NORTHEASTERN UNIVERSITY

School of Engineering

MECHANICAL & INDUSTRIAL ENGINEERING DEPARTMENT

IE7200 Supply Chain Engineering

1st Partial Exam Project

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I. Introduction

In recent years, businesses have faced heightened competition due to increasing globalization, demand uncertainties, and environmental changes. To stay competitive, companies are adopting customer-centric and integrated approaches. Supply chain management (SCM) is crucial for adapting to the unpredictable business environment.

Successful companies focus on minimizing disruptions, understanding customer demand, and efficiently managing production. Decision-makers continuously evaluate and improve policies to meet customer needs at lower costs.

Inventory management is key, considering supply chain fluctuations. Decision-makers often use analytic methods for inventory modeling. In this study, system dynamics modeling is applied to explore how customer demand uncertainties affect downstream automobile companies in Nigeria. The research develops and tests push and hybrid push/pull inventory models, considering different demand patterns and policies.

The push model relies on downstream demand forecasts, leading to increased inventories for unexpected changes. In contrast, the hybrid push/pull model combines push and pull processes, holding fewer inventories and using a pull system in later stages. The study evaluates inventory levels, costs, profits, and cash balances under different policies and demand patterns.

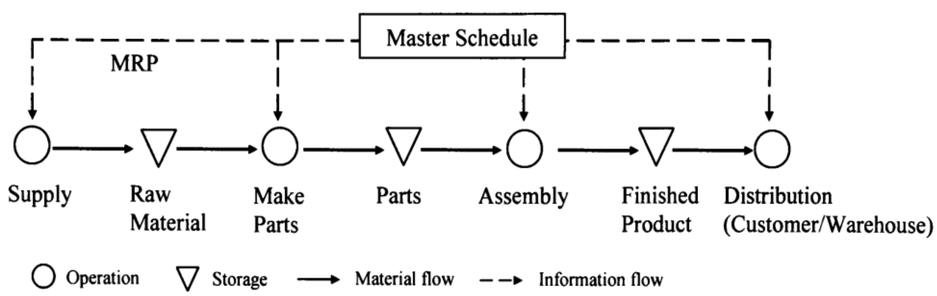

FIGURE 1. 1. INVENTORY AND INFORMATION FLOW FOR A TYPICAL PUSH MODEL
(Bazin, 2010)

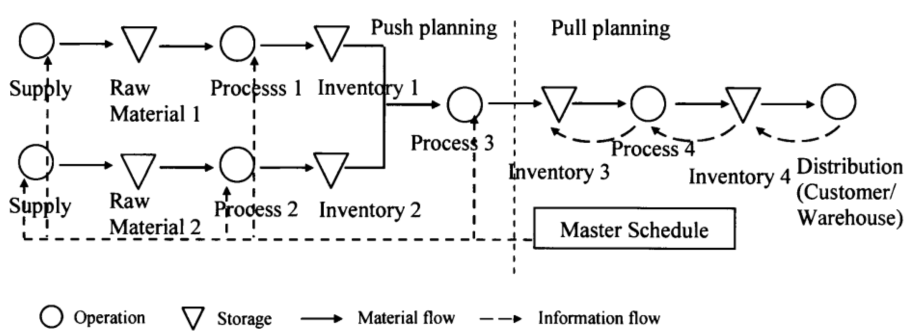

FIGURE 1. 2. INVENTORY AND INFORMATION FLOW FOR A TYPICAL HYBRID PUSH/PULL MODEL
(Hodgson and Wang 1991a)

The research involves three tests on the push/pull inventory models. The test uses a smoothing parameter in the

STELLA simulation software to align manager expectations with unexpected changes in customer demand. Financial metrics resulting from fluctuations and instabilities in inventory levels are calculated. Findings show that managers' actions to respond quickly to demand changes only slightly minimize costs under specific demand patterns. The sensitivity analysis examines several different scenarios in which rates and initial conditions in the system are perturbed. Sensitivity tests identify parameters with the most impact on inventory levels, costs, profit, and cash balance.

The research motivation stems from uncertainties in downstream automobile supply chains in developing economies, categorized as process, supply, demand, and control uncertainties. The study links supply chain uncertainties to the behavior of suppliers, customer demand, and variations in processing time. Uncertainties arise from random events, material availability, judgment inaccuracies, and order uncertainty. Companies can address uncertainties by improving performance and managing relationships and strategies.

Supply chain uncertainties are influenced by supplier delays, manufacturing process delays, and inaccuracies in demand forecasting. The universal supply chain involves forward material flows and backward information flows among suppliers, factories, manufacturers, warehouses, distribution centers, and retailers. The research aims to address the challenges posed by these uncertainties through the analysis of inventory models and their financial implications.

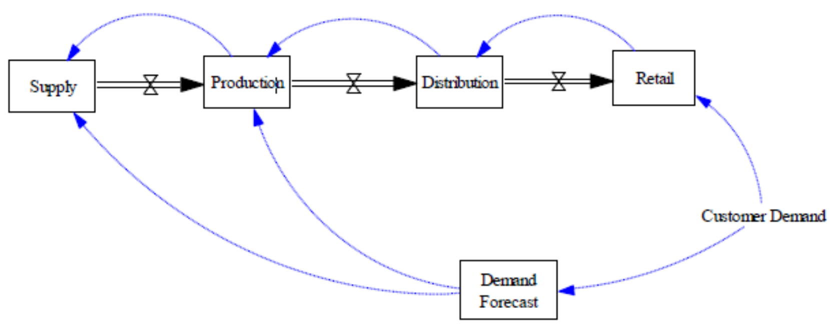

FIGURE 1. 3. GENERIC STRUCTURE OF A SUPPLY CHAIN

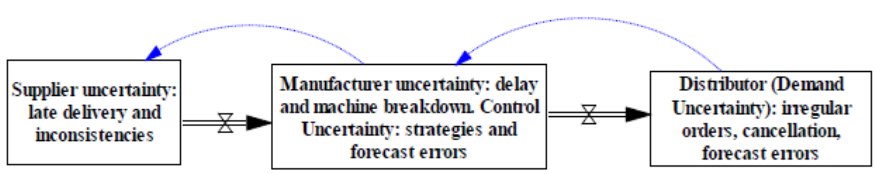

FIGURE 1. 4. SUPPLY CHAIN UNCERTAINTIES

Figure 1.4 illustrates the role of each supply chain member in causing uncertainties, based on Fox et al. (2000) and Cannella et al. (2018). Control and process uncertainties are perceived in factory processes, flowing to supply chain partners through information and material flows.

Geary et al. (2002, 2006) conducted a supply chain audit, finding that only 10% of companies quickly reach supply chain objectives, while 45% still face major uncertainties. This underscores the imperfect performance of supply chains. The study emphasizes the need for reducing uncertainty, a key practice in exemplary supply chains. A smooth supply chain is achieved through improved information and material flow, visibility, and effective communication among partners.

Addressing process uncertainty is crucial, as it allows companies to understand and control their operations, reducing control uncertainty. Fisher (1997) highlights the challenge of planning effective supply chains due to managers' inability to align operations with customer demand trends. System-induced uncertainties within a

company's operations are easier to control than marketplace uncertainties influenced by customers.
Given the significant role of the downstream in a supply chain, this thesis focuses on investigating downstream supply chain performance under different demand patterns. This exploration aims to understand how a company's supply chain reacts to various demand patterns, assisting downstream managers in reducing uncertainty.

The escalating unpredictability in the current market environment poses a significant challenge in supply chain management, as defined by Christopher and Holweg (2011) as the end-to-end management of the system and connections between various links. Managers must not only handle uncertainties within their company processes but also manage uncertainties in demand from end-users and suppliers.
Geary et al. (2006) identify the bullwhip effect, amplification of customer demand, as a major problem in supply chain management. This phenomenon, recognized by Forrester in 1958, remains challenging to solve. Lee et al. (1997) attributes the bullwhip effect to price fluctuations, demand forecasting, shortage gaming, and order batching, indicating that participants' actions to gain a competitive advantage increase uncertainty in the supply chain.
Despite research improvements, interest in supply chain problems persists, indicating that some issues remain unresolved. Dooley et al. (2010) provided evidence of the bullwhip effect during the economic downturn from 2007 to 2009. Sprague and Callarman (2010) highlight a CEO's speech, emphasizing that the economic decline's effect is amplified moving down the supply chain. This underscores that the bullwhip effect remains a significant, unanswered challenge in supply chain management, where uncertainty experienced by a partner affects the entire chain through information and materials flow.

The escalating uncertainty in customer demand and the growing demand for product customization have intensified business competition and instability. Since the introduction of the Material Requirement Planning system (MRP) in the 1960s, various systems have emerged to manage the transition from mass production to mass customization in response to the changing business environment. The dynamic and complex nature of the entire system requires periodic study of the inventory policies implemented by companies in their supply chain network.
Christopher and Holweg (2011) highlight three unfavorable situations for companies: increasing unpredictability of customer demand, challenges in accurately forecasting demand, and a reduction in product life cycles. Dai et al. (2017) argue that companies must grapple with significant reductions in product life cycles, unpredictable customer demand, high product variety, short customer lead times, and long delivery lead times.
Inventory management challenges stem from customer demand uncertainty, product variety, reduced product life cycles, and the need for shorter delivery times. As companies aim for a global and customer-focused supply chain, these challenges become more pressing.
The move towards customer orientation requires supply chain managers to handle extensive product customization and reduce delivery times. Shorter delivery times allow companies to produce and ship products faster, ensuring competitiveness. In a competitive market, companies strive to survive by minimizing costs to maintain profit margins. These challenges underscore the urgency for improvements in supply chain management.
In a globalized and complex supply chain landscape, effective management of uncertainty becomes crucial. Researchers and practitioners suggest various ways to enhance supply chains, including outsourcing non-essential activities, reducing the number of suppliers, and sourcing globally. Managing uncertainty, particularly from customers, is vital. This study explores supply chain inventory management concerning demand uncertainty in downstream automobile companies. The investigation aims to address issues like the discrepancy between supply and demand and the inefficiency in serving customers caused by demand uncertainties. While some studies have modeled this issue hypothetically, there is limited research using system dynamics to model the supply chain problem, especially in the downstream supply chain of developing countries. This thesis focuses on the performance of inventory levels and costs in downstream automobile companies in Nigeria, aiming to provide valuable insights for managers in devising actions or policies to address the bullwhip effect.

This research is motivated by the presence of the bullwhip effect in two automobile companies in Nigeria. Despite the well-documented nature of the bullwhip effect, companies find it challenging to identify its occurrence, understand its causes, and implement corrective measures. The investigated automobile companies in Nigeria, specializing in sales, confirmed the existence of the bullwhip effect during discussions with their managers. This phenomenon has subjected these companies to significant financial pressures, resulting in lost sales despite maintaining high inventory levels. Additionally, these companies face competition that has reduced their profit margins.

Ineffectively managing the bullwhip effect has further strained these companies' cash flow, jeopardizing their sustainability. An initial review of the companies' policies revealed the causes of demand amplification. However, due to their current financial constraints, managers hesitated to initiate major operational changes, fearing that a wrong decision could lead to business closure. Therefore, the focus shifted towards reducing demand amplification based on cost and impact considerations. Unfortunately, existing knowledge is insufficient for managers to determine the best policy due to the inherent complexity of supply chain operations.

Recognizing the challenges faced by managers in addressing this problem, this study employs the system dynamics modeling methodology to investigate the bullwhip effect and its impact on company performance. System dynamics offers a continuous, system-thinking approach, allowing the development of comprehensive simulation models for complex supply chain systems in a cost-effective manner. The study adopts a well-established system dynamic inventory model that is sophisticated yet simple and inexpensive, encompassing operational decision-making levels to assist managers in policy development and comprehensive testing.

The research objectives are as follows:

1. Model the downstream automobile inventory in Nigeria using system dynamics methodology, focusing on both push and hybrid push/pull approaches.
2. Test interventions in the push and hybrid push/pull downstream automobile inventory policies by simulating various customer demand patterns to replicate the current rise in demand uncertainty.
3. Explore the dynamic effects on the inventory level of downstream automobile inventory in Nigeria under different demand patterns, considering both push and hybrid push/pull models.
4. Investigate the costs incurred due to fluctuations and instabilities in the inventory level of downstream automobile companies, assessing the impact of various policy interventions.

Research Questions:

- How do customer demand uncertainties impact downstream automobile companies in Nigeria?
- What is the relationship between customer demand uncertainties and costs incurred by downstream automobile companies in Nigeria?
- Which parts of the system dynamics inventory model are more significantly affected?
- What are the most effective policies for reducing costs?

Research Scope:

- The research primarily focuses on information flow and inventory flow within distributor and dealer inventory policies in the downstream automobile sector. The system dynamics model's boundary includes customer demand, as depicted in Figure 1.5. The broader context of the research topic, as discussed in the supply chain issues above, emphasizes the importance of comprehensive exploration.

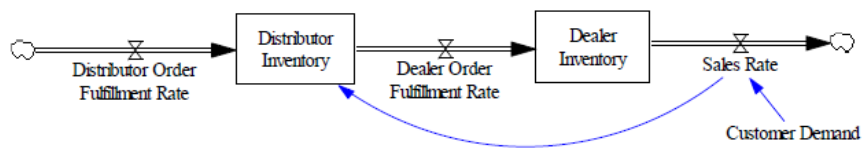

FIGURE 1. 5. RESEARCH BOUNDARY

Research Methodology:

The initial stage involves identifying issues in supply chains, particularly in downstream automobile inventory, through a comprehensive literature review. Performance metrics for evaluating the downstream automobile supply chain are derived from an extensive literature review in supply chain and inventory management.
To understand feedback effects, the next stage employs system dynamics modeling, a prevalent approach in addressing supply chain and inventory issues. Push and hybrid push/pull system dynamics inventory models are developed based on their mental models. Subsequent simulation rounds validate these models, ensuring their behavior aligns with existing knowledge.
Following model development and validation, policy analysis tests are conducted to assess model responses to changes in customer demand. Performance metrics, including distributor and dealer inventory levels, costs, profit, and cash balance, are used for evaluation in each case.
In the final stage, sensitivity tests are applied to both push and hybrid push/pull models to identify optimal policy combinations that minimize costs while maximizing profit and cash balance. The research structure, as illustrated in Figure 1.6, guides this comprehensive methodology.

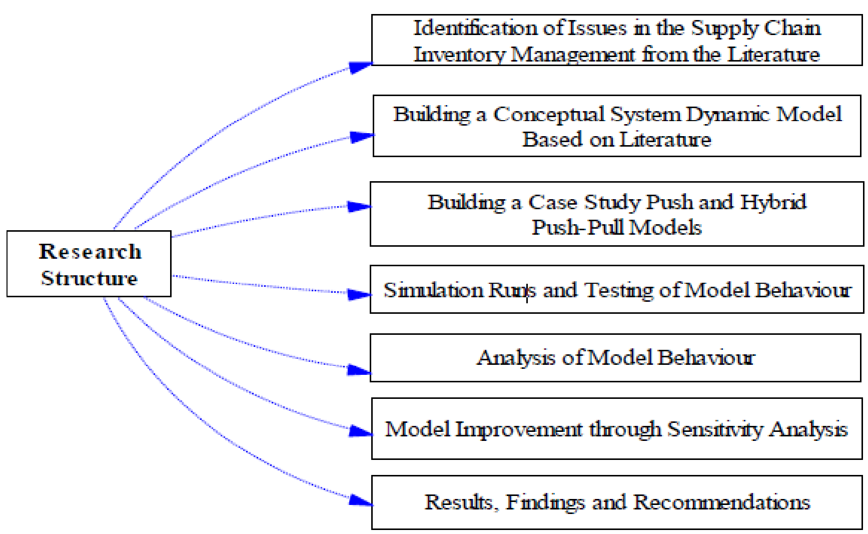

FIGURE 1.6. RESEARCH STRUCTURE

Expected Research Contribution:
This research aims to advance the comprehension of push and hybrid push/pull inventory models' performance in the downstream automobile supply chains in Nigeria, considering three distinct customer demand patterns: business as usual, optimistic, and pessimistic demand patterns. The anticipated contributions are:
1.Validation and promotion of system dynamics methodology as a valuable approach for managing complexity

and enhancing understanding in the development of supply chain inventory models.
2. Introduction of a novel perspective by testing the push/pull inventory system dynamic models under different studies of downstream automobile companies, providing insights into evaluating supply chain model performance.
3. Provision of additional policy insights based on model responses to the tests conducted, contributing to a deeper understanding of the dynamics under various demand patterns.
4. Enhancement of the push/pull model, enabling the formulation of policies aimed at reducing total costs while improving profit and cash balance within the downstream automobile supply chains.

Paper Structure:

1. Introduction (Chapter One):
   - Background and context of the research.
   - Research purpose, objectives, scope, and questions.
   - Research methodology overview.
   - Expected contributions and thesis structure.
2. Introduction to the bull whip effect (Chapter Two):
   - Comprehensive review of current and past research in supply chains.
   - Focus on the use of system dynamics modeling and other simulation methods.
3. Description of the Systems Dynamics Model (Chapter Three):
   - Detailed explanation of the research philosophy employed in the thesis.
4. Sensitivity Analysis (Chapter Four):
   - In-depth description and explanation of push and hybrid push/pull inventory models.
   - Construction of conceptual models, including stock and flow diagrams for distributor and dealer inventory.
   - Introduction and validation of the case study for the research.
   - Extraction and discussion of important equations from the models.
5. Performance Analysis - Case Study A (Chapter Five):
   - Analysis of the models for validation and performance measurement.
   - Exploration of findings specific to case study A.
6. Performance Analysis - Case Study B (Chapter Six):
   - Extending the analysis to case study B.
   - Further insights and comparisons between the two case studies.
7. Findings and Contributions (Chapter Seven):
   - Discussion of the research findings.
   - Overview of the contributions made by the research.

This structured approach allows for a systematic exploration of the research topic, incorporating literature, methodology, modeling, and case study analyses to provide comprehensive insights and contributions.

In the conclusion of Chapter Five, the outcomes of the tests are presented, emphasizing inventory levels (volume measures) and the accompanying analysis of costs (financial measures) associated with the inventory level in both models. Model enhancement is applied to both models to uncover innovative policies aimed at reducing costs, maximizing profit, and improving cash balance. The results and insights derived from the cost analysis and model enhancement are reported.

Chapter Six follows the same analytical process used in examining Case Study A, extending the analysis to Case Study B.

Ultimately, in Chapter Seven, the thesis concludes with a thorough discussion of the findings, contributions to knowledge, and suggestions for future research.

II. Introduction to the Push/Pull Effect

The complexities of modern supply chain management have given rise to different paradigms and techniques aimed at increasing efficiency, lowering costs, and enhancing overall responsiveness to consumer demand. Among these tactics, the push-pull paradigm has emerged as a key idea in supply chain planning and execution. The push-pull effect is a dynamic interaction between two opposing methods - the push model and the pull model - each of which governs how commodities move through the supply chain. This sophisticated ballet of push and pull mechanisms is critical for firms looking to strike a careful balance between forecasting accuracy, inventory management, and customer demand response.

The Push Effect:

The Push Model is a classic method of supply chain management that forecasts and plans based on historical data and market trends. In a push system, production and distribution decisions are determined in advance, with long-term forecasts used to calculate the quantity of items required. This planned technique is properly termed because products are simply pushed through the supply chain, from manufacturing to distribution, with no direct relationship to real-time client demand.

One of the push model's distinguishing traits is its dependence on economies of scale. Large production batches are prevalent in push-based systems, as they strive to leverage on efficiency and cost-effectiveness. While this method provides for more efficient production processes and reduced unit costs, it also increases the danger of overproduction and excess inventories. The push model's inability to respond to changes in consumer demand can lead to stockouts or excess inventory, increasing carrying costs and even resulting in financial losses for supply chain entities

The Pull Effect:

The Pull Model prioritizes client demand to drive production and distribution decisions. Products are moved through the supply chain in real time depending on signals such as client orders, consumption statistics, or point-of-sale information. The pull strategy promotes flexibility and reactivity, with the goal of producing and delivering commodities precisely when and where they are required.

One of the pull model's key features is its capacity to decrease excess inventory and the risk of stockouts. Organizations can improve supply chain agility by matching production and distribution with current demand. However, the pull model has its own set of issues, including the requirement for strong communication and information-sharing channels across supply chain partners to provide prompt responses to client needs.

The Push-Pull Dynamics:

Organizations can construct a hybrid supply chain model by carefully combining components of both push and pull models, each with its own advantages and disadvantages. This combination enables businesses to reap the benefits of economies of scale provided by the push model while retaining the responsiveness and flexibility inherent in the pull model.

Push-pull dynamics are especially important in businesses with volatile demand, seasonality, and rapidly changing market conditions. Organizations may respond to demand variations, optimize inventory levels, and improve customer satisfaction by carefully deploying push and pull elements throughout the supply chain.

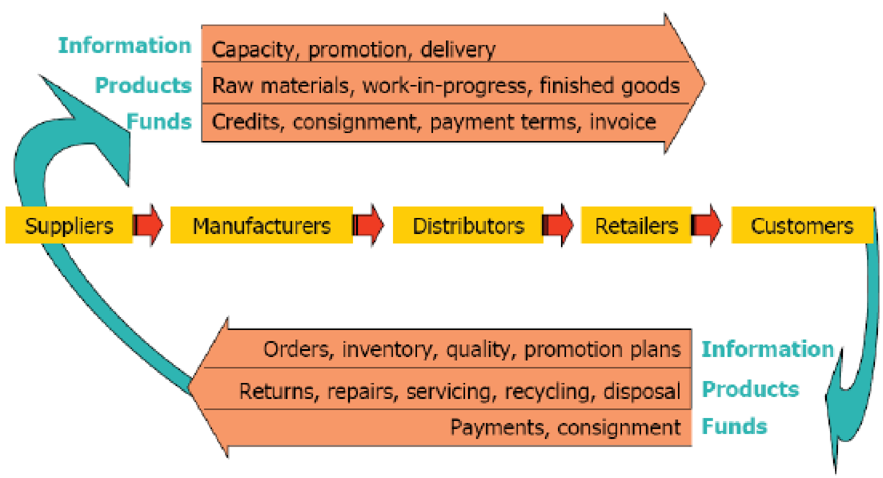

FIGURE 2.1. BASIC FLOWS IN THE SUPPLY CHAIN NETWORK
(Anne, 2009)

III The Bullwhip Effect

The bullwhip effect is a prevalent issue in supply chains, describing the phenomenon where demand fluctuations intensify as orders move upstream from customers to suppliers (Lee et al., 1997a, b). This effect poses challenges such as excessive inventory, unused capacity, overtime, and labor idling, incurring substantial costs for supply chains. Additionally, Aeppel (2010) and Cannella et al. (2014) highlight that economic volatility can further amplify the bullwhip effect.

Research by Dooley et al. (2010) identified the bullwhip effect in monthly sales data and inventory of US manufacturers during an economic recession, impacting retailers, wholesalers, and manufacturers. The application of demand variance results from replenishment policies adopted by decision-makers as supply chain players respond rapidly to individual demand signals (Forrester, 1958).

Lee et al. (1997a, b) categorized five main operational causes of the bullwhip effect, including shortage gaming, order batching, demand signal processing, rationing, and lead time. Moreover, behavioral aspects, as highlighted by Croson and Donohue (2006), can also contribute to the bullwhip effect. Sterman (1989) introduced the beer game, a management game depicting a four-tier supply chain distribution process, providing anecdotal evidence on how individuals react in the supply chain. While the beer game is representative of real-world supply chains, its limitation lies in the lack of mathematical proof (Wang and Disney, 2016).

Recognizing this limitation, researchers have turned to simulation models to gain a deeper understanding of the bullwhip effect. Van Ackere et al. (1993), Hong-Ming et al. (2000), and Coppini et al. (2010) emphasized the development of simulation models to allow supply chain players to test inventory models and policies. Wang and Disney (2016) noted ongoing efforts to enhance the literature on the bullwhip effect through simulation methods, statistical research, control theory, operational research methods, and system dynamics methods. These approaches aim to provide a more comprehensive and mathematically supported understanding of the complexities associated with the bullwhip effect in supply chains.

History of The Bullwhip Effect:

The history of the bullwhip effect traces back to the pioneering work of Jay Forrester in 1958. Forrester, a renowned systems scientist, was the first researcher to delve into the oscillations observed in supply chains, coining the term "Bullwhip Effect." In his seminal work, however, he initially referred to this phenomenon as "Demand Amplification." Forrester's research focused on illustrating the discrepancies between manufacturer orders and actual customer demand within a supply chain.
Forrester's groundbreaking study served as a catalyst, inspiring subsequent researchers to explore and understand the bullwhip effect in greater detail. The term "bullwhip" gained popularity over time as a vivid metaphor for the increasing magnitude of demand fluctuations moving upstream in a supply chain, reminiscent of the way a bullwhip's crack amplifies along its length.
Motivated by Forrester's work, researchers sought to uncover the root causes of the bullwhip effect and propose solutions to enhance supply chain efficiency. Notable studies by researchers like Wanphanich (2008), Wu et al. (2017),

Wang et al. (2015), Jaipuria and Mahapatra (2014), Poornikoo (2017), and Naim et al. (2017) reinforced the idea that the bullwhip effect is a prevalent phenomenon affecting nearly every supply chain. These studies went beyond mere acknowledgment and delved into identifying potential causes and suggesting strategies to mitigate the adverse impacts of the bullwhip effect.Figure 2.2, presumably included in the original text, visually represents the bullwhip amplification as orders progress upstream in the supply chain from downstream to upstream. This graphical depiction helps illustrate how demand fluctuations magnify as they move through different stages of the supply chain, underscoring the essence of the bullwhip effect.

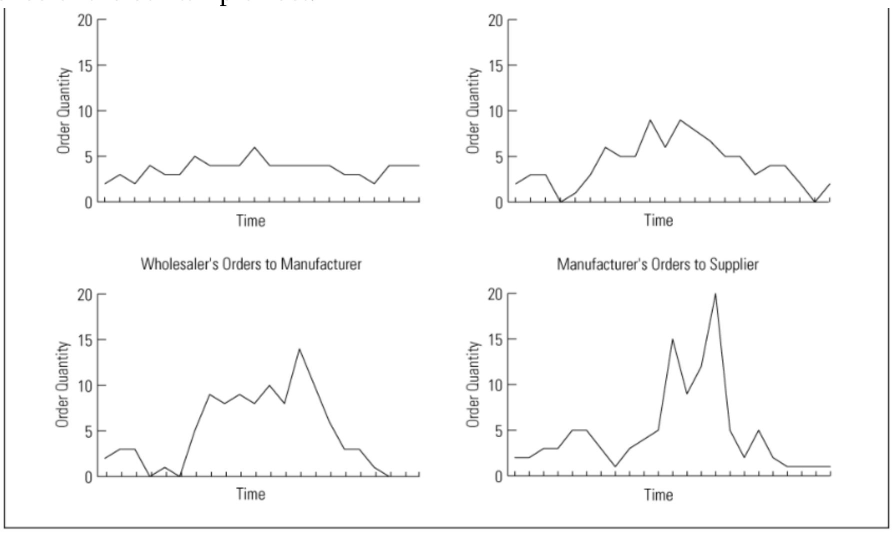

FIGURE 3.1 BULLWHIP EFFECT
(Forrester, 1958)

Lee et al. (1997a, b) conducted comprehensive research on the bullwhip effect and identified five primary reasons for its occurrence within a supply chain. These reasons were categorized as lead times, demand forecasting, rationing and gaming, price fluctuations, and batch ordering. Understanding the presence and impact of the bullwhip effect has been a crucial aspect of supply chain management, and researchers have employed various approaches to demonstrate and study this phenomenon.

One widely used method to illustrate the bullwhip effect is the Beer Distribution Game (BDG), as discussed by Simchi-Levi et al. (2000). The BDG involves a 4-stage supply chain comprising a seller, a factory, a supplier, and a wholesaler. Researchers have extended this game, created electronic versions and adapted it for different settings, including computerized or manual web-based variations.

Chen et al. (1998) investigated the bullwhip effect in a simple 2-stage supply chain to understand the impact of forecasting and lead times. Their study revealed that utilizing a moving average forecasting technique could mitigate oscillations in the supply chain. Also, centralizing customer demand information was found to reduce the bullwhip effect, although complete elimination was not achieved. The study identified factors such as centralized information sharing and reduced lead times as critical in dampening the bullwhip effect.

Further exploration into the impact of customer demand and lead time on the bullwhip effect was conducted by Cantor and MacDonald (2008). They utilized a beer game simulation with laboratory students, emphasizing the role of information sharing methods and ordering policies as typical causes of the bullwhip effect.

Amaya (2011) emphasized that methods of sharing information and ordering policies are common culprits of the bullwhip effect. However, he also highlighted the significance of factors like cost structure, demand forecasting techniques, and ordering decisions influencing the bullwhip effect. Despite these insights, the research landscape is characterized by a limited number of studies that comprehensively examine and discuss all causes of the bullwhip effect and their impacts across different real-world scenarios with established simulation tools. The need for in-depth research addressing these aspects remains a critical gap in the current understanding of the bullwhip effect in supply chains.

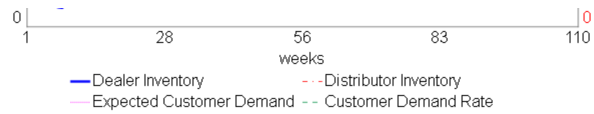

Figure 4. An illustration of the bullwhip effect/mm Customers to suppliers

In conclusion, two models, push and hybrid push/pull inventory system dynamic models, are provided for this study to give effective management tools while addressing supply chain management concerns in depth. Developing improved supply chain inventory management methodologies based on customer demand unpredictability presents opportunities to expand expertise. In Chapter Four, the push and hybrid push/pull models for constructing supply chains are developed using system dynamics modeling. This provides a deeper knowledge of the models' structure and characteristics for addressing the problem.

IV. Sensitivity Analysis

4.1 Setup

The scenario was analyzed by modifying the elements to shape the features of the bullwhip effect in advantageous ways. In this scenario, order batching is eliminated by adjusting the formulas in the initial model that allowed for order batching to propagate through the supply chain. To analyze what other effects within the model could aid in lessening or exacerbating the bullwhip effect, the key features in Table 4.1 were initially perturbed for investigation.

Adjusted Values	Bullwhip Effect	Recommended actions
Distributor Adjustment Time (weeks)	Increase reduces bullwhip amplitude	Small demand changes can be reacted to quickly, larger demand shifts should increase this value
Time to Average Customer Demand (weeks)	Lower values increase bullwhip frequency	Company controls can modify this value to lessen bullwhip frequency
Safety Stock Coverage (Weeks)	Uniform increase or decrease	Increase when leading market indicators predict demand changes
Adjusted Unit Cost (NGN)	No Effect	N/A
Sales Price (NGN)	No Effect	N/A
Inventory Carrying Cost (NGN)	No Effect	N/A
Dealer Inventory Initial Conditions (Units)	Increased initial whip if too high, or reaches zero if too low	This value should be optimized to be above zero with some safety margin
Distributor Inventory Initial Conditions (Units)	Can cause issues with the dealer supply chain if too low	This value should typically be slightly above the dealer inventory value with some lag

Table 4.1 – Perturbed values of sensitivity analysis

In choosing these values, we attempt to see how different adjustments carry forward into the sine waves of the inventory and demand. Notably, costs had very little to do with the bullwhip effect in the push/pull model. This result makes sense, as this concept should be relatively robust to price given a high enough market volume (i.e. non-luxury items). There are specific controls that the company can use to both lessen the frequency and amplitude of the bullwhip effect according to this analysis.

First, the Distributor Adjustment Time increases, there is an increase in the amplitude of the whip effect. These are not very large for small changes, so it would be acceptable for the Distributor to chase small changes in demand with inventory. However, once larger changes in inventory are detected, the Distributor should be allowed more time to match inventory to avoid the bullwhip effect.

In contrast to the Distributor Adjustment Time, the Time to Average Customer Demand is a control that the company can use to either lessen or increase the frequency. There could be cause for either case if indicators predicting when customer demand will spike are available.

As for a safety factor, the Safety Stock Coverage can be used to ensure that the Dealer Inventory does not go below the minimum desired threshold. The changes do not affect the bullwhip effect, but instead offer a uniform change to the entire curve.

The last set of variables adjusted are the Dealer and Distributor Inventory initial conditions. In each of these cases, the initial conditions adjusted the intensity of the first bullwhip effect, but did not have an appreciable effect on the amplitude or frequency of the effect. The main recommendation for the Distributor Inventory initial conditions is for them to be at least 30-40% higher than the Dealer Inventory initial conditions to minimize the bullwhip effect there.

4.2 Sensitivity Analysis Runs

Once the most significant factors on the model's performance were determined through individual perturbations, sensitivity analysis is then run in combination according to Table A.9. These models runs are from left to right, ordered 1-27 for the different combinations of values for Distributor Adjustment Time (DAT), Time to Average Customer Demand (TACD), and Safety Stock Coverage (SSC). The range of values are 1, 2, 3 (DAT), 4, 6, 8 (TACD), 2, 3, and 4 (SSC), respectively.

4.3 Sensivity Analysis Results

The worst-case scenario is when all three of DAT, TACD, and SSC are low, resulting in low or even negative dealer stocks. With area under the curve for inventory representing additional costs due to stockage, supply chain goals are to keep inventory low, within an allowable safety margin. In our model, Run 9 im Figure 4.2 is the closest to zero inventory while still maintaining sufficient clearance for Dealer Inventory to avoid lost revenue, with DAT=3, TACD=8, and SSC=2. In plain language, this means not chasing customer demand with inventory so tightly and offering a moderate safety net for stocks of 2 weeks on hand. Given the experience with COVID, supply chain managers may wish to opt for more robust safety stocks at the distributor level as a cushion. This course of action does assume risk in the area of transportation, should the distributor to dealer supply chain break down, although we note here that at no time did distributor inventory get close to zero during our sensitivity analysis.

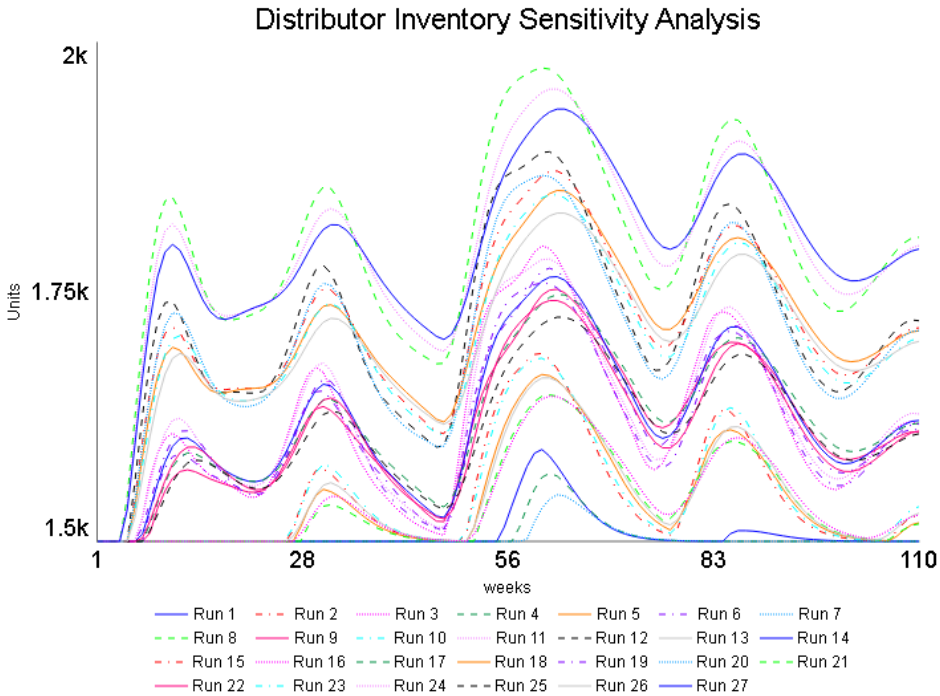

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Figure 4.1 - Distributor Inventory Sensitivity Analysis

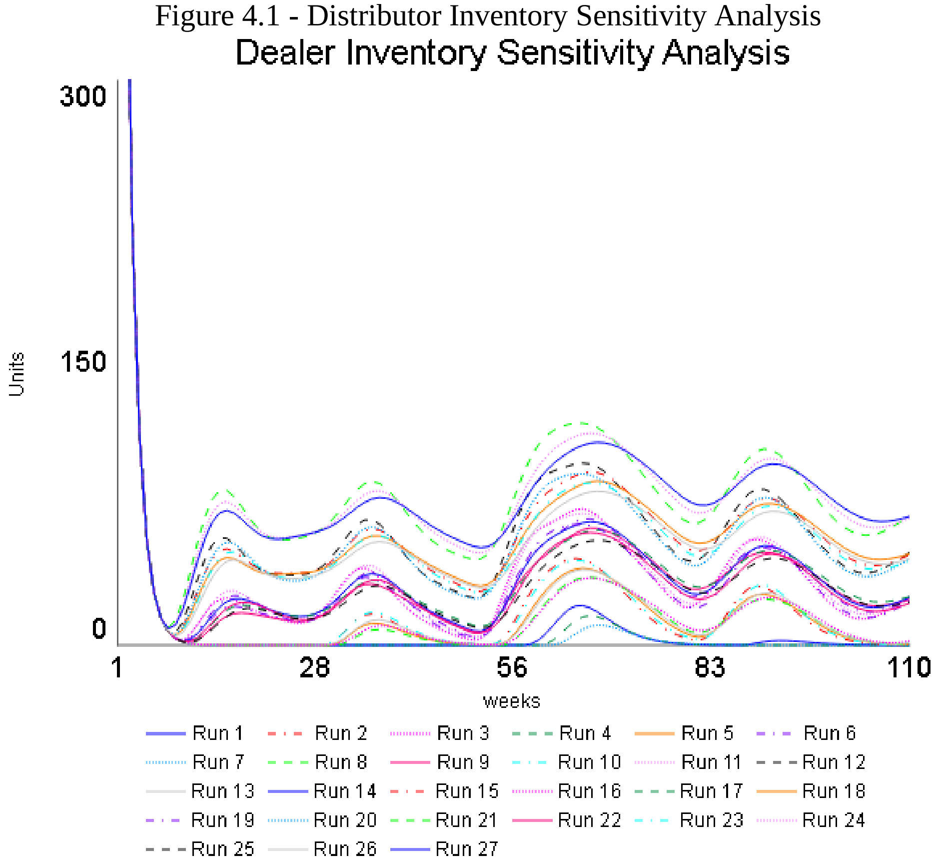

Figure 4.2 - Dealer Inventory Sensitivity Analaysis

V. Analysis of the described Scenarios using STELLA

In the initial bullwhip effect model, over-ordering and reproduction cause increasingly high order quantities and levels of inventory. As seen in the output of the first scenario, the bullwhip effect is minimized by eliminating order batching. While inventory is relatively high compared to orders at the beginning. the two levels stabilize.as more time passes, and order quantities and inventory levels remain steady. This can also be seen in the second scenario which eliminates order batching. However, in the second scenario, the reduction of lead times also contributes to lower inventory levels. Both scenarios were run over the course of fifty-eight weeks.

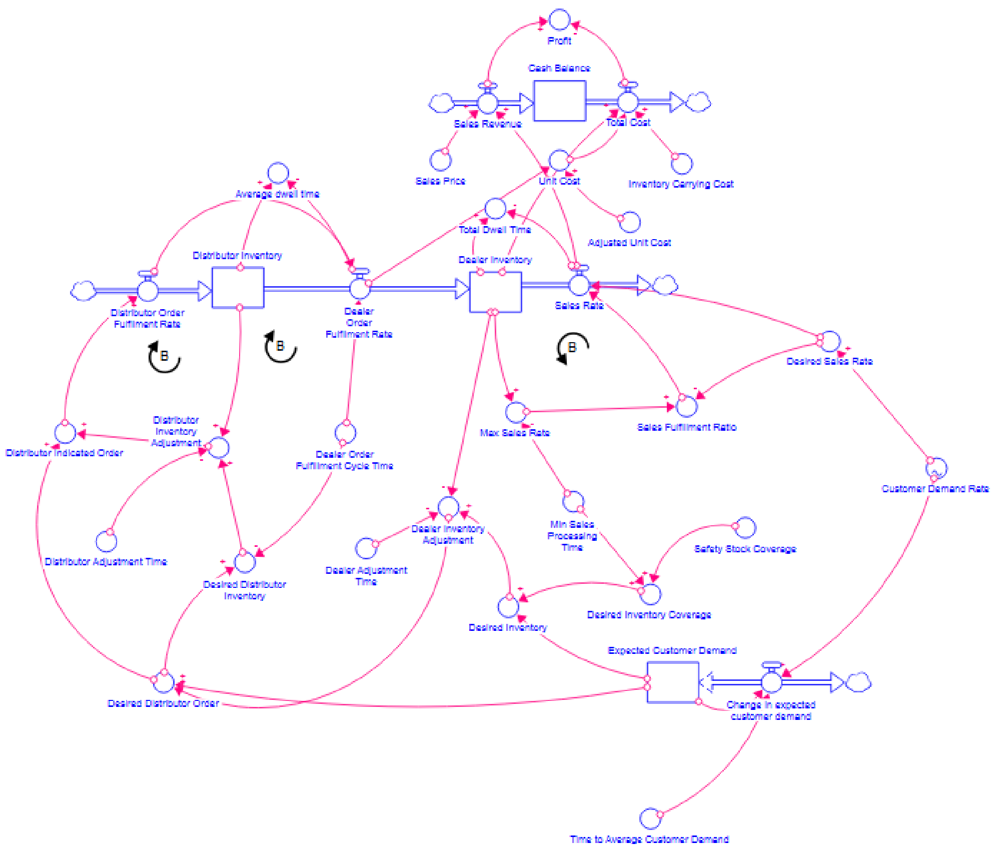

FIGURE 4. HYBRID PUSH/PULL MODEL (MODIFIED FROM STERMAN 2000 PG 768)

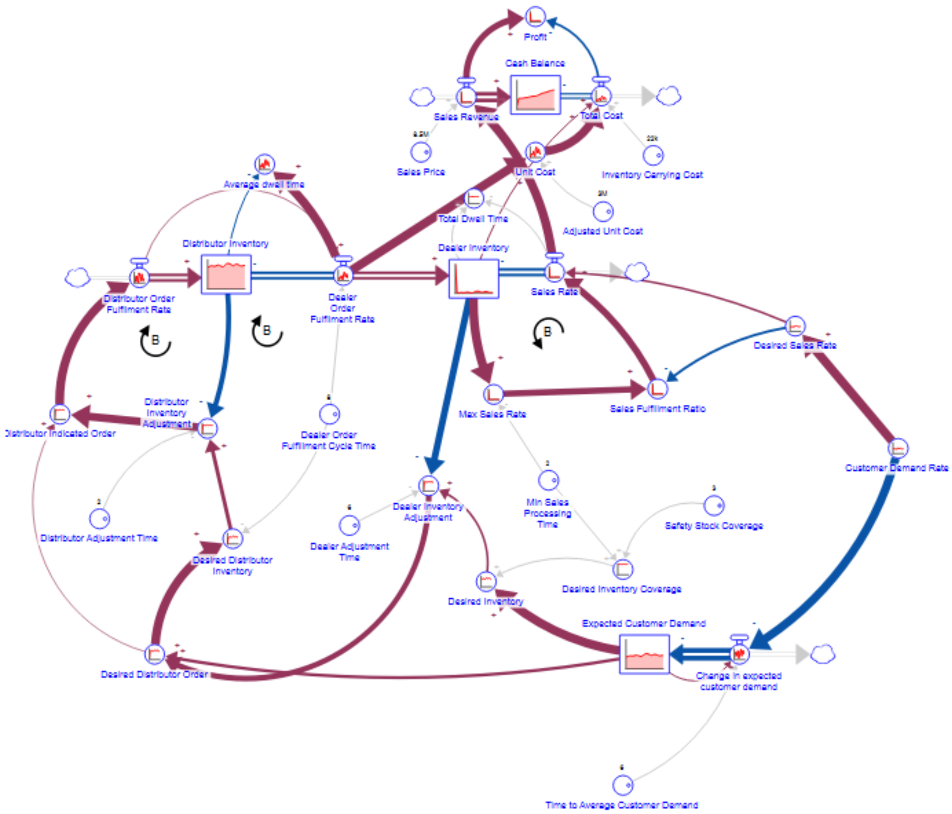

Figure 5. STELLA model of the Network.

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IX. Appendix X

Data Collected Table								
Category of Data	**Operational Definition**	**Model Equations**	**Unit**	**Type**	**Data Availability**	**Data Source**	**Data Quality**	**Notes Summary**
Profit (P)	Denote the amount of money made after costs have been incorporated (Revenues – Costs)	Total Sales-Sales Revenue	NGN	Auxiliary variable	Unknown	Company report	Data not found	This data is fact which is available in the company.
Dealer Inventory (DI)	Denote the current amount of inventory the dealer has in stock ready for shipment to customer	Dealer Order Fulfilment Rate-Sales Rate	Units	Stock variable	Fully available	Company report	Good	This data is fact which is available in the company.
Expected Customer Demand (ECD)	Stands as the value of the expected order rate in this model	(Changes in Demand Expectation, Expected Customer Demand)	Units	Stock variable	Equation	Data not required	Data not required	Non
Distributor Order Fulfilment Rate (DOFR)	Distributor order to replace expected outflow from the stock and reduce any discrepancy between the desired and actual stock	MAX(Distributor Target Inventory, Distributor Indicated Order)	Units/Week	Flow variable	Equation	Data not required	Data not required	Non
Dealer Order Fulfilment Rate (DOFR)	Dealership order's to replace expected sales from the stock and reduce any discrepancies between the desired and actual stock	DELAY3(Distributor Inventory, Dealer Order Fulfilment Cycle Time)	Units/Week	Flow variable	Equation	Data not required	Data not required	Non
Changes in Demand Expectation (CDE)	Denotes changes in incoming orders	(Customer Demand-Expected Customer Demand)/Time to Average Customer Demand	Units/Week	Flow variable	Equation	Data not required	Data not required	Non
Distributor Indicated Order (DIO)	The distributor indicated order is expressed as an anchoring and adjustment process	Desired Distributor Order + Distributor Inventory Adjustment	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Distributor Inventory Adjustment (DIA)	The distributor maintains an adequate inventory of unfilled orders by adjusting it so that ordering are closed to the desired state	(Desired Distributor Inventory-Distributor Inventory)/Distributor Adjustment Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Dealer Order Fulfilment Cycle Time (DOFCT)	Denotes the average transit time for all items aggregated together	Data Required	Week	Auxiliary variable	Equation	Company record	Good	This data is fact which is available in the company.
Dealer Inventory Adjustment (DIA)	The dealer try to maintain an adequate inventory of unfilled orders by adjusting it so that ordering are closed to the desired state	(Desired Inventory-Dealer Inventory)/Dealer Adjustment Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non

Max Sales Rate (MSR)	Denotes the company current inventory level and the minimum order fulfilment time	Dealer Inventory/Min Sales Processing Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Sales Fulfilment Ratio (SFR)	Denotes the function of the ratio of the maximum sales rate to the desired sales rate	(Max Sales Rate/Desired Sales Rate)	Dimensionless	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Sales Rate (DSR)	Indicates that the firm can sell what it wants or what it can sell	Customer Demand	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Min Sales Processing Time (MSPT)	Indicates minimum order fulfilment time is determined by the firms order fulfilment process	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Distributor Adjustment Time (DAT)	Indicates the time it takes to correct the records of the distributor to bring them into agreement with the findings of the actual (physical) inventory from the desired	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	All these data are more or less facts which are available in the company.

Customer Demand (CD)	Is the percentage of customer orders satisfied from stock at hand and a measure of an inventory's ability to meet demand	Data Required	Vehicle	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Desired Distributor Order (DDO)	This is an anchor which is then adjusted by an amount designed to bring the distributor inventory of unfilled orders in line with its goal	MAX(0, Expected Customer Demand + Dealer Inventory Adjustment)	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Time to Average Customer Demand (TACD)	This is the time required, on average, for expectations to respond to change in actual conditions in this model	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Average Dwell Time (ADT)	Calculates the time it takes for the distributor to fulfil dealer order	Distributor Inventory/Dealer Order Fulfilment Rate	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Total Dwell Time (TDT)	Determines the time it takes for the dealer to finally fulfil customer demand	Data Required	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Push Rate (DPR)	The number of inventory push down the supply chain	Data Required	Unit/Week	Auxiliary variable	Available	Company report	Good	This data is fact which is available in the company.

Desired Distributor Inventory (DDI)	This variable provides a level of inventory to yield the desired rate of order given the current dealer order cycle time	Dealer Order Fulfilment Cycle Time*Desired Distributor Order	Units	Auxiliary variable	Equation	Data not required	Data not required	Non
Dealer Adjustment Time (DAT)	Indicates the time it takes to correct the records of the dealer to bring them into agreement with the findings of the actual (physical) inventory from the desired	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Desired Inventory (DI)	Indicates the preferred amount of inventory	Desired Inventory Coverage*Expected Customer Purchases	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Inventory Coverage (DIC)	Denotes the preferred amount of time for which inventory is able to fulfil customer demand	Min Sales Processing Time + Safety Stock Coverage	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Safety Stock Coverage (SSC)	(Also called buffer stock) is a level of extra stock (cars) in this model that is maintained to mitigate risks of stock out due to uncertainties in demand and sales	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.

Adjusted Unit Price (AUP)	Denotes the cost of the company's vehicles which may be adjusted up by adding the initial cash basis used to purchase the asset to the costs associated with increasing the value of the asset	Data Required	NGN	Auxiliary variable	Available	Company report	Average	This data is fact which is available in the company.
Unit Cost (UC)	Denotes the total expenditure incurred by the company to produce, store and sell one unit of vehicle.	Adjusted Unit Price	NGN	Auxiliary variable	Equation	Data not required	Data not required	Non
Inventory Cost (IC)	Denotes the cost of holding inventory	Distributor Unit Carrying Cost	NGN	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Sales Price (SP)	Denotes the price of the company's vehicles for sales.	Data Required	NGN	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Sales Revenue (SR)	Denotes the income from sales of goods and services, minus the cost associated with things like returned or undeliverable merchandise	Sales Price*Sales Rate	NGN/Units	Flow variable	Equation	Data not required	Data not required	Non

Cash Balance (CB)	Denotes the amount of money the company has in the bank at a particular period	Sales Revenue-Total Sales	NGN	Stock variable	Equation	Data not required	Data not required	Non
Total Cost (TC)	Denotes the total expense incurred in reaching a particular level of output by the firm	Unit Cost+(Inventory Cost*Dealer Inventory)	NGN/Unit	Flow variable	Equation	Data not required	Data not required	Non
Distributor Inventory (DI)	Denotes the current amount of inventory the distributor has in stock ready for shipment to dealer	Distributor Order Fulfilment Rate-Dealer Order Fulfilment Rate	Units	Stock variable	Available	Company report	Good	This data is fact which is available in the company.

Run	Distributor Adjustment Time	Time to Average Customer Demand	Safety Stock Coverage
1	1	4	2
2	2	4	2
3	3	4	2
4	1	6	2
5	2	6	2
6	3	6	2
7	1	8	2
8	2	8	2
9	3	8	2
10	1	4	3
11	2	4	3
12	3	4	3
13	1	6	3
14	2	6	3
15	3	6	3
16	1	8	3
17	2	8	3
18	3	8	3
19	1	4	4
20	2	4	4
21	3	4	4
22	1	6	4
23	2	6	4
24	3	6	4
25	1	8	4
26	2	8	4
27	3	8	4

Table A.9 - Sensitivity Analysis Run Values

Part II of the Partial Review: When is the Professor the Customer?

A professor is considered a customer when they prioritize students' understanding, engagement, and growth, influencing their teaching methods and content.

Take Home LP

You have the following logistic network (see Figure 1). As a Supply Chain manager you know that you need to send your only truck available, from either the MN site or the MS site (but not from both), to the to the GN site or the GS site (but not to both).Also, you know that:

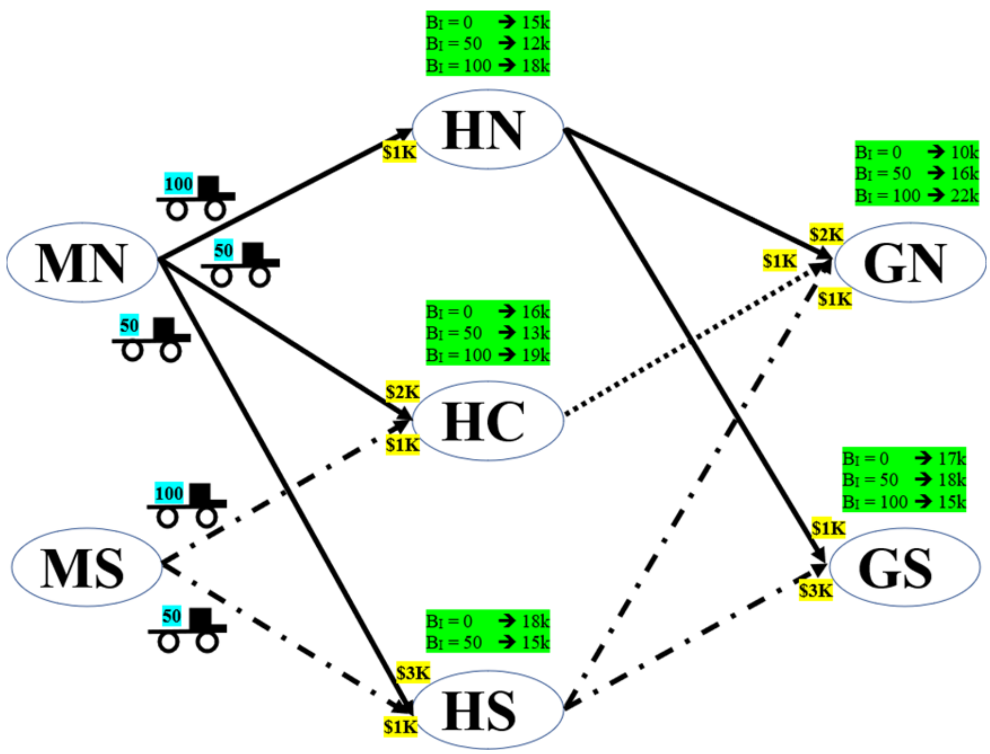
• Depending on where you initially send your only truck, the units of cargo in the truck is going to change (see Figure 1), i.e.50 units of cargo can be sent from MN to HC, while100 units of cargo can be sent from MS to HC.

• When arriving to the HN, HC, HS sites, the truck can leave the 100% of its cargo units, or 50%, or a 0% , where the remaining units of cargo can be used later on the GN or GS sites, i.e. when sending the truck from MS to HC – with 100 units of cargo –if 50 units are left at this last site (so the Beginning Inventory or BI at HC would be 50), the remaining units of cargo left in the truck, will be used on the next site (either GN or GS).

• Depending on the BI at each site, an expected profit is expected (see Figure 1), i.e. a BI of 100 units of cargo at the HN site, a profit of 18k is expected.

• There is a transportation cost between sites (see Figure 1). Use a Linear Programing approach to establish the most profitable route.

1.



(Figure 1)

We offer two distinct solutions to address this challenge: maximizing the total profit and maximizing the profit per unit. These alternatives provide decision-makers with comprehensive insights into different facets of the problem, enabling them to make informed decisions tailored to their specific scenarios.

2. Let's first consider the solution for maximizing total profit:

Max = 15*B_HN_0+12*B_HN_50+18*B_HN_100

+16*B_HC_0+13*B_HC_50+19*B_HC_100

+18*B_HS_0+15*B_HS_50

+10*B_GN_0+16*B_GN_50+22*B_GN_100

+17*B_GS_0+18*B_GS_50+15*B_GS_100

-1*X_MN_HN-2*X_HN_GN-1*X_HN_GS-2*X_MN_HC-1*X_HC_GN-3*X_MN_HS-1*X_HS_GN-3*X_HS_GS-1*X_MS_HC-1*X_MS_HS;

Subject to:
X_MN_HN+X_MN_HC+X_MN_HS+X_MS_HC+X_MS_HS=1;

X_MN_HN+X_HC_GN<=1;

X_MN_HN+X_HS_GN<=1;

X_MN_HN+X_HS_GS<=1;

X_MN_HC+X_HN_GN<=1;

X_MN_HC+X_HN_GS<=1;

X_MN_HC+X_HS_GN<=1;

X_MN_HC+X_HS_GS<=1;

X_MN_HS+X_HN_GN<=1;

X_MN_HS+X_HN_GS<=1;

X_MN_HS+X_HC_GN<=1;

X_MS_HC+X_HN_GN<=1;

X_MS_HC+X_HN_GS<=1;

X_MS_HC+X_HS_GN<=1;

X_MS_HC+X_HS_GS<=1;

X_MS_HS+X_HN_GN<=1;

X_MS_HS+X_HN_GS<=1;

X_MS_HS+X_HC_GN<=1;

X_MN_HN<=X_HN_GN+X_HN_GS;

X_MN_HC<=X_HC_GN;

X_MN_HS<=X_HS_GN+X_HS_GS;

X_MS_HC<=X_HC_GN;

X_MS_HS<=X_HS_GN+X_HS_GS;

B_HN_0+B_HN_50+B_HN_100+B_HC_0+B_HC_50+B_HC_100+B_HS_0+B_HS_50=1;

B_GN_0+B_GN_50+B_GN_100+B_GS_0+B_GS_50+B_GS_100=1;

B_HN_0+B_GN_0<=1;

B_HN_0+B_GS_0<=1;

B_HN_50+B_GN_100<=1;

B_HN_50+B_GS_100<=1;

B_HN_100+B_GN_100<=1;

B_HN_100+B_GN_50<=1;

B_HN_100+B_GS_100<=1;

B_HN_100+B_GS_50<=1;

B_HC_0+B_GN_0<=1;

B_HC_50+B_GN_100<=1;

B_HC_100+B_GN_100<=1;

B_HC_100+B_GN_50<=1;

B_HS_0+B_GN_0<=1;

B_HS_0+B_GS_100<=1;

B_HS_0+B_GS_0<=1;

B_HS_0+B_GN_100<=1;

B_HS_50+B_GN_50<=1;

B_HS_50+B_GS_50<=1;

B_HS_50+B_GN_100<=1;

B_HS_50+B_GS_100<=1;

X_MN_HN+B_HC_0<=1; X_MN_HN+B_HC_50<=1; X_MN_HN+B_HC_100<=1; X_MN_HN+B_HS_0<=1; X_MN_HN+B_HS_50<=1;

X_HN_GN+B_GS_0<=1; X_HN_GN+B_GS_50<=1; X_HN_GN+B_GS_100<=1;

X_HN_GS+B_GN_0<=1; X_HN_GS+B_GN_50<=1; X_HN_GS+B_GN_100<=1;

X_MN_HC+B_HN_0<=1; X_MN_HC+B_HN_50<=1; X_MN_HC+B_HN_100<=1; X_MN_HC+B_HS_0<=1; X_MN_HC+B_HS_50<=1;

X_HC_GN+B_GS_0<=1; X_HC_GN+B_GS_50<=1; X_HC_GN+B_GS_100<=1;

X_MN_HS+B_HN_0<=1; X_MN_HS+B_HN_50<=1; X_MN_HS+B_HN_100<=1; X_MN_HS+B_HC_0<=1; X_MN_HS+B_HC_50<=1; X_MN_HS+B_HC_100<=1;

X_HS_GN+B_GS_0<=1; X_HS_GN+B_GS_50<=1; X_HS_GN+B_GS_100<=1;

X_HS_GS+B_GN_0<=1; X_HS_GS+B_GN_50<=1; X_HS_GS+B_GN_100<=1;

X_MS_HC+B_HN_0<=1; X_MS_HC+B_HN_50<=1; X_MS_HC+B_HN_100<=1; X_MS_HC+B_HS_0<=1; X_MS_HC+B_HS_50<=1;

X_MS_HS+B_HN_0<=1; X_MS_HS+B_HN_50<=1; X_MS_HS+B_HN_100<=1; X_MS_HS+B_HC_0<=1; X_MS_HS+B_HC_50<=1; X_MS_HS+B_HC_100<=1;

Whereas, All variables are binary variables

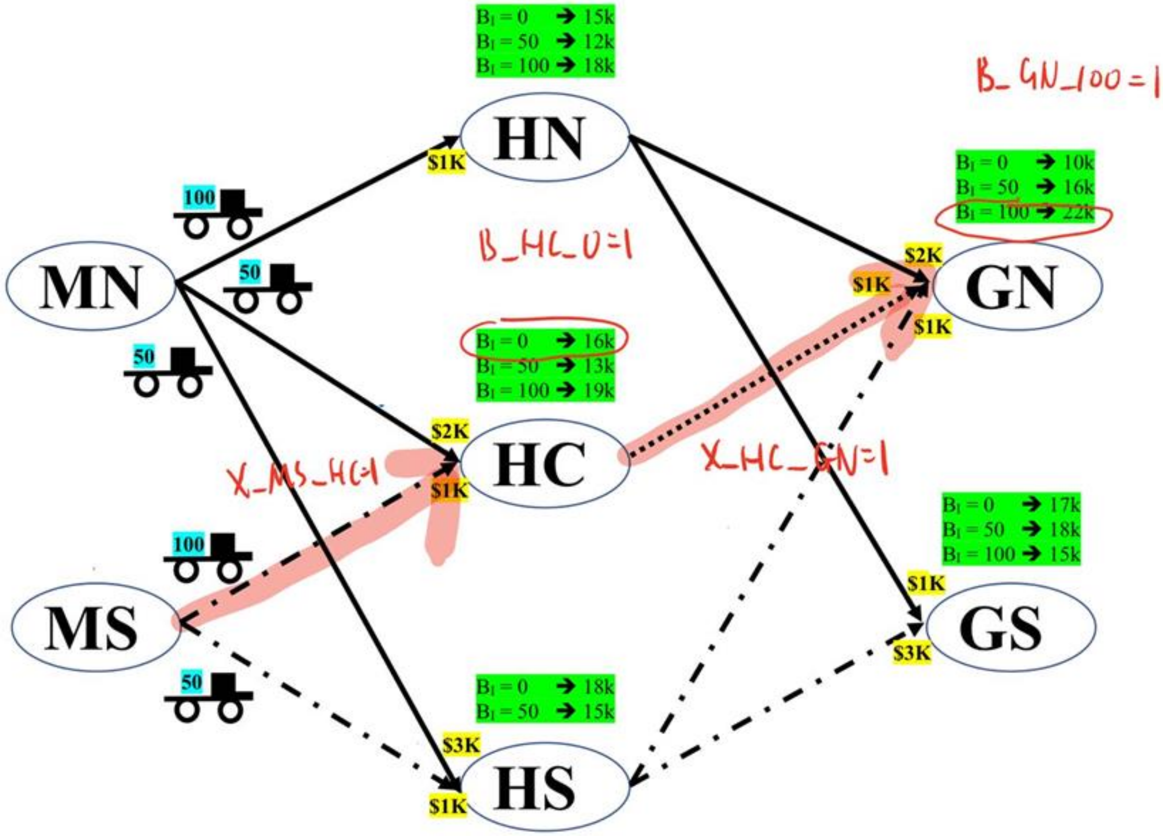
3.- LINGO/AMPL code

```
Max = 15*B_HN_0+12*B_HN_50+18*B_HN_100
     +16*B_HC_0+13*B_HC_50+19*B_HC_100
     +18*B_HS_0+15*B_HS_50
     +10*B_GN_0+16*B_GN_50+22*B_GN_100
     +17*B_GS_0+18*B_GS_50+15*B_GS_100
     -1*X_MN_HN-2*X_HN_GN-1*X_HN_GS-2*X_MN_HC-1*X_HC_GN-3*X_MN_HS-1*X_HS_GN-3*X_HS_GS-
1*X_MS_HC-1*X_MS_HS;

X_MN_HN+X_MN_HC+X_MN_HS+X_MS_HC+X_MS_HS=1;

X_MN_HN+X_HC_GN<=1;
X_MN_HN+X_HS_GN<=1;
X_MN_HN+X_HS_GS<=1;
X_MN_HC+X_HN_GN<=1;
X_MN_HC+X_HN_GS<=1;
X_MN_HC+X_HS_GN<=1;
X_MN_HC+X_HS_GS<=1;
X_MN_HS+X_HN_GN<=1;
X_MN_HS+X_HN_GS<=1;
X_MN_HS+X_HC_GN<=1;
X_MS_HC+X_HN_GN<=1;
X_MS_HC+X_HN_GS<=1;
X_MS_HC+X_HS_GN<=1;
X_MS_HC+X_HS_GS<=1;
X_MS_HS+X_HN_GN<=1;
X_MS_HS+X_HN_GS<=1;
X_MS_HS+X_HC_GN<=1;

X_MN_HN<=X_HN_GN+X_HN_GS;
X_MN_HC<=X_HC_GN;
X_MN_HS<=X_HS_GN+X_HS_GS;
```

```
X_MS_HC<=X_HC_GN;
X_MS_HS<=X_HS_GN+X_HS_GS;

B_HN_0+B_HN_50+B_HN_100+B_HC_0+B_HC_50+B_HC_100+B_HS_0+B_HS_50=1;
B_GN_0+B_GN_50+B_GN_100+B_GS_0+B_GS_50+B_GS_100=1;

B_HN_0+B_GN_0<=1;
B_HN_0+B_GS_0<=1;
B_HN_50+B_GN_100<=1;
B_HN_50+B_GS_100<=1;
B_HN_100+B_GN_100<=1;
B_HN_100+B_GN_50<=1;
B_HN_100+B_GS_100<=1;
B_HN_100+B_GS_50<=1;


B_HC_0+B_GN_0<=1;
B_HC_50+B_GN_100<=1;
B_HC_100+B_GN_100<=1;
B_HC_100+B_GN_50<=1;


B_HS_0+B_GN_0<=1;
B_HS_0+B_GS_100<=1;
B_HS_0+B_GS_0<=1;
B_HS_0+B_GN_100<=1;
B_HS_50+B_GN_50<=1;
B_HS_50+B_GS_50<=1;
B_HS_50+B_GN_100<=1;
B_HS_50+B_GS_100<=1;


X_MN_HN+B_HC_0<=1; X_MN_HN+B_HC_50<=1; X_MN_HN+B_HC_100<=1; X_MN_HN+B_HS_0<=1;
X_MN_HN+B_HS_50<=1;
X_HN_GN+B_GS_0<=1; X_HN_GN+B_GS_50<=1; X_HN_GN+B_GS_100<=1;
X_HN_GS+B_GN_0<=1; X_HN_GS+B_GN_50<=1; X_HN_GS+B_GN_100<=1;
X_MN_HC+B_HN_0<=1; X_MN_HC+B_HN_50<=1; X_MN_HC+B_HN_100<=1; X_MN_HC+B_HS_0<=1;
X_MN_HC+B_HS_50<=1;
X_HC_GN+B_GS_0<=1; X_HC_GN+B_GS_50<=1; X_HC_GN+B_GS_100<=1;
X_MN_HS+B_HN_0<=1; X_MN_HS+B_HN_50<=1; X_MN_HS+B_HN_100<=1; X_MN_HS+B_HC_0<=1;
X_MN_HS+B_HC_50<=1; X_MN_HS+B_HC_100<=1;
X_HS_GN+B_GS_0<=1; X_HS_GN+B_GS_50<=1; X_HS_GN+B_GS_100<=1;
X_HS_GS+B_GN_0<=1; X_HS_GS+B_GN_50<=1; X_HS_GS+B_GN_100<=1;
X_MS_HC+B_HN_0<=1; X_MS_HC+B_HN_50<=1; X_MS_HC+B_HN_100<=1; X_MS_HC+B_HS_0<=1;
X_MS_HC+B_HS_50<=1;
X_MS_HS+B_HN_0<=1; X_MS_HS+B_HN_50<=1; X_MS_HS+B_HN_100<=1; X_MS_HS+B_HC_0<=1;
X_MS_HS+B_HC_50<=1; X_MS_HS+B_HC_100<=1;

@GIN(B_HN_0);
@GIN(B_HN_50);
@GIN(B_HN_100);
@GIN(B_HC_0);
@GIN(B_HC_50);
@GIN(B_HC_100);
@GIN(B_HS_0);
```

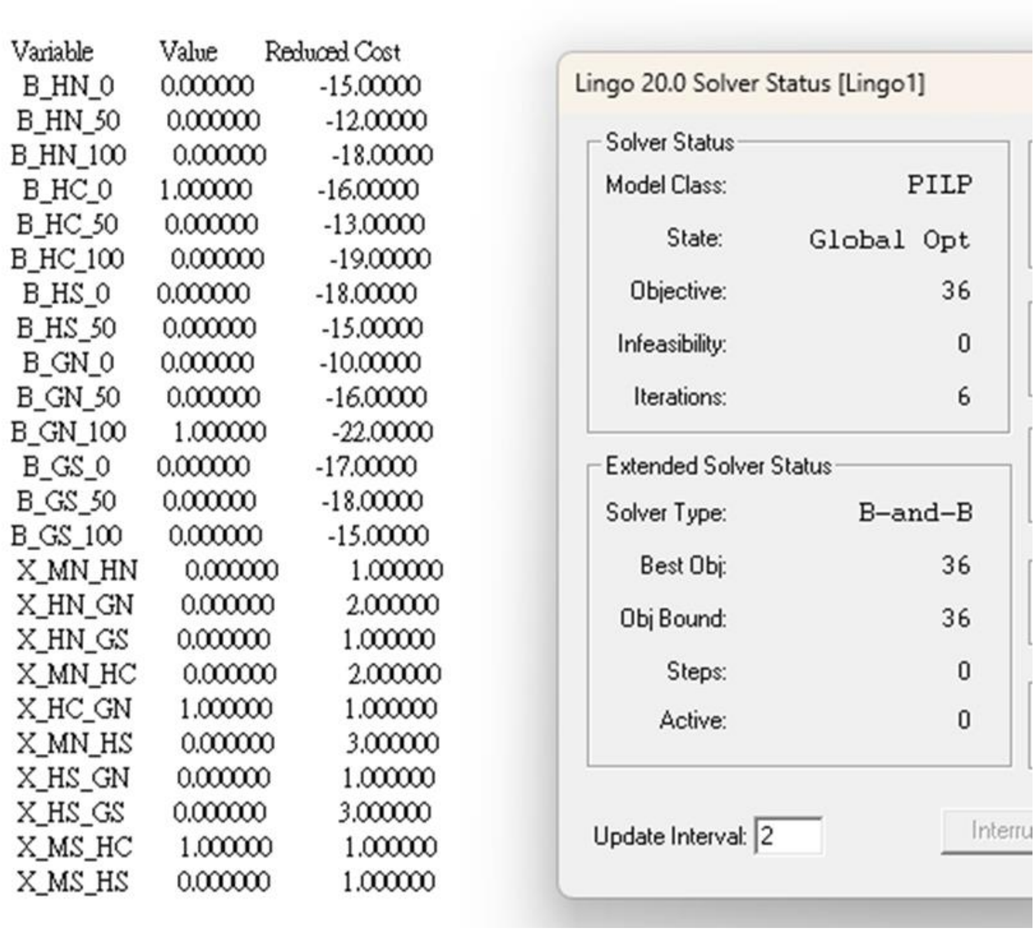
```
@GIN(B_HS_50);
@GIN(B_GN_0);
@GIN(B_GN_50);
@GIN(B_GN_100);
@GIN(B_GS_0);
@GIN(B_GS_50);
@GIN(B_GS_100);
@GIN(X_MN_HN);
@GIN(X_HN_GN);
@GIN(X_HN_GS);
@GIN(X_MN_HC);
@GIN(X_HC_GN);
@GIN(X_MN_HS);
@GIN(X_HS_GN);
@GIN(X_HS_GS);
@GIN(X_MS_HC);
@GIN(X_MS_HS);

End
```

4.- Solution (software output and graphical representation)



B_GN_100 = 1
B_HC_0=1
X_MS_HC=1
X_HC_GN=1
MN
MS
HN
HC
HS
GN
GS
100
50
50
100
50
$1K
$2K
$1K
$3K
$1K
$2K
$1K
$1K
$1K
$3K
$B_I = 0 \rightarrow 15k$
$B_I = 50 \rightarrow 12k$
$B_I = 100 \rightarrow 18k$
$B_I = 0 \rightarrow 16k$
$B_I = 50 \rightarrow 13k$
$B_I = 100 \rightarrow 19k$
$B_I = 0 \rightarrow 18k$
$B_I = 50 \rightarrow 15k$
$B_I = 0 \rightarrow 10k$
$B_I = 50 \rightarrow 16k$
$B_I = 100 \rightarrow 22k$
$B_I = 0 \rightarrow 17k$
$B_I = 50 \rightarrow 18k$
$B_I = 100 \rightarrow 15k$

Figure 1



Variable	Value	Reduced Cost
B_HN_0	0.000000	-15.00000
B_HN_50	0.000000	-12.00000
B_HN_100	0.000000	-18.00000
B_HC_0	1.000000	-16.00000
B_HC_50	0.000000	-13.00000
B_HC_100	0.000000	-19.00000
B_HS_0	0.000000	-18.00000
B_HS_50	0.000000	-15.00000
B_GN_0	0.000000	-10.00000
B_GN_50	0.000000	-16.00000
B_GN_100	1.000000	-22.00000
B_GS_0	0.000000	-17.00000
B_GS_50	0.000000	-18.00000
B_GS_100	0.000000	-15.00000
X_MN_HN	0.000000	1.000000
X_HN_GN	0.000000	2.000000
X_HN_GS	0.000000	1.000000
X_MN_HC	0.000000	2.000000
X_HC_GN	1.000000	1.000000
X_MN_HS	0.000000	3.000000
X_HS_GN	0.000000	1.000000
X_HS_GS	0.000000	3.000000
X_MS_HC	1.000000	1.000000
X_MS_HS	0.000000	1.000000

Objective Function Solution: Max Total Profit=*MS_HC_GN*=16−1−1+22=36(k)

This calculation reveals that the maximum total profit is achieved by transporting 100 units. However, when evaluating the maximum profit per unit, the same route may not yield the highest value. This is because the total profit needs to be divided by the number of units. Therefore, a route transporting fewer units, such as 50, might have a higher profit per unit.

Second is the Maximum profit per unit

We are using the same objective but adding the units for each route at the end to the dividend (red part).

Max z = (15*B_HN_0+12*B_HN_50+18*B_HN_100
+16*B_HC_0+13*B_HC_50+19*B_HC_100
+18*B_HS_0+15*B_HS_50
+10*B_GN_0+16*B_GN_50+22*B_GN_100
+17*B_GS_0+18*B_GS_50+15*B_GS_100
-1*X_MN_HN-2*X_HN_GN-1*X_HN_GS-2*X_MN_HC-1*X_HC_GN-3*X_MN_HS-1*X_HS_GN-3*X_HS_GS-1*X_MS_HC-1*X_MS_HS)/(100*X_MN_HN+50*X_MN_HC+50*X_MN_HS+100*X_MS_HC+50*X_MS_HS)

Max z = (15*B_HN_0+12*B_HN_50+18*B_HN_100
+16*B_HC_0+13*B_HC_50+19*B_HC_100

+18*B_HS_0+15*B_HS_50
+10*B_GN_0+16*B_GN_50+22*B_GN_100
+17*B_GS_0+18*B_GS_50+15*B_GS_100
-1*X_MN_HN-2*X_HN_GN-1*X_HN_GS-2*X_MN_HC-1*X_HC_GN-3*X_MN_HS-1*X_HS_GN-3*X_HS_GS-1*X_MS_HC-1*X_MS_HS)/(100*X_MN_HN+50*X_MN_HC+50*X_MN_HS+100*X_MS_HC+50*X_MS_HS)

Subject to:

X_MN_HN+X_MN_HC+X_MN_HS+X_MS_HC+X_MS_HS=1;

X_MN_HN+X_HC_GN<=1;
X_MN_HN+X_HS_GN<=1;
X_MN_HN+X_HS_GS<=1;
X_MN_HC+X_HN_GN<=1;
X_MN_HC+X_HN_GS<=1;
X_MN_HC+X_HS_GN<=1;
X_MN_HC+X_HS_GS<=1;
X_MN_HS+X_HN_GN<=1;
X_MN_HS+X_HN_GS<=1;
X_MN_HS+X_HC_GN<=1;
X_MS_HC+X_HN_GN<=1;
X_MS_HC+X_HN_GS<=1;
X_MS_HC+X_HS_GN<=1;
X_MS_HC+X_HS_GS<=1;
X_MS_HS+X_HN_GN<=1;
X_MS_HS+X_HN_GS<=1;
X_MS_HS+X_HC_GN<=1;

X_MN_HN<=X_HN_GN+X_HN_GS;
X_MN_HC<=X_HC_GN;
X_MN_HS<=X_HS_GN+X_HS_GS;
X_MS_HC<=X_HC_GN;
X_MS_HS<=X_HS_GN+X_HS_GS;

B_HN_0+B_HN_50+B_HN_100+B_HC_0+B_HC_50+B_HC_100+B_HS_0+B_HS_50=1;
B_GN_0+B_GN_50+B_GN_100+B_GS_0+B_GS_50+B_GS_100=1;

B_HN_0+B_GN_0<=1;
B_HN_0+B_GS_0<=1;
B_HN_50+B_GN_100<=1;
B_HN_50+B_GS_100<=1;
B_HN_100+B_GN_100<=1;
B_HN_100+B_GN_50<=1;
B_HN_100+B_GS_100<=1;
B_HN_100+B_GS_50<=1;

B_HC_0+B_GN_0<=1;
X_MN_HC+B_HC_0+B_GN_100<=2;

B_HC_50+B_GN_100<=1;
B_HC_100+B_GN_100<=1;
B_HC_100+B_GN_50<=1;

B_HS_0+B_GN_0<=1;
B_HS_0+B_GS_100<=1;
B_HS_0+B_GS_0<=1;
B_HS_0+B_GN_100<=1;
B_HS_50+B_GN_50<=1;
B_HS_50+B_GS_50<=1;
B_HS_50+B_GN_100<=1;
B_HS_50+B_GS_100<=1;

X_MN_HN+B_HC_0<=1; X_MN_HN+B_HC_50<=1; X_MN_HN+B_HC_100<=1; X_MN_HN+B_HS_0<=1;
X_MN_HN+B_HS_50<=1;
X_HN_GN+B_GS_0<=1; X_HN_GN+B_GS_50<=1; X_HN_GN+B_GS_100<=1;
X_HN_GS+B_GN_0<=1; X_HN_GS+B_GN_50<=1; X_HN_GS+B_GN_100<=1;
X_MN_HC+B_HN_0<=1; X_MN_HC+B_HN_50<=1; X_MN_HC+B_HN_100<=1; X_MN_HC+B_HS_0<=1;
X_MN_HC+B_HS_50<=1;
X_HC_GN+B_GS_0<=1; X_HC_GN+B_GS_50<=1; X_HC_GN+B_GS_100<=1;
X_MN_HS+B_HN_0<=1; X_MN_HS+B_HN_50<=1; X_MN_HS+B_HN_100<=1; X_MN_HS+B_HC_0<=1;
X_MN_HS+B_HC_50<=1; X_MN_HS+B_HC_100<=1;
X_HS_GN+B_GS_0<=1; X_HS_GN+B_GS_50<=1; X_HS_GN+B_GS_100<=1;
X_HS_GS+B_GN_0<=1; X_HS_GS+B_GN_50<=1; X_HS_GS+B_GN_100<=1;
X_MS_HC+B_HN_0<=1; X_MS_HC+B_HN_50<=1; X_MS_HC+B_HN_100<=1; X_MS_HC+B_HS_0<=1;
X_MS_HC+B_HS_50<=1;
X_MS_HS+B_HN_0<=1; X_MS_HS+B_HN_50<=1; X_MS_HS+B_HN_100<=1; X_MS_HS+B_HC_0<=1;
X_MS_HS+B_HC_50<=1; X_MS_HS+B_HC_100<=1;

Whereas, All variables are binary variables

3.- LINGO/AMPL code

```
Max =(15*B_HN_0+12*B_HN_50+18*B_HN_100
     +16*B_HC_0+13*B_HC_50+19*B_HC_100
     +18*B_HS_0+15*B_HS_50
     +10*B_GN_0+16*B_GN_50+22*B_GN_100
     +17*B_GS_0+18*B_GS_50+15*B_GS_100
     -1*X_MN_HN-2*X_HN_GN-1*X_HN_GS-2*X_MN_HC-1*X_HC_GN-3*X_MN_HS-1*X_HS_GN-3*X_HS_GS-1*X_MS_HC-
1*X_MS_HS)/(100*X_MN_HN+50*X_MN_HC+50*X_MN_HS+100*X_MS_HC+50*X_MS_HS);
X_MN_HN+X_MN_HC+X_MN_HS+X_MS_HC+X_MS_HS=1;

X_MN_HN+X_HC_GN<=1;
X_MN_HN+X_HS_GN<=1;
X_MN_HN+X_HS_GS<=1;
X_MN_HC+X_HN_GN<=1;
X_MN_HC+X_HN_GS<=1;
X_MN_HC+X_HS_GN<=1;
X_MN_HC+X_HS_GS<=1;
X_MN_HS+X_HN_GN<=1;
```

```
X_MN_HS+X_HN_GS<=1;
X_MN_HS+X_HC_GN<=1;
X_MS_HC+X_HN_GN<=1;
X_MS_HC+X_HN_GS<=1;
X_MS_HC+X_HS_GN<=1;
X_MS_HC+X_HS_GS<=1;
X_MS_HS+X_HN_GN<=1;
X_MS_HS+X_HN_GS<=1;
X_MS_HS+X_HC_GN<=1;

X_MN_HN<=X_HN_GN+X_HN_GS;
X_MN_HC<=X_HC_GN;
X_MN_HS<=X_HS_GN+X_HS_GS;
X_MS_HC<=X_HC_GN;
X_MS_HS<=X_HS_GN+X_HS_GS;

B_HN_0+B_HN_50+B_HN_100+B_HC_0+B_HC_50+B_HC_100+B_HS_0+B_HS_50=1;
B_GN_0+B_GN_50+B_GN_100+B_GS_0+B_GS_50+B_GS_100=1;

B_HN_0+B_GN_0<=1;
B_HN_0+B_GS_0<=1;
B_HN_50+B_GN_100<=1;
B_HN_50+B_GS_100<=1;
B_HN_100+B_GN_100<=1;
B_HN_100+B_GN_50<=1;
B_HN_100+B_GS_100<=1;
B_HN_100+B_GS_50<=1;


B_HC_0+B_GN_0<=1;
X_MN_HC+B_HC_0+B_GN_100<=2;
B_HC_50+B_GN_100<=1;
B_HC_100+B_GN_100<=1;
B_HC_100+B_GN_50<=1;

B_HS_0+B_GN_0<=1;
B_HS_0+B_GS_100<=1;
B_HS_0+B_GS_0<=1;
B_HS_0+B_GN_100<=1;
B_HS_50+B_GN_50<=1;
B_HS_50+B_GS_50<=1;
B_HS_50+B_GN_100<=1;
B_HS_50+B_GS_100<=1;

X_MN_HN+B_HC_0<=1; X_MN_HN+B_HC_50<=1; X_MN_HN+B_HC_100<=1; X_MN_HN+B_HS_0<=1; X_MN_HN+B_HS_50<=1;
X_HN_GN+B_GS_0<=1; X_HN_GN+B_GS_50<=1; X_HN_GN+B_GS_100<=1;
X_HN_GS+B_GN_0<=1; X_HN_GS+B_GN_50<=1; X_HN_GS+B_GN_100<=1;
X_MN_HC+B_HN_0<=1; X_MN_HC+B_HN_50<=1; X_MN_HC+B_HN_100<=1; X_MN_HC+B_HS_0<=1; X_MN_HC+B_HS_50<=1;
X_HC_GN+B_GS_0<=1; X_HC_GN+B_GS_50<=1; X_HC_GN+B_GS_100<=1;
X_MN_HS+B_HN_0<=1; X_MN_HS+B_HN_50<=1; X_MN_HS+B_HN_100<=1; X_MN_HS+B_HC_0<=1; X_MN_HS+B_HC_50<=1;
X_MN_HS+B_HC_100<=1;
X_HS_GN+B_GS_0<=1; X_HS_GN+B_GS_50<=1; X_HS_GN+B_GS_100<=1;
X_HS_GS+B_GN_0<=1; X_HS_GS+B_GN_50<=1; X_HS_GS+B_GN_100<=1;
X_MS_HC+B_HN_0<=1; X_MS_HC+B_HN_50<=1; X_MS_HC+B_HN_100<=1; X_MS_HC+B_HS_0<=1; X_MS_HC+B_HS_50<=1;
X_MS_HS+B_HN_0<=1; X_MS_HS+B_HN_50<=1; X_MS_HS+B_HN_100<=1; X_MS_HS+B_HC_0<=1; X_MS_HS+B_HC_50<=1;
X_MS_HS+B_HC_100<=1;
```

```
@GIN(B_HN_0);
@GIN(B_HN_50);
@GIN(B_HN_100);
@GIN(B_HC_0);
@GIN(B_HC_50);
@GIN(B_HC_100);
@GIN(B_HS_0);
@GIN(B_HS_50);
@GIN(B_GN_0);
@GIN(B_GN_50);
@GIN(B_GN_100);
@GIN(B_GS_0);
@GIN(B_GS_50);
@GIN(B_GS_100);
@GIN(X_MN_HN);
@GIN(X_HN_GN);
@GIN(X_HN_GS);
@GIN(X_MN_HC);
@GIN(X_HC_GN);
@GIN(X_MN_HS);
@GIN(X_HS_GN);
@GIN(X_HS_GS);
@GIN(X_MS_HC);
@GIN(X_MS_HS);

end
```

4.- Solution (software output and graphical representation)

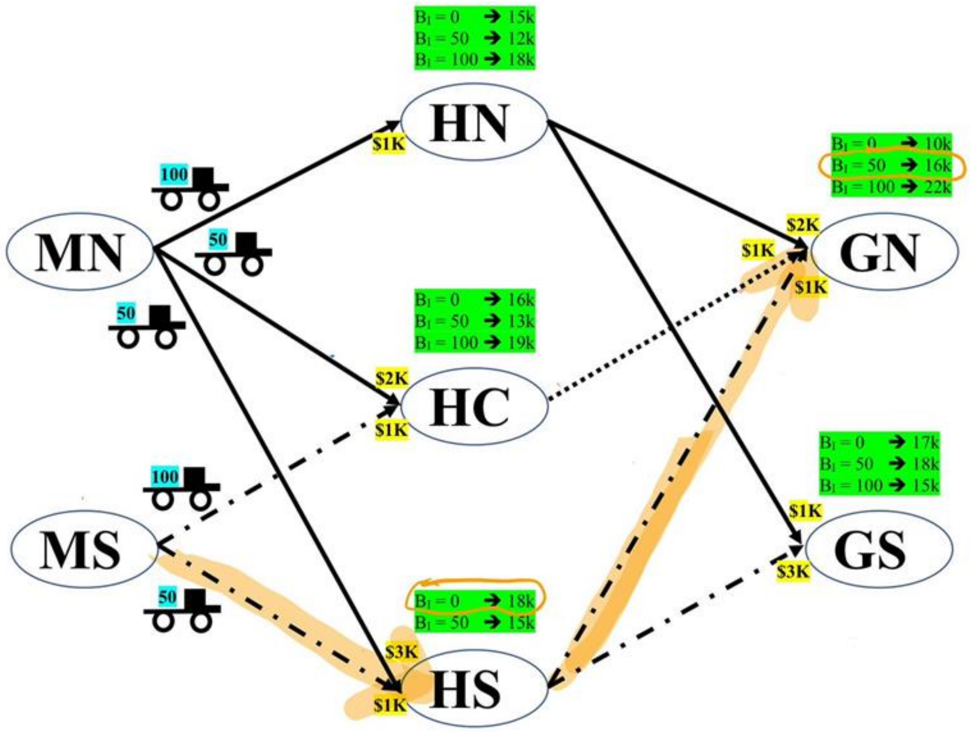
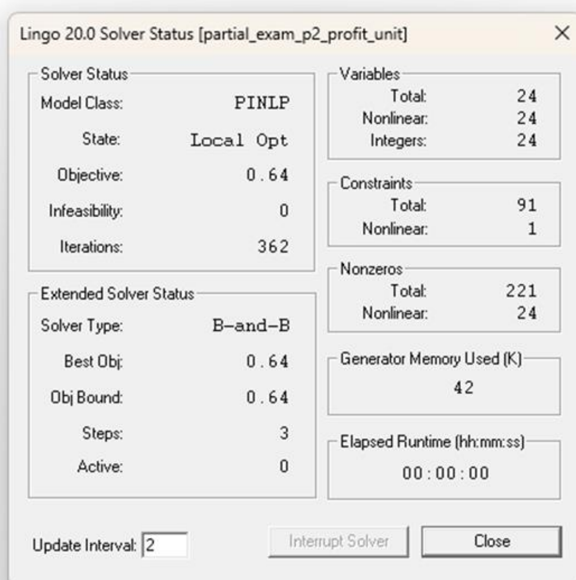


Figure 1

Variable	Value	Reduced Cost
B_HN_0	0.000000	0.6000000E-01
B_HN_50	0.000000	0.1200000
B_HN_100	0.000000	0.000000
B_HC_0	0.000000	0.4000000E-01
B_HC_50	0.000000	0.1000000
B_HC_100	0.000000	0.000000
B_HS_0	1.000000	0.000000
B_HS_50	0.000000	0.6000000E-01
B_GN_0	0.000000	0.1600000
B_GN_50	1.000000	0.4000000E-01
B_GN_100	0.000000	-0.8000000E-01
B_GS_0	0.000000	0.2000000E-01
B_GS_50	0.000000	0.000000
B_GS_100	0.000000	0.6000000E-01
X_MN_HN	0.000000	0.6200001
X_HN_GN	0.000000	0.2000000E-01
X_HN_GS	0.000000	0.000000
X_MN_HC	0.000000	0.000000
X_HC_GN	0.000000	0.000000
X_MN_HS	0.000000	0.000000
X_HS_GN	1.000000	0.000000
X_HS_GS	0.000000	0.4000000E-01
X_MS_HC	0.000000	0.6000001
X_MS_HS	1.000000	0.000000

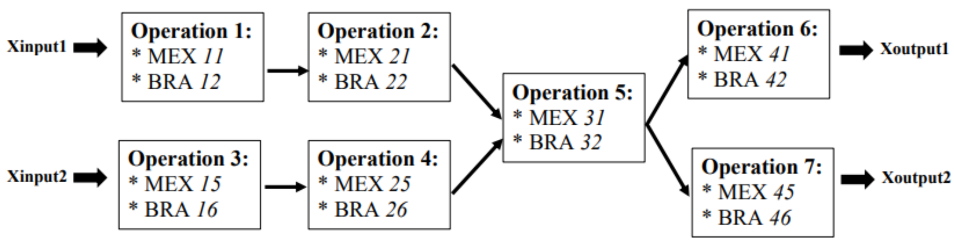


Second possible solution: Max Profit *per Unit=MN_HS_GN*=(18−1−1+16) k */ 50 units* =0.64(k/unit)

As illustrated, maximizing the profit per unit results in a value of 0.64 k per unit, showcasing the importance of considering unit quantities in the decision-making process.

In this linear program, the objective function is to maximize flow through two interconnected processes, subject to the constraints that only one occur per node combined country/node operation in two separate flows. In plain language, there are two transformation processes at work, that briefly come together in node 5, and then are separated agin to their respective outputs.

A depiction of the model is below:



Transformation Operations Costs are:

Manufacturing Country	Operation #						
	1	2	3	4	5	6	7
MEX	10	20	40	30	30	10	50
BRA	20	10	30	40	40	20	30

With new constraints

Manufacturing Country	Operation #
	5
GER	50

:

Shipping Costs are:

	Shipment #											
	1: Op#1 - Op# 2		2: Op#2 – Op#5		3: Op#3 – Op#4		4: Op#4 – Op#5		5: Op#5 – Op#6		6: Op#5 – Op#7	
	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA
MEX	500	300	200	250	300	150	100	200	200	300	150	200
BRA	200	100	300	500	200	400	250	300	500	400	250	400

With new constraints:

	Shipment #					
	2: Op#2 – Op#5	4: Op#4 – Op#5	5: Op#5 – Op#6		6: Op#5 – Op#7	
	GER	GER	MEX	BRA	MEX	BRA
MEX	450	150				
BRA	350	400				
GER			100	600	100	350

Maximum Flow Capacities for arcs are:

	Shipment #											
	1: Op#1 - Op# 2		2: Op#2 – Op#5		3: Op#3 – Op#4		4: Op#4 – Op#5		5: Op#5 – Op#6		6: Op#5 – Op#7	
	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA	MEX	BRA
MEX	3000	2000	6000	4000	5000	6000	5000	2000	4000	4000	6000	5000
BRA	1000	4000	3000	2000	2000	4000	3000	4000	5000	6000	4000	2000

With new constraints:

	Shipment #					
	2: Op#2 – Op#5	4: Op#4 – Op#5	5: Op#5 – Op#6		6: Op#5 – Op#7	
	GER	GER	MEX	BRA	MEX	BRA
MEX	from 8000 to 9000					
BRA		from 5000 to 6000				
GER				from 7000 to 8000	from 8000 to 9000	

The solution we arrived At is z=9000

Non-zero variables are:

X1222=4000

X1526=5000

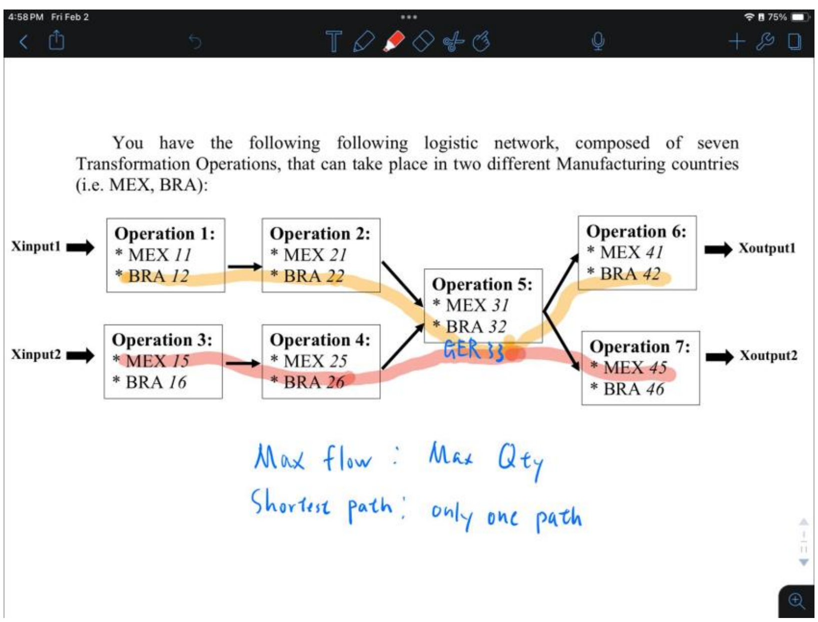
X2233= 4000

X2633= 5000

X3342 = 9000

X3344= 4000

Graphical depiction of the path taken:



The formulation for the LP is below:

Objective function (inputs of Processes 1 and 2):

$$\max \quad z = x_{o1} + x_{o2}$$

Subject to:

Xinput1 - X1121 - X1122 - X1221 - X1222 = 0 (Balance Operation 1)
Xinput2 - X1525 - X1526 - X1625 - X1626 = 0 (Balance Operation 3)
X1121 + X1122 + X1221 + X1222 - X2131 - X2132 - X2231 - X2232 = 0 (Balance Operation 2)
X1525 + X1526 + X1625 + X1626 - X2531 - X2532 - X2631 - X2632 = 0 (Balance Operation 4)

X2131 + X2132 + X2231 + X2232 + X2531 + X2532 + X2631 + X2632 - X3141 - X3142 - X3241 - X3242 - X3145 - X3146 - X3245 - X3246 = 0 (Balance Operation 5)

X3141 + X3142 + X3241 + X3242 - Xoutput1 = 0 (Balance Operation 6 against inputs into Process 1)
X3145 + X3146 + X3245 + X3246 - Xoutput2 = 0 (Balance Operation 7 against inputs into Process 2)
Xoutput1 + Xoutput2 - Xinput1 - Xinput2 = 0 (Total inputs must equal outputs)

(Enforcing Binary Supply and Demand)
Yinput1 = 1
Yinput2 = 1
Youtput1 = 1
Youtput2 = 1

(Balance Operation 1 Location)
Yinput1 - S1121 - S1122 - S1221 - S1222 = 0 (only one of the outputs of Operation 1 will be non-zero)
Op1MEX - S1121 - S1122 = 0 (Forces one Sn to take a value of 1, the other 0)
Op1BRA - S1221 - S1222 = 0 (Forces one Sn to take a value of 1, the other 0)
Op1MEX + Op1BRA = 1 (Op1 can take place in MEX or BRA, not both, i.e. one will be 1, one will be 0)

(Balance Operation 3 Location)
Yinput2- S1525 - S1526 - S1625 - S1626 = 0
Op3MEX - S1525 - S1526 = 0
Op3BRA - S1625 - S1626 = 0
Op3MEX + Op3BRA = 1

(Balance Operation 2 Location)
Op2MEX - S2131 - S2132 = 0
Op2BRA - S2231 - S2232 = 0
Op2MEX - S1121 - S1221 = 0
Op2BRA - S1122 - S1222 = 0
Op2MEX + Op2BRA = 1

(Balance Operation 4 Location)
Op4MEX - S2531 - S2532 = 0
Op4BRA - S2631 - S2632 = 0
Op4MEX - S1525 - S1625 = 0
Op4BRA - S1526 - S1626 = 0
Op4MEX + Op4BRA = 1

(Balance Operation 5 Location)
Op5MEX - S3141 - S3142 = 0
Op5BRA - S3241 - S3242 = 0 from Op#5 to Op#6
Op5MEX - S3145 - S3146 = 0
Op5BRA - S3245 - S3246 = 0 from Op#5 to Op#7
Op5MEX - S2131 - S2231 = 0
Op5BRA - S2132 - S2232 = 0 to Op#5 from Op#2
Op5MEX - S2531 - S2631 = 0
Op5BRA - S2532 - S2632 = 0 to Op#5 from Op#4
Op5MEX + Op5BRA = 1

(Balance Operation 6 Location)

Op6MEX - S3141 - S3241 = 0
Op6BRA - S3142 - S3242 = 0
Op6MEX + Op6BRA = 1

(Balance Operation 7 Location)
Op7MEX - S3145 - S3245 = 0
Op7BRA - S3146 - S3246 = 0
Op7MEX + Op7BRA = 1

Connecting flow capacities with binary flow decisions

Xinput1 - 7000Yinput1 <= 0
Xinput2 - 6000Yinput2 <= 0
Xoutput1 - 4000Youtput1 <= 0
Xoutput2 - 5000Youtput2 <= 0
X1121 – 3000*S1121 <= 0
X1122 – 2000*S1122 <= 0
X1221 – 1000*S1221 <= 0
X1222 – 4000*S1222 <= 0
X2131 – 6000*S2131 <= 0
X2132 – 4000*S2132 <= 0
X2231 – 3000*S2231 <= 0
X2232 – 2000*S2232 <= 0
X1525 – 5000*S1525 <= 0
X1526 – 6000*S1526 <= 0
X1625 – 2000*S1625 <= 0
X1626 – 4000*S1626 <= 0
X2531 – 5000*S2531 <= 0
X2532 – 2000*S2532 <= 0
X2631 – 3000*S2631 <= 0
X2632 – 4000*S2632 <= 0
X3141 – 4000*S3141 <= 0
X3142 – 4000*S3142 <= 0
X3241 – 5000*S3241 <= 0

X3242 – 6000*S3242 <= 0
X3145 – 6000*S3145 <= 0
X3146 – 5000*S3146 <= 0
X3245 – 4000*S3245 <= 0
X3246 – 2000*S3246 <= 0

Connecting transformation operation costs with binary flow decisions

CostOp1 – 10*Op1MEX – 20*Op1BRA = 0
CostOp2 – 20*Op2MEX – 10*Op2BRA = 0
CostOp3 – 40*Op3MEX – 30*Op3BRA = 0
CostOp4 – 30*Op4MEX – 40*Op4BRA = 0
CostOp5 – 30*Op5MEX – 40*Op5BRA = 0
CostOp6 – 10*Op6MEX – 20*Op6BRA = 0
CostOp7 – 50*Op7MEX – 30*Op7BRA = 0

Connecting shipping costs with binary flow decisions

CostSp1 – 500*S1121 – 300*S1122 – 200*S1221 – 100*S1222 = 0
CostSp2 – 200*S2131 – 250*S2132 – 300*S2231 – 500*S2232 = 0
CostSp3 – 300*S1525 – 150*S1526 – 200*S1625 – 400*S1626 = 0
CostSp4 – 100*S2531 – 200*S2532 – 250*S2631 – 300*S2632 = 0
CostSp5 – 200*S3141 – 300*S3142 – 500*S3241 – 400*S3242 = 0
CostSp6 – 150*S3145 – 200*S3146 – 250*S3245 – 400*S3246 = 0

$$x_{ijkl},\ X_{in},\ X_{out},\ CostSp,\ CostOp \geq 0$$
$$s_{ijkl},\ Op(m)(ABC)\ are\ binary$$

Our sensitivity analysis for this will be to introduce a new operation location for Germany which will be conducting at operation 5, with some new transformation operation costs, GOpCost23, GOpCost27, Transportation costs from 3 to 5, 4 to 5, 5 to 6, and 5 to 7 for Germany:

MAX = Xinput1 + Xinput2;

Xinput1 - X1121 - X1122 - X1221 - X1222 = 0;
Xinput2 - X1525 - X1526 - X1625 - X1626 = 0;

X1121 + X1122 + X1221 + X1222 - X2131 - X2132 - X2231 - X2232 -X2133-x2233 = 0;
X1525 + X1526 + X1625 + X1626 - X2531 - X2532 - X2631 - X2632 -x2533-x2633 = 0;

X2131 + X2132 + X2231 + X2232 + X2531 + X2532 + X2631 + X2632 +X2133+X2233+X2533+X2633- X3141 - X3142 - X3241 - X3242 - X3145 - X3146 - X3245 - X3246 -X3341-X3342-X3345-X3346= 0;

X3141 + X3142 + X3241 + X3242 +X3341+X3344- Xoutput1 = 0;

X3145 + X3146 + X3245 + X3246 +X2533+X2633- Xoutput2 = 0;
Xoutput1 + Xoutput2 - Xinput1 - Xinput2 = 0;

Yinput1 = 1;
Yinput2 = 1;
Youtput1 = 1;
Youtput2 = 1;

Yinput1 - S1121 - S1122 - S1221 - S1222 = 0;
Op1MEX - S1121 - S1122 = 0;
Op1BRA - S1221 - S1222 = 0;
Op1MEX + Op1BRA = 1;

Yinput2- S1525 - S1526 - S1625 - S1626 = 0;
Op3MEX - S1525 - S1526 = 0;
Op3BRA - S1625 - S1626 = 0;
Op3MEX + Op3BRA = 1;

Op2MEX - S2131 - S2132 -S2133= 0;
Op2BRA - S2231 - S2232 -S2233= 0;
Op2MEX - S1121 - S1221 = 0;
Op2BRA - S1122 - S1222 = 0;
Op2MEX + Op2BRA = 1;

Op4MEX - S2531 - S2532 -S2533= 0;
Op4BRA - S2631 - S2632 -S2633= 0;
Op4MEX - S1525 - S1625 = 0;
Op4BRA - S1526 - S1626 = 0;
Op4MEX + Op4BRA = 1;

Op5GER-S3341-S3342=0;
Op5MEX - S3141 - S3142 = 0;
Op5BRA - S3241 - S3242 = 0;

Op5MEX - S3145 - S3146 = 0;
Op5BRA - S3245 - S3246 = 0;
OpsGER-S3345-S3346=0;

Op5MEX - S2131 - S2231 = 0;
Op5BRA - S2132 - S2232 = 0;
OpsGER-S2133-S2233=0;

Op5MEX - S2531 - S2631 = 0;
Op5BRA - S2532 - S2632 = 0;
OpsGER-S2533-S2633=0;
Op5MEX + Op5BRA +Op6GER= 1;

```
Op6MEX - S3141 - S3241 -S3341= 0;
Op6BRA - S3142 - S3242 -S3342= 0;
Op6MEX + Op6BRA = 1;

Op7MEX - S3145 - S3245 -S3345= 0;
Op7BRA - S3146 - S3246 -S3346= 0;
Op7MEX + Op7BRA = 1;

Xinput1 - 7000*Yinput1 <= 0;
Xinput2 - 6000*Yinput2 <= 0;
Xoutput1 - 4000*Youtput1 <= 0;
Xoutput2 - 5000*Youtput2 <= 0;

X1121 - 3000*S1121 <= 0;
X1122 - 2000*S1122 <= 0;
X1221 - 1000*S1221 <= 0;
X1222 - 4000*S1222 <= 0;
X2131 - 6000*S2131 <= 0;
X2132 - 4000*S2132 <= 0;
X2133-8000*S2133<= 0;

X2231 - 3000*S2231 <= 0;
X2232 - 2000*S2232 <= 0;
X2233-5000*S2233<= 0;


X1525 - 5000*S1525 <= 0;
X1526 - 6000*S1526 <= 0;
X1625 - 2000*S1625 <= 0;
X1626 - 4000*S1626 <= 0;
X2531 - 5000*S2531 <= 0;
X2532 - 2000*S2532 <= 0;
X2533 - 6000*S2533 <= 0;

X2631 - 3000*S2631 <= 0;
X2632 - 4000*S2632 <= 0;
X2633 - 5000*S2633 <= 0;

X3141 - 4000*S3141 <= 0;
X3142 - 4000*S3142 <= 0;
X3241 - 5000*S3241 <= 0;
X3341 - 6000*S3341 <= 0;
X3341 - 7000*S3341 <= 0;

X3242 - 6000*S3242 <= 0;
```

```
X3145 - 6000*S3145 <= 0;
X3146 - 5000*S3146 <= 0;
X3245 - 4000*S3245 <= 0;
X3246 - 2000*S3246 <= 0;
X3346 - 8000*S3345 <= 0;
X3346 - 6000*S3346 <= 0;

CostOp1 - 10*Op1MEX - 20*Op1BRA = 0;
CostOp2 - 20*Op2MEX - 10*Op2BRA = 0;
CostOp3 - 40*Op3MEX - 30*Op3BRA = 0;
CostOp4 - 30*Op4MEX - 40*Op4BRA = 0;
CostOp5 - 30*Op5MEX - 40*Op5BRA -50*OpsGEM= 0;
CostOp6 - 10*Op6MEX - 20*Op6BRA = 0;
CostOp7 - 50*Op7MEX - 30*Op7BRA = 0;

CostSp1 - 500*S1121 - 300*S1122 - 200*S1221 - 100*S1222 = 0;
CostSp2 - 200*S2131 - 250*S2132 - 300*S2231 - 500*S2232 -450*S2133-350*S2233= 0;
CostSp3 - 300*S1525 - 150*S1526 - 200*S1625 - 400*S1626 = 0;
CostSp4 - 100*S2531 - 200*S2532 - 250*S2631 - 300*S2632 -150*S2533-400*S2633= 0;
CostSp5 - 200*S3141 - 300*S3142 - 500*S3241 - 400*S3242 -100*S3341-600*S3342= 0;
CostSp6 - 150*S3145 - 200*S3146 - 250*S3245 - 400*S3246 -100*S3345-350*S3346= 0;


@GIN(Yinput1);
@GIN(Yinput2);
@GIN(Youtput1);
@GIN(Youtput2);
@GIN(S1121);
@GIN(S1222 );
@GIN(OP1MEX );
@GIN(OP1BRA);
@GIN(S1525);
@GIN(S1526);
@GIN(S1625);
@GIN(S1626);
@GIN(OP3MEX);
@GIN(OP3BRA);
@GIN(OP2MEX);
@GIN(S2131);
@GIN(S2132);
@GIN(OP2BRA);
@GIN(S2231);
@GIN(S2232);
@GIN(OP4MEX);
@GIN(S2531);
@GIN(S2532);
```

```
@GIN(OP4BRA);
@GIN(S2631);
@GIN(S2632);
@GIN(OP5MEX);
@GIN(S3141);
@GIN(S3142);
@GIN(OP5BRA);
@GIN(S3241);
@GIN(S3242);
@GIN(S3145);
@GIN(S3146);
@GIN(S3245);
@GIN(S3246);
@GIN(OP6MEX);
@GIN(OP6BRA);
@GIN(OP7MEX);
@GIN(OP7BRA);

END
```