3 - W2 = 0$

$O1 - 44W1 <= 0$
$O2 - 36W2 <= 0$
$O3 - 40W3 <= 0$

9E