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Coordination Improvement in Inventory Management for Electricity Distribution Materials

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Abstract: Electricity is a fundamental necessity. Its demand is characterized by fluctuation and broad geographic dispersion, requiring distribution units of electricity companies to be prepared to serve customer needs across all areas. The growing demand also necessitates expanding distribution networks. Establishing new connections for customers requires various materials, among which power cables are among the most crucial. However, procuring and managing these materials involves multiple stakeholders, leading to inventory management complexities. This study aims to enhance coordination in power cable inventory management by analyzing how improved coordination influences procurement costs through simulation. This study utilizes system dynamics method to understand the system of inventory management and the interactions among its elements. The existing inventory management was simulated and compared with a coordination policy scenario. The coordination policy yields better cost outcomes by managing internal coordination between two divisions, efficiently changing the use of budget and cost related to inventory. These insights can guide company management to apply the policy and enhance inventory performance for primary electricity distribution materials.

Keywords: Power cable and conductor, complexity, multiple stakeholders, system dynamics, uncertainty

Introduction

The availability of materials in an energy company is a key component in providing reliable and sustainable services. One of the largest sources of electricity demand is the data center sector, which is growing [1]. An electricity distribution company examined in this study is responsible for providing supplies in two districts. Although the company does not yet operate a data center, customer growth reached 26,057 new subscribers in 2024. Electricity sales in 2024 rose by 4,6%, with the industrial sector contributing the most usage. The highest demand comes from the textile industry. Since the COVID-19 pandemic began to subside in 2022, 53,010 new customers have been added, indicating a rising need for electricity. This increase underscores the large number of customers to be managed and highlights the electricity demand growth from both current and prospective customers.

To fulfil the electricity needs of existing and potential customers, the company encounters two primary conditions when establishing connections to the proposed locations: direct connections, which are feasible due to the availability of an existing distribution network, and indirect connections, which arise when the distribution network is either unavailable or does not meet the required technical standards. Indirect connections require the construction of a new electricity distribution network or replacement of distribution materials with a higher capacity. As demand grows and new customers enter the system, indirect conditions have become more frequent, driving the need for more materials. To manage this condition, the company must procure and control stocks of primary materials. One critical type of primary material is power cable and conductor. The procurement process for this material involves several stakeholders, including the construction and logistics section in the Customer Service Implementation Unit (UP3), the connection planning section in the main distribution unit (UID), and external suppliers. The users and controllers of material stock in this inventory control system are the construction and logistics section of UP3. The connection planning section of UID manages requirements, makes procurement decisions, and handles supplier contracts. In meeting these needs, the company often experiences delays in receiving material, which subsequently delays the connection of electricity to existing and potential customers.

This study aims to examine the inventory control system in the company and enhance coordination in the management of power cable and conductor materials by analyzing how improved coordination influences procurement costs through simulation. Different decisions among stakeholders can affect material availability and extend service delivery timelines needed to meet customer requests. The need to provide the best service remains a priority. To analyze the complexity of the material control system, a dynamic system simulation was developed. Alternative improvements were subsequently performed to enhance company performance.

This study has two primary objectives. The first is to explore the complexity and dynamics of the inventory control system at the company. By understanding the function of each stakeholder and the interactions that occur, the second objective can be developed to provide improvements to the system. The proposed improvement seeks to enhance stakeholder interactions and improve efficiency within the existing system.

This paper is structured into two parts. The next section presents the literature review and methodology related to the inventory control system. Thereafter, the simulation model and discussion are addressed. The final section concludes with the summary of the research findings.

Methods

Several studies have been conducted related to inventory control. Effective inventory management aims to fulfil three key goals: satisfying customer demand, minimizing costs, and maintaining optimal stock levels to avoid both shortages and excess inventory [2]. Under such probabilistic conditions, the continuous review method is widely utilized to formulate inventory policies, with the primary goal of identifying the optimal order quantity (Q) and reorder point (R) that together minimize total inventory-related costs.

Inventory control for perishable products using the discrete event simulation method has been developed, and improvements to control policies have been proposed using periodic review. This policy is simulated to control discounts on products with a remaining shelf life of two to three days and has succeeded in increasing daily profits [3]. Determining the right EOQ (Economic Order Quantity) value can improve service levels in retail inventory management [2]. Determining the correct EOQ is carried out using discrete event simulation to optimize order values that can lower inventory levels, reduce the number of lost customers, and minimize total inventory costs.

To ensure that the automatic vending machine operates properly, the availability of items for MRO (maintenance, repair, and operation) must be managed appropriately. The optimal “min-max” policy for each item in the multi-item joint replenishment inventory problem is simulated to maximize profits on the materials used in the automatic vending machine operations. Discrete event simulation is developed and optimized using OptQuest method in Arena, gradient-based methods (steepest descent), and non-gradient-based method (particle swarm optimization). The PSO optimization approach has proven more effective for small and medium-scale demand problems [4].

A system dynamics approach has been conducted to improve procurement planning by analyzing the root causes of problems for the availability of office stationery. The addition of safety stock and the scheduled purchase policy reduce excess stock and mitigate supply shortages [5]. Building on several studies related to simulation-based inventory control, a system dynamics simulation study for critical materials in the electrical energy distribution sector (i.e., power cables and conductors) can be developed and contribute meaningfully to inventory control policy discourse.

This study adopts a dynamic systems approach because the inventory management problem at the examined company involves complex dynamics among stakeholders. Each decision made by an actor can propagate changes throughout the system. Internal policy limitations and uncertain material availability further exacerbate these challenges. Delays in material deliveries directly impact service performance indicators, such as the speed of electricity connections to customers. System dynamics is well-suited for this context, as it enables a holistic representation of feedback loops, time delays, and policy alternative evaluation. Furthermore, it facilitates cross-functional understanding within the organization by clearly illustrating the roles and impacts of each unit. This approach provides a structured framework for identifying system interactions and supporting strategic improvements in service delivery and inventory control.

System Dynamics

The system dynamics method was first introduced by Jay. W. Forrester at the Massachusetts Institute of Technology under the name industrial dynamics in the mid-1950s. The approach focuses on the complexity of systems with feedback processes. The underlying premise is that dynamic behavior is a consequence of the system structure and is both meaningful and robust [6]. The perspective used in system dynamics development is a system in which each element interacts, provides reciprocal relationships, and produces certain behavior. The interactions are translated into mathematical models. Two important indications must be identified prior to applying the system dynamics approach: the presence of dynamics characteristics in the problem, and the ability to describe them through feedback. In the omni-channel retailing context, system dynamics is used to simulate various policies concerning distribution centers, demand, and inventory management to identify strategies that minimize delivery time [7].

System dynamics simulation enables the visualization of causal relationships within a system through system thinking, making it a valuable tool for evaluating the impacts of specific policies. The beer game simulation is a well-established approach for analyzing the effects of partnership strategies within business supply chains; however, its application to humanitarian logistics remains limited. A modified version of the beer game model is considered potentially effective for representing the dynamics of disaster relief operations in humanitarian logistics, particularly during the emergency response phase—the critical initial seven days following a disaster [8].

System dynamics is grounded in two fundamental philosophical principles: causality, which emphasizes cause-and-effect relationships among system components, and the identification of opportunities for system improvement by analyzing feedback and dynamic behaviors. Causality states that every event has a traceable cause, while the philosophy of opportunity means that there is a possibility that occurs. In system dynamics, model development and analysis involve several phases including problem definition, dynamic hypothesis formulation, simulation model development, model validation, and policy design and evaluation [7]. The formulation of a system dynamics hypothesis reflects an understanding of the main causes and effects in the problem being studied. This hypothesis is represented through mapping techniques such as causal loop diagrams (CLD), stock-and-flow diagrams (SFD), or model boundary diagrams. The model is validated to ensure its reliability and practical relevance [6]. System dynamics models are based on the concept that system complexity can be represented through two core variables: stocks, which capture the accumulation of resources or information over time, and flows, which represent the rates of change influencing those accumulations. Flow consists of inflow and outflow that shows movement per unit time and is visualized with arrows. The value of a stock variable changes as it is influenced by associated inflow and outflow rates, which regulate the accumulation or depletion within the system over time.

The initial stage of system dynamics modelling can be explored through several steps. In a study forecasting tourism development in Banyumas Regency, the initial stage included model adaptation and the development of a mental model. This involved defining the research topic and scope, reviewing literature on tourism supply chain models and transportation systems—particularly transit-oriented development (TOD)—and compiling relevant mental model frameworks. Expert perceptions were referenced to validate the constructed model. The system description entailed identifying the current structure of the tourism supply chain and transportation system, their interconnections, and associated stakeholders. Actor analysis was conducted to detail the roles and involvement of key stakeholders within the model. A system diagram framework was formulated to integrate elements from the previous stages, followed by the development of a causal loop diagram (CLD) [9].

Inventory Management

Inventory arises either through strategic planning or from a lack of information. Uncertainty also affects many companies operating under a make-to-stock system. Several metrics can be used to monitor inventory performance, including inventory turnover rate, inventory days of supply (the average number of days a company can operate with the amount of inventory on hand), and fill rate (the percentage of items available when requested). Inventory can be classified based on form, function, and dependency. Classification by form includes raw materials, work-in-process (WIP), and finished products. Classification by function includes pipeline/transit inventory, cycle stock, safety stock, and anticipation stock. Classification by dependency includes dependent and independent demand.

Inventory management is a component of supply chain management. Effective supply chain coordination is essential to maximize total supply chain surplus, as it ensures that all stages work toward aligned objectives and consider the impact of their actions on others. Poor coordination often arises due to conflicting local goals and distorted or delayed information sharing, especially in modern supply chains with multiple independent entities and high product variety. Without coordination, individual stages tend to act in isolation, leading to inefficiencies such as the bullwhip effect—where small fluctuations in consumer demand cause increasingly larger order variations upstream. Derived from the concept of coordination in supply chain management, coordination is also essential in inventory management, especially when multiple elements must work collectively to reach common goals.

Advancements of internet-based information technology have facilitated collaborative interactions and synchronized decision-making among closely connected supply chain participants. These technologies support the integrated management of supply chain functions—from routine operations to strategic partnership planning—by enhancing the system's ability to make informed decisions [10]. In the pharmaceutical industry, supply has become crucial, and inventory management must consider unlimited product supply from the manufacturer to the third-party logistics provider (3PL); hence, strong coordination is necessary [10]. In the construction material supply chain (CMSC), the supply of construction materials is a major factor of construction progress. CMSC managers must have access to information from the first stage to the final stage of procurement. Suppliers require visibility into the order backlog to develop an effective fulfillment plan that minimizes or eliminates delays by aligning it with inventory levels and processing schedules. Additionally, the impact of material supply coordination varies among CMSC members depending on the terms and conditions specified in their contracts. To serve the collective interest, fostering a collaborative culture is essential. It supports the achievement of shared, conflict-free objectives through the timely exchange of information, which helps prevent delays, budget and schedule overruns, excess inventory, and slow response times in material procurement [11].

Methodology

This research involved several stages presented in Figure 1. To identify and understand the problem, the initial step included observations and collecting data. Once the condition was understood, it was modelled based on system observations. The modelling process followed system dynamics method. After constructing and validating the real model, experimentation stage was conducted to provide a better impact on system performance. The hypothesis was that optimizing internal coordination yields positive impact on system performance, including budget usage, total cost related to inventory, and total time of service days. The final stage comprised findings and recommendations.

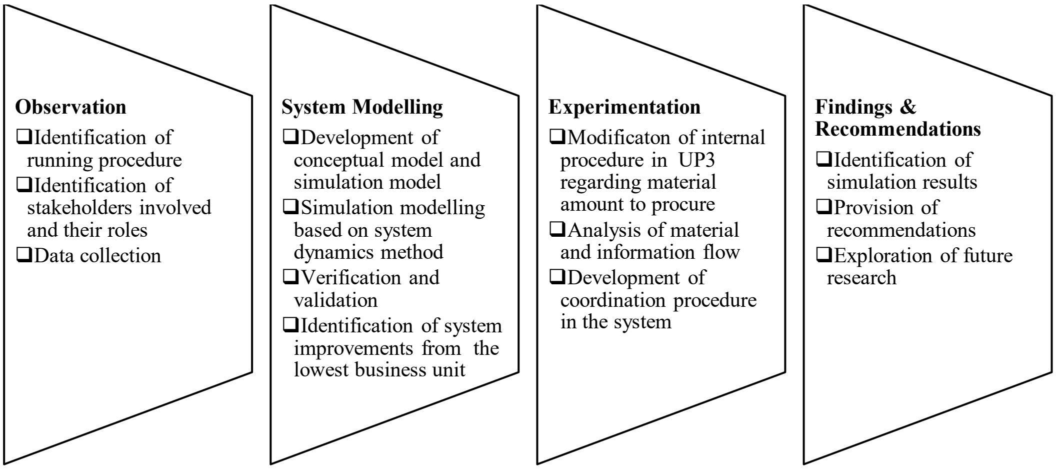

Figure 1. Research methodology

Results and Discussions

Existing Procedure for Power Cable and Conductor Inventory Management

Power cable and conductor materials are needed to provide electrical energy supply to current and potential customers in areas without an existing electricity distribution network. When a request is received, the service unit conducts a site survey to determine the material requirements. Once the survey is completed and the customer connection planning document is approved, the Construction Section at UP3 of a company submits a material procurement request to the Connection Planning Section at UID. This request process is performed monthly. The Connection Planning Section manages incoming requests and submits purchase approval to the Supply Chain Management Division at the Head Office. The Supply Chain Management Division then allocates orders that can be transacted.

Following the allocation, the Connection Planning Section adjusts and arranges administrative documents for ordering materials from suppliers. The supplier delivers the material within the agreed lead time. The Logistics Section at UP3 receives the materials, conducts inspections, and collects data. Once the materials are available, the Construction Section reserves them so that vendors can install them at the customer and potential customer locations. In practice, the delivery of materials from suppliers to users (UP3) is not always fulfilled in the same month. The quantity of materials received often varies, resulting in unmet monthly requirements. In addition, the allocation of orders that can be transacted is often smaller, requiring coordination between the Construction Section and the UID Planning Section to mitigate material shortages.

Simulation Model

Model development was carried out by dividing the system into several sub-models. UP3 Construction Section (shown in Figure 2): This sub-model illustrates the process through which demand is received and processed by the construction section. It also includes the activation of the coordination scenario. UID Connection Planning Section (depicted in Figure 3): This section represents the final requests from the construction section as input, which are then processed to be sent to the Supply Chain Division. This process includes allocation and the creation of purchase orders. Inventory Level (illustrated in Figure 4): This component will dynamically update the status of stock utilized in several sub-models. Supplier and Logistics Section (presented in Figure 5): This section demonstrates the dynamic interactions between suppliers who send orders and the logistics section, which inspects and invents the materials. Construction and Vendor Section (shown in Figure 6): This section is also included in the model. It represents the stage where material which has been reserved by the construction to be installed by vendor. Duration time of installation will be counted based on vendor capacity. Coordination (represented in Figure Figure **7.** Coordination sub-model

): This part highlights interactions between stakeholders aimed at resolving issues related to material fulfilment. System Performance: This aspect encompasses system performance indicators, including budget usage and inventory turnover (ITO), as displayed in Figure 8. Budget usage is defined as percentage by comparing the purchase order per month with monthly investments budget. The less budget usage will reflect efficiency. Inventory turnover (ITO) is additional measurement to check how fast the stock rotation. In addition, service levels and service day durations are illustrated in Figure 9. Service level represents ability of the company to fulfil material demands each month. The results analyzed is the average of service level every month. The bigger service level from a scenario will be considered as recommendation to the company because it is directly related to customer service. Meanwhile, service day duration is a count of all process starting from demand processing, purchasing order, supplier fulfillment, and material installation. The total cost includes purchasing costs, ordering costs, and holding costs. The holding cost fraction was set at 33.3%, while the ordering cost amounted to Rp4,794,900 (reference USD 295,67).

Two assumptions were used in this study. First, the time required for final installation of materials was based on the average installation rate achievable by a single vendor. Second, climate and weather conditions were assumed not to affect material delivery or installation at customer sites. The simulation used a monthly time unit over a span of 24 months.

The system dynamics methodology accommodated nonlinear behavior using feedback loops, time delays, and nonlinear functions where appropriate, while certain simplifications were necessary to maintain model clarity and manageability. In this study, key nonlinear characteristics, such as the impact of inventory shortages and the variability in supplier (lead time and shipment quantity) were modelled using nonlinear formulations through distribution expression that had undergone statistical procedures. The feedback loop focused on inventory levels. When shortages occur, the coordination sub-model addressed them by performing reconciliation with other business units to source materials or by urging suppliers to deliver remaining purchase order items. The success rate of delivery acceleration depended on both supplier capability and UID staff initiative to coordinate with suppliers. The nonlinearity was expressed as a percentage.

The starting order was initiated from the historical demand as shown in Figure 2, tested to determine the distribution expression: INTEGER (RANDOM EXPONENTIAL (255, 79017, 0, 29131, 24688)). The current demand formula is: [start order - A*(1+STEP("Growth of Industry", 12))], with a value of 0 used for industry growth to simulate real demand conditions. The unit price was Rp124.940,- (USD 7,7) per meter. To capture uncertainty in unit arrival, a formula based on historical data was used: (INTEGER(50 + RANDOM EXPONENTIAL(50, 50270, 0, 12300, 25135))). In the real condition, the lead time was also uncertain, using the following formula: RANDOM WEIBULL(0.0333, 2.225, 1.72, 0, 0.808, 1)

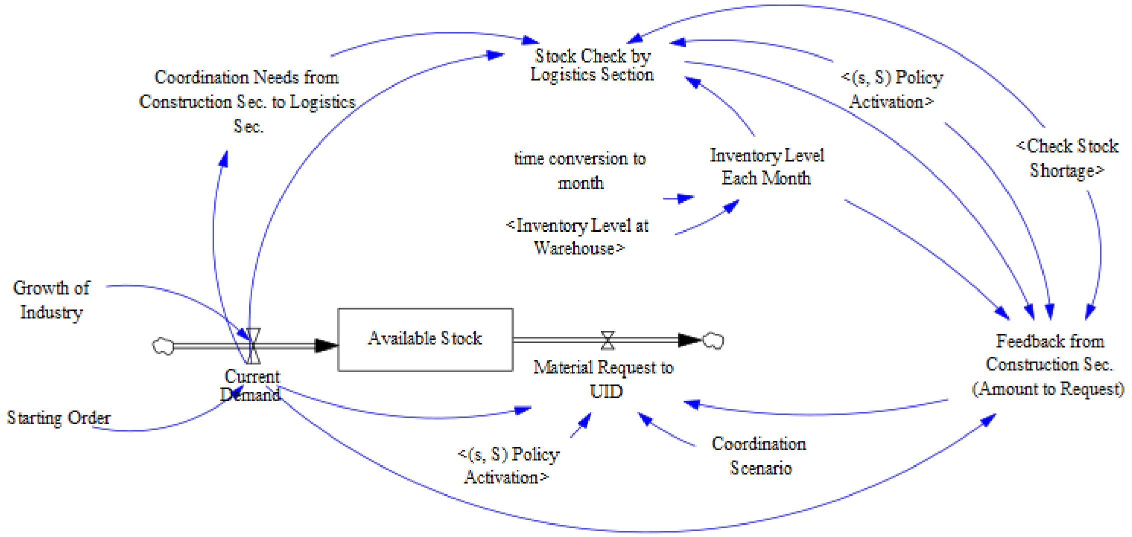

Figure 2. UP3 construction section

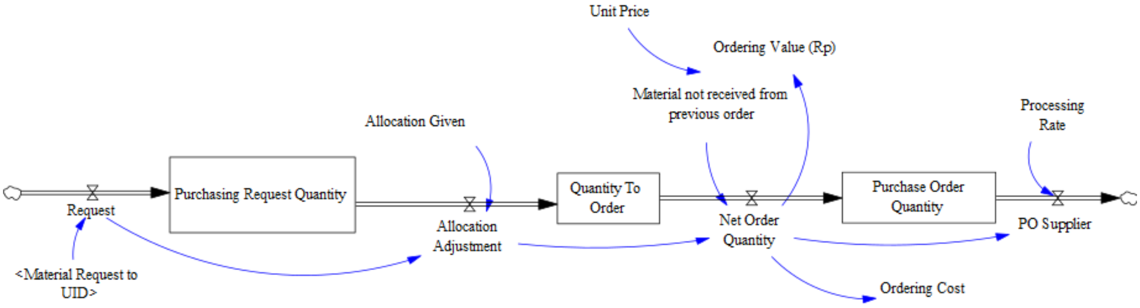

Figure 3. UID connection planning section sub-model

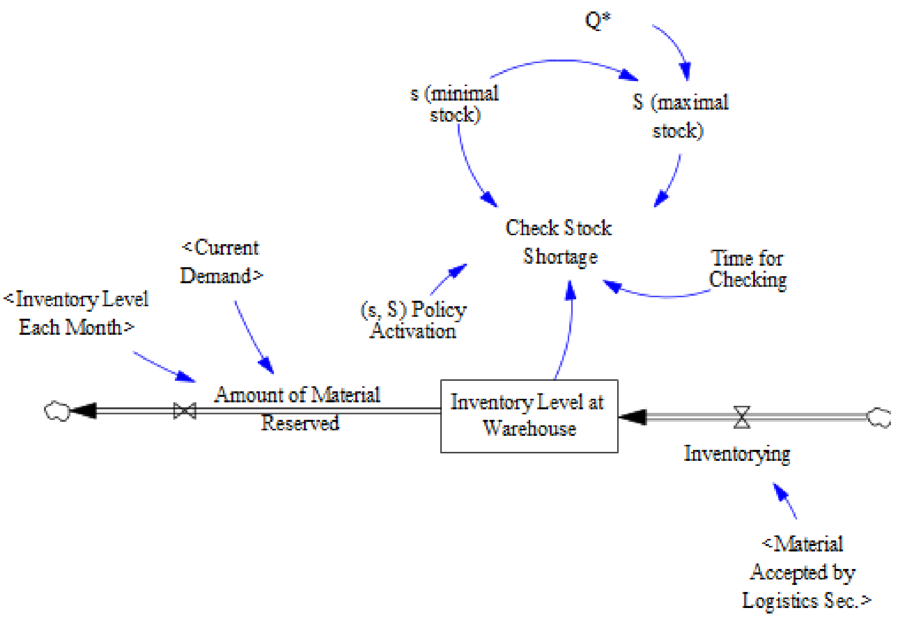

Figure 4. Inventory level sub-model

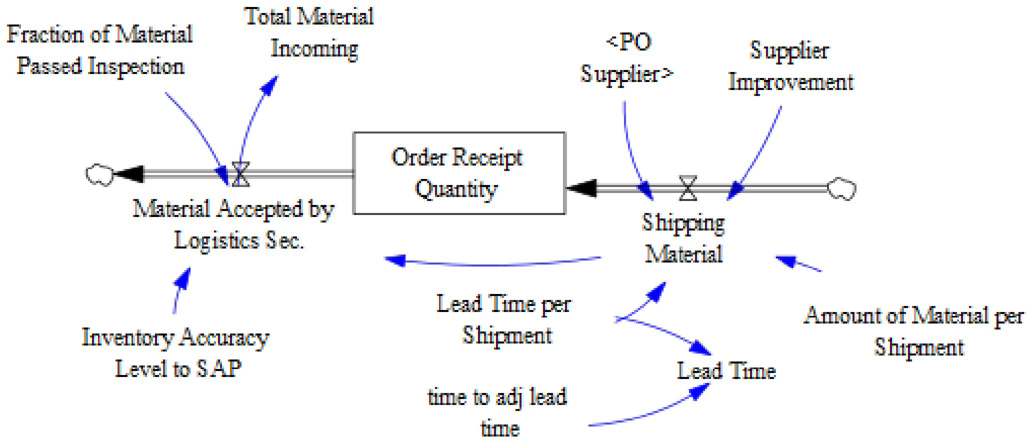

Figure 5. Supplier and logistics section sub-model

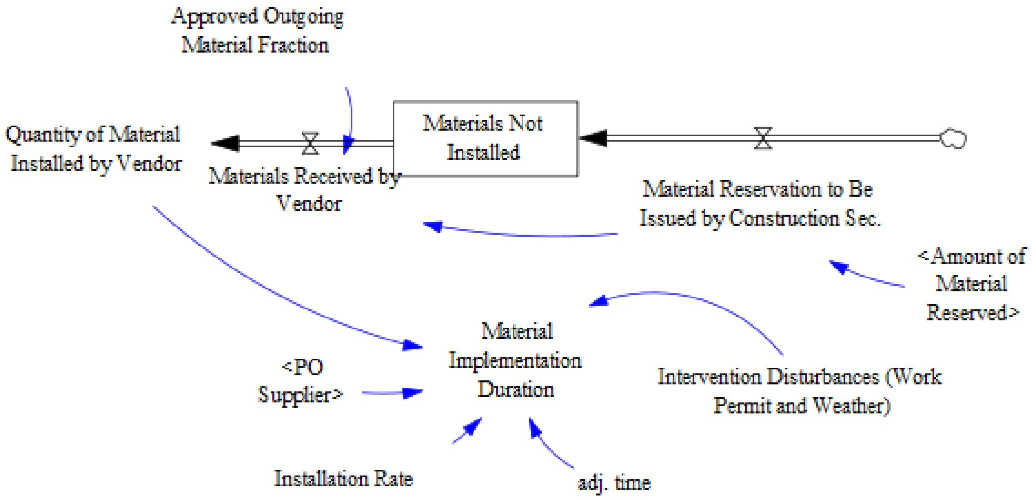

Figure 6. Construction and vendor section

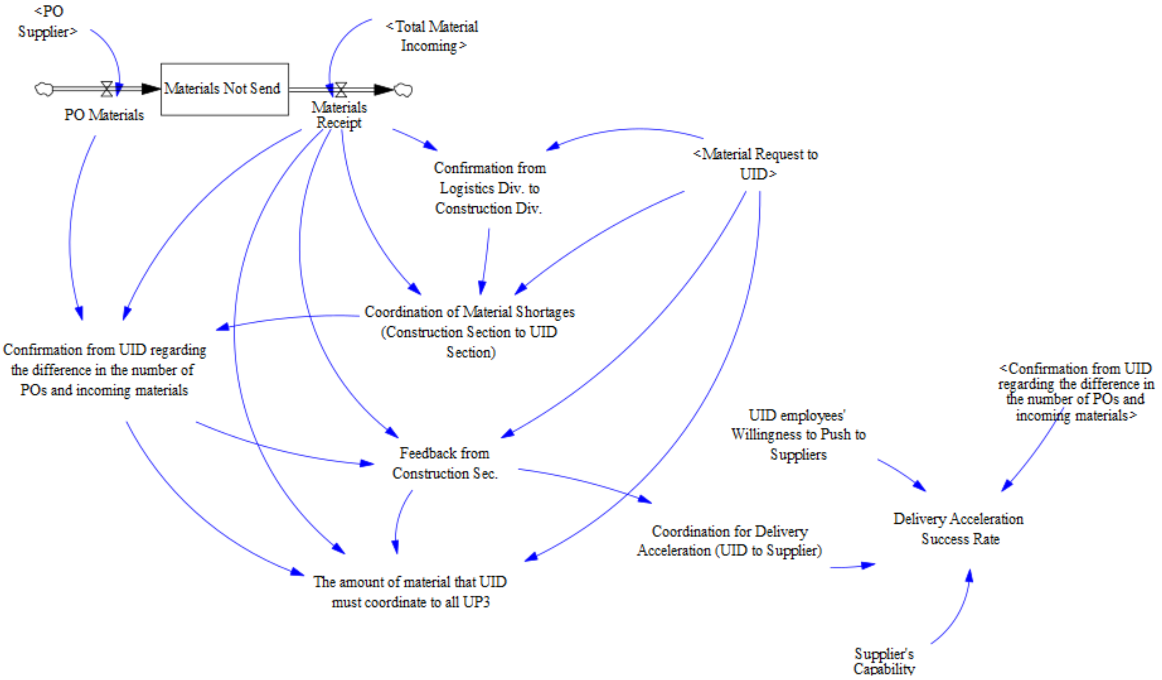

Figure 7. Coordination sub-model

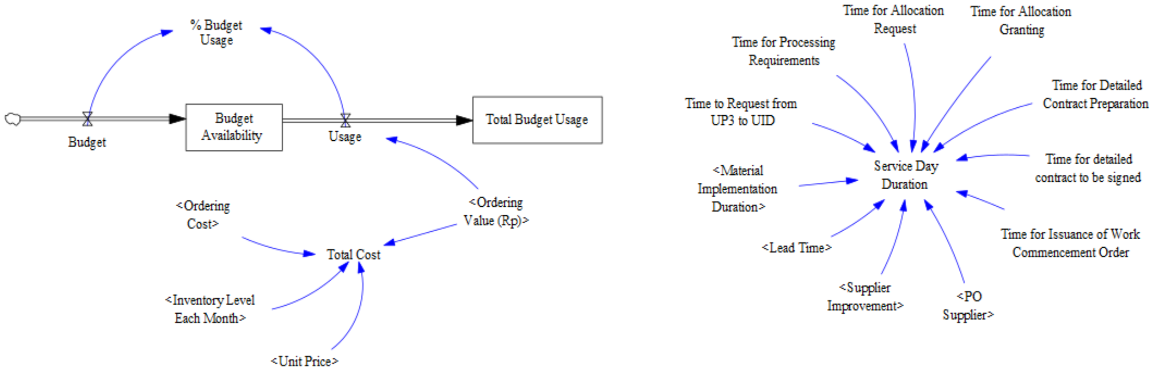

Figure 8. Budget usage and total cost, service duration sub-model

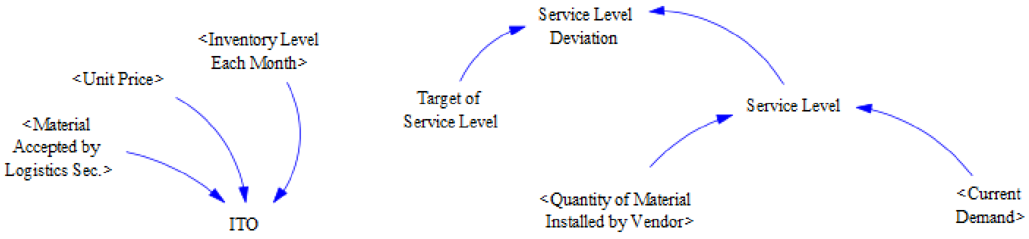

Figure 9. ITO and service level sub-model

Key time delays relevant to inventory management, such as demand recognition, order processing, and material delivery were embedded in the model using stock-and-flow structures fundamental to system dynamics methodology. These delays were parameterized based on historical records and validated through expert consultation to ensure alignment with actual lag times observed within the system. The development process involved iterative validation with practitioners to enhance model reliability. In practice, demand recognition occurs approximately one month prior to order processing. Material requests are scheduled between the 1st and the 20th of each month (n-month), managed by the Construction Division at the company, and are reported monthly to the UID Connection Planning Section. These requests are processed during the first week of the subsequent month by the UID Connection Planning Section. This scheduling introduces a delay in the procurement cycle, which is represented in the model through a corresponding stock-and-flow structure across two sub-models. Material receipts are accumulated monthly to reflect inventory levels. Materials delivered by suppliers are fully processed by the Logistics Division and made available for use in the following month, consistent with the model's monthly time-step configuration.

Verification and Validation

The developed model was verified to ensure consistency with the conceptual model and the real-world conditions. Verification was also carried out to ensure that the model logic can be run on a computer program with no errors. In Vensim PLE software, model verification was carried out using Units Check and Check Model. Units Check ensured that all units across variables were in accordance with the mathematical operations, while Check Model evaluated all variables for simulatability. In addition to software-based and manual checks, verification was also reinforced through consultations with the company and its higher-level business units.

The time unit for simulation is months. After the logic flow was successfully verified, the model was executed over a 24-month period. Data validation employed parameters E1 (mean) and E2 (standard deviation) as shown in Table 1. E1 measures the difference between simulation and real condition averages, with data accepted if the E1 values are ≤ 5%. E2 compares standard deviations produced by the simulation with the standard deviation values in real conditions, accepted if the E2 values are ≤ 30%. Three variables (demand, delivery lead time, and quantity per shipment) were validated, alongside order allocation outputs.

This study did not conduct sensitivity analysis due to limited time and a primary focus on policy comparison. The primary objective was to understand system behavior and evaluate the impact of specific policy interventions, rather than assess the responsiveness of outcomes to parameter variations. Therefore, sensitivity analysis was not prioritized. The model was built upon well-validated assumptions confirmed by users and the simulation parameters were considered sufficiently reliable, having been derived and verified using historical data.

Table 1. Validation test for variables

Validation Component	Demand	Allocation Adjustment	Quantity Per Shipment	Lead Time Per Shipment
Mean of Simulation	23,527	14,319.400	12,290.360	0.730
Mean of Real Data	24,687	13,693.250	12,320.785	0.72
E1	4.70%	4.57%	0.25%	1.40%
St. Dev Simulation	15,604	18,262.635	10,563.704	0.392
St. Dev of Real Data	21,626	16,672.620	12,341.803	0.447
E2	27.84%	9.54%	14.41%	12.32%

Experiment and Results

Based on the fitted model and data, simulations were run under existing conditions. The scenario experiment involved changing existing procedures. When there is a need of materials, the Construction Section must coordinate with the Logistics Section to determine the quantity requested from the Planning Section at UID. This coordination improves ordering efficiency. Results from both the existing conditions and the internal coordination scenarios are presented below.

When determining the amount of demand, internal coordination improved service level from 64.49% to 89.19% as shown in Table 2. Inventory turnover (ITO) showed better performance, decreasing by 0.16 due to reduced purchasing volume. Delivery acceleration success rate is defined as the quantity of purchase order items not yet received. The total was calculated over the 24-month simulation. Coordination reduces this success rate by 55%. Material shortages requiring fulfilment arise from order limitations, often caused by allocation by the head office. The number of material shortages that need to be allocated from other business unit due to smaller purchase allocations decreased by 101,346 m using the coordination policy.

Table 2. Results A

Scenario	Delivery Acceleration Success Rate (m)	Total Shortages to Be Fulfilled (m)	Service Level	ITO
0	152,490	228,548	64.49%	0.86
1	68,355	127,202	89.18%	0.68

Notes: (m) indicates meter unit

By optimizing coordination at UP3, the amount of existing stock can be maximized for use, reducing the volume of new material orders. The decrease in monthly budget usage by 23% based on Table 2 by calculating the difference, enabling savings or alternative investment allocations. Service day duration, defined as the duration from request to installation, was reduced by 0,11 months or approximately four days. Total cost reduction in the coordination scenario was Rp24,673,335,400, - (USD 1,521,458.19).

Table 3. Results B

Scenario	Service Day Duration	% Budget Usage	Total Budget Usage	Total Cost
0	2.73	41%	Rp46,516,570,900	Rp47,155,087,000
1	2.62	18%	Rp20,915,662,160	Rp22,481,751,600

Even though the coordination policy is implemented between two sections in the company, broader implications extend beyond the supply chain. It lowers demand requests, allowing suppliers to improve their capability in fulfilling purchase orders. Lead time may be shortened. Material receipt efficiency may improve by sending the total purchase order directly in a month although in the model, the lead time and number of materials per shipment are using the same pattern. These implications can be developed to become suggestions and other scenarios to improve all aspects and benefit all stakeholders.

Conclusions

In primary energy distribution companies such as electricity providers, material availability is crucial. When a request for electricity connection cannot be completed, the construction of a new network or replacement of materials must be done. Understanding the procurement and control of materials reveals opportunities for improvement. A system dynamics model was developed to assess inventory control at the UP3 of PT X, focusing on power cable and conductor inventory. This unit involves the participation of two key sections: the Construction Section and the Logistics Section. By changing the procedure before the material request with coordination optimization, the quantity of purchase can be reduced to lower budget usage and the duration of service days to meet these needs can also be shortened.

Acknowledgment

This study may be extended through integration of inventory management policies with system-wide coordination mechanisms. Future research could incorporate experimental factors, such as demand fluctuations, to further explore coordination requirements beyond the current simulation. Additionally, the model could be enhanced to account for multiple material types and their specific specifications, providing a more comprehensive approach to inventory optimization.

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