



DEVELOPMENT OF A MODEL FOR TRANSPORT AND LOGISTICS PROCESS USING HIERARCHICAL TIMED COLOURED PETRI NETS

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ABSTRACT

Transport and logistics are important for modern supply chains, involving activities like warehousing, inventory management, distribution planning, and transportation. Ekeson Transport Company has a significant reliance on manual processing, resulting in prolonged queuing and waiting times, reduced service delivery, customer attrition, and revenue loss. To address this issue, a Hierarchical Timed Coloured Petri Net (HTCPN) model was developed using direct observation data from 20 observations at the company. The model consists of three sub modules: sender, reception, and receiver. The simulated values were validated using bivariate correlation coefficients, indicating the model can effectively manage sender and reception numbers, reduce queueing and waiting times. The result showed that the p-value obtained was less than the level of significance of 0.05, which depicts that the simulated values are a representation of the real system. Therefore, the model can be used in making decisions about the effective Transport and Logistics Services, thus reducing queueing time and waiting time.

Keywords: Transport, Logistic, Correlation, Simulation outputs

INTRODUCTION

Transportation has to do with the movement of people, goods, and information from one location to another. People have been acknowledged to possess the zeal to move from one point to another in the world. And they would usually carry with them food, property, and culture, depending on the technology available to them and what they could afford at a particular point in time. The different options for the movement of goods and services from one place to another are referred to as modes of transportation. Road, rail, air, water, and pipelines are seen as the five basic modes of transportation (Onokala, 2016; Farahani *et al.*, 2019). Access to various locations is made possible by transportation, enabling people, products, and services to get to their destinations. Effective transportation facilitates investment, trade, and commerce. It also connects continents, countries, and regions, promoting cooperation, cross-cultural interchange, and globalization. The different modes of transportation facilitate quick and easy travel, increasing one's own mobility and freedom of movement (Jyotish & Kumar, 2022). Logistics is a part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption to satisfy the customers' requirements. Additionally, logistics explains the entire process of materials and products moving into, through, and out of an organization. Logistics covers the movement of material received from suppliers. Materials management defines the movement of materials and components within an organization. Physical distribution refers to the transfer of goods from the end of the assembly line to the clients (Mahdi, 2022). Transportation and logistics are vital components of modern supply chains, enabling the smooth flow of goods and services from production to end-users. Transport and logistics processes cover a series of activities involved in the management and movement of goods and services. These processes include transportation, warehousing, inventory management, order

processing, and distribution planning. Efficient transportation and logistics ensure products reach their destination accurately, on schedule, and in perfect condition.

The development of advanced modeling techniques has transformed the way optimization of transport and logistics is handled. One of such techniques which has gained prominence is the use of HTCPNs (Jenkins, 2022). A Model provides the means of representing a real-world problem using diagrams, graphs and equations. The model is usually developed when it proves challenging and difficult to represent a system in the real world. HTCPNs Models is the model which seeks to address processes with the queueing problems and seeks to provide a system to significantly tackle the challenges, such as long waiting time, delayed delivery of goods and services and loss of revenue due to delays in service operations (Verbeek & Fahland, 2021).

Coloured Petri Nets (CPNs) are highly effective for modeling and evaluation of system performance. By integrating data, time, and hierarchy, CPNs provide a powerful framework for modeling intricate systems and procedures using the CPNs without being forced to abstract from essential features (Jyotish & Kumar, 2022). Hierarchical Timed Colored Petri-nets provide a means to represent and simulate complicated systems, which may include air traffic control systems and distributed manufacturing networks. Hierarchical Timed Colored Petri-nets (HTCPNs) enable the organization of a complicated parallel system into hierarchical modules, allowing for better understanding and analysis of its performance (Debbage & Debbage, 2021).

The rest of the paper is organized as follows: Section I introduces the study by discussing the keywords briefly as well as the study's objectives. Section II explains various related works in the field of transport and logistics process. Section III describes the study's methodology in detail. Section IV discusses the results of the algorithms. Section V concludes the study with recommendations for additional research.

Related Works

Numerous researchers have significantly contributed to fields where efficient transport and logistics services are crucial for businesses to stay competitive in today's fast-paced market. (Odeniyi *et al.*, 2021) developed a model for restaurant food serving using Hierarchical Timed Coloured Petri Nets to solve long waiting times, but no validation was conducted. Also employed a modularized model using Hierarchical Timed Coloured Petri Nets (HTCPN) for a multi-process food manufacturing system. The model accurately describes the production process of Garri, reducing production time as the number of critical resources increases.

In (Afolabi *et al.*; 2020). proposed a model for an inbound call centre using Hierarchical Timed Coloured Petri Nets (HTCPN). The model classifies agent utilization and call abandonment rates, leveraging ARENA simulation software to analyze data and determine key parameters, including call arrival, hang-up processes, sales, customer care, and enterprise process modules.

(Bobbio & Trivedi, 2018) utilized Hierarchical Coloured Petri Nets to evaluate maintenance processes in technological facilities, focusing on the maintainability evaluation of the stages of maintenance and repair using Timed Colored Nets. (van der Aalst, 2020) introduced a novel method for general hierarchical system modeling using colored Petri nets based on transition extractions from real datasets, introducing timing characteristics for more accurate models and integrating real system events into Petri net sequences. According to (Shan & Chen, 2023) highlighted the importance of logistics in modern organizations, as they aim to provide a wide range of products in less time and at lower prices, integrating control of various logistic activities. (Jensen, 2018) Conducted a study on logistic transport systems simulation in the Petri Nets environment, analyzing the content, features, and capabilities of Petri Nets, which are built using the structural logistic system method of agro-products delivery.

Table 1: Comparison Analysis of Existing Techniques

S/N	Author(s)	Strategy	Limitations	Performance %
1	Odeniyi et al. (2021)	HTCPN	No validation of the developed model.	Optimization process reduced queueing and waiting times.
2	Afolabi et al. (2020)	HTCPNs	Calls and queue abandonment.	An increase in quality service, reduce rate of abandonment.
3	Ganiyu et al. (2020)	HTCPN	Model does not consider the demand time.	Improved resources and production time.
4	Mahdi, (2022)	HTCPN	Targets built with OO are difficult to represent.	SRMCPN was developed.
5	Odeniyi, et al. (2022)	HTCPN	There was a long waiting time.	Simulated results represented the actual system.

MATERIALS AND METHODS

The research methodology is premised on the adoption of the Hierarchical Timed Coloured Petri Net, that was being used in modeling the transport and logistics process. Essential materials were considered, including data collection from the

system that was studied; development of the HTCPN model for the logistics process; description of the developed HTCPN model, also, the simulation and validation of the developed Hierarchical Timed Coloured Petri Nets Model.

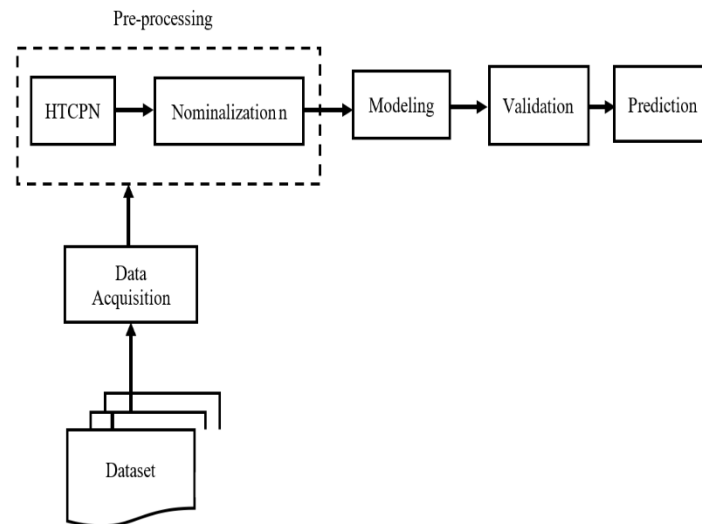


Figure 1: Proposed Block Diagram of HTCPN Model

Data Acquisition

The data that was used for the development of the HTCPN model for the transport and logistics process with emphasis on the delivery of items which include cargo, goods and parcels, was collected primarily by direct observation at Ekeson's Transport and Logistics Company, Jibowu, Lagos. The data collected was through direct observations of the system, a

thirty-minute interval collection of data was adopted, this was for a period of ten (10) hours, with twenty (20) observations recorded. The observations in minutes were converted into seconds for effective analysis. The data collected includes the number of senders, number of receptions, queueing time and waiting time. Data was also generated as a result of the simulation.

Preprocessing of Dataset

Hierarchical Timed Coloured Petri Nets (HTCPN) are powerful tools for modeling and simulating complex systems, particularly in transport and logistics. To use these models, datasets were cleaned, extracted meaningful features and built into the model. Simulations were conducted to evaluate system performance and identify potential issues. Also, validation and parameter adjustments are employed to ensure model accuracy. By following these steps, entities can gain a better understanding of their transportation and logistics procedures, leading to improved decision-making and performance.

Processing of Dataset

Hierarchical Timed Colored Petri Nets (HTCPN) are powerful tools for modeling and simulating complex systems, including those in transportation and logistics. To ensure accurate representation and effective analysis, processing datasets for these models involves several key steps. Relevant datasets containing information on items, senders, receivers, waiting times, and queueing times are consolidated and cleaned to remove duplicates, handle missing values, and standardize formats, resulting in a consistent and analysis-ready dataset.

Feature Extraction

Extract relevant features from the dataset, including queueing time, waiting time, sender and receiver counts, and reception data. Develop an HTCPN model that accurately represents the transport and logistics system's structure, interactions, and dynamics by defining locations, arcs, transitions, and tokens. Carry out simulations using the HTCPN model to analyze different scenarios, evaluate system performance, and identify potential inadequacies. This step helps in improving operations and resource allocation. To make sure the HTCPN model is accurate and dependable, validate it using actual data. To increase the model's capacity for prediction, adjust its parameters as necessary

Modeling Approach

There exists a definition of Hierarchical Timed Coloured Petri Nets

(HTCPN), which was adopted in the modeling the Transport and Logistics Process under consideration. The formalization included hierarchy concept to Timed Coloured Petri Nets.

A Hierarchical Timed Coloured Petri Nets is a finite set of nets $H = \{N_1, N_2, N_3, \dots\}$. Each net

N in H is a tuple $N =$

$(\Sigma, P, T, A, C, G, Exp, I, \tau, h)$ where:

- i. Σ, A, C, Exp, I : are defined as in TCPN.

- ii. $P = O P \cup IP$, where: OP is a set of ordinary places as defined in TCPN, and IP is a set of interface places. An interface place is a place which is shared between more than one net. An interface place is used in communication between nets in H .
- iii. $T = O T \cup HT$, where OT is a set of ordinary transitions as defined in TCPN, and HT : a set of hyper- transitions.
- iv. G : is a guard function. It is defined from T into expression such that:
If $tr \in T$ then $Type(G(tr)) \in Boolean$
and $Type(Var(G(tr))) \subseteq \Sigma$
- v. τ : is a time function which associates with each ordinary transition a stamp.
 $\tau: OT \rightarrow \Gamma$. (Γ is a time set).
- vi. h : is a function that maps each hyper- transition to a net.
 $h: HT \rightarrow H$. It is required that if ht is a hyper-transition in N , so $h(ht)$ must not be N and must not lead to N indirectly. This means recursion is not allowed in the model. The input places of $ht(^{\circ}ht)$ and the output places of $ht(ht^{\circ})$ are places in the net $h(ht)$. [18]

Developing a Transport and Logistics Model with HTCPN

Step 1: Scope Definition: Identify the processes, entities, and resources to be modeled, requiring a deep understanding of the transport and logistics system.

Step 2: Hierarchical Structure: Determine the system's hierarchical structure, including levels of abstraction and interdependence, to define the model's complexity.

Step 3: System Definition: Define the model's components:

Places (e.g., warehouses, stores)

Transitions (e.g., movement of goods)

Arcs (connections between places and transitions)

Colors (token attributes, such as product types)

Timing aspects (event durations and intervals)

Step 4: Simulation and Analysis: Run simulations to test scenarios, evaluate system performance, and identify areas for improvement.

Description of the Case Study

The process begins when the sender sends a number of items through the reception when all payments are made. Usually, before payment is made the items are weighed and this will determine what the price the sender will have to pay. Deliveries are made after payment for the transmission of the items. The receiver receives the items that have been sent and sends an acknowledgement to the reception that all the items have been received

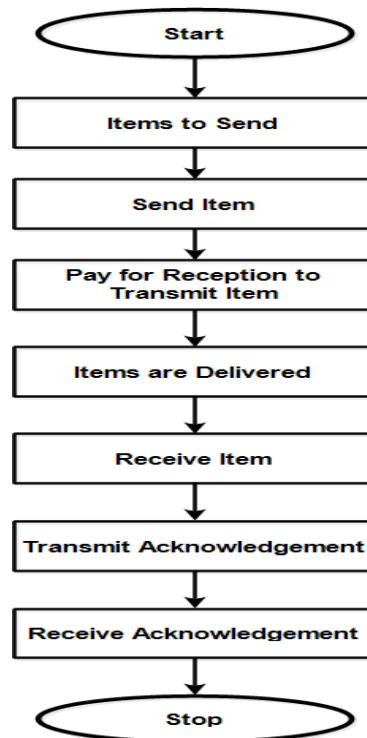


Figure 2: Block Diagram of a Logistics Process

Table 2: Terms used and Meaning

Terms	Meaning
Sender	Customer who sends pieces of Items to be transmitted
Item	Items refers to goods, parcels and goods to be delivered or transmitted
Reception	Personnel who store items, orders for transmission or delivery of items
Transmit	To transmit has to do with the delivery of items
Receiver	The receiver acknowledges receipt of items sent.

Validation of the Developed HTCPN Model

The developed HTCPN model was validated by carrying out the Pearson Bivariate Correlations Analysis. The Pearson correlation coefficient, denoted as r , measures the strength and direction of the linear relationship between two variables. Also, the p-value indicates the strength of evidence against the null hypothesis.

RESULTS AND DISCUSSION

A p-value less than or equal to a predetermined significance level, denoted as alpha (α) and commonly set at 0.05 or 0.01, indicates statistical significance. This means that the

observed effect is unlikely to have occurred by random chance alone.

A p-value greater than the significance level fails to reach statistical significance. In such situations, the hypothesis cannot be rejected, suggesting that the observed effect could possibly be due to chance. The study validated the simulated results with that of the real time values by using the p-value from the bivariate correlation coefficients. When the p-value is less than 0.05 level of significance then it shows that the values obtained from the simulation are a valid representation of the real system.

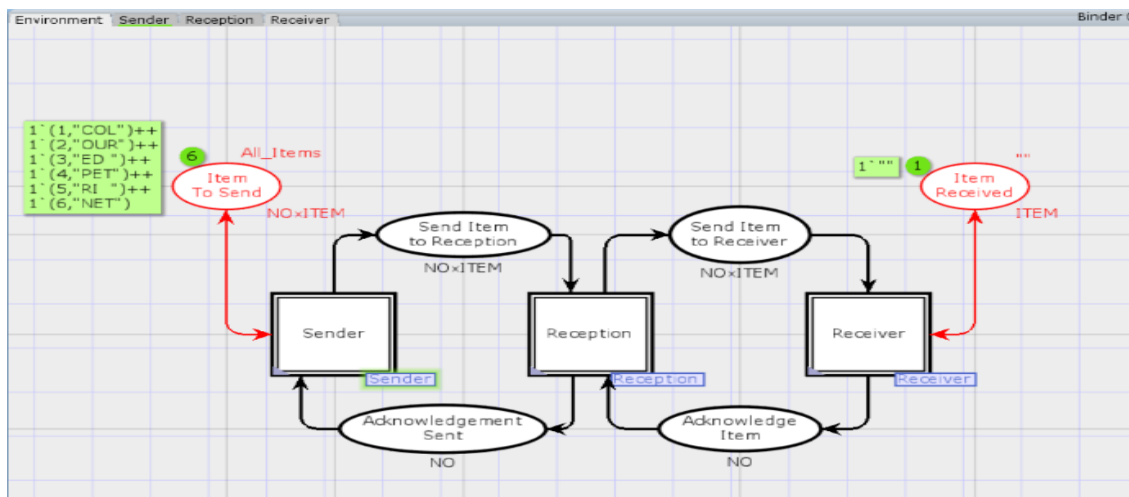


Figure 3: Environment Page of the developed HTCPN Model

The Environment Page of the developed HTCPN Model" illustrates the interactions among three key components: Sender, Reception, and Receiver in a Hierarchical Timed Coloured Petri Net (HTCPN) model. The sender initiates item transmission by checking for available items, which, if present, are sent to the reception. The reception then processes

these items, determining their validity before forwarding them to the receiver. The receiver confirms the receipt of items and sends an acknowledgment back to the sender. The model includes decision points that branch based on item availability and acknowledgment status, effectively capturing the dynamics of item transfer and management within the system.

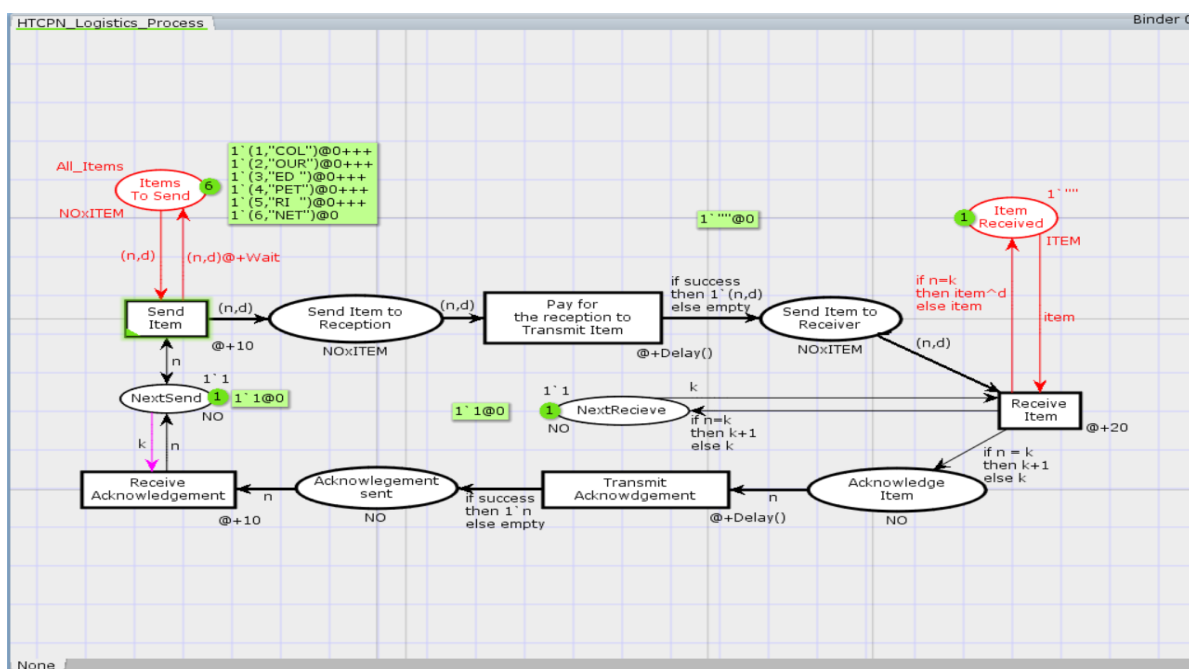


Figure 4: Sender Subpage HTCPN Model

The sender sends items to the reception and prepares them to make the next send of items available. The sender receives an acknowledgement of the item sent, which was transmitted by the reception.

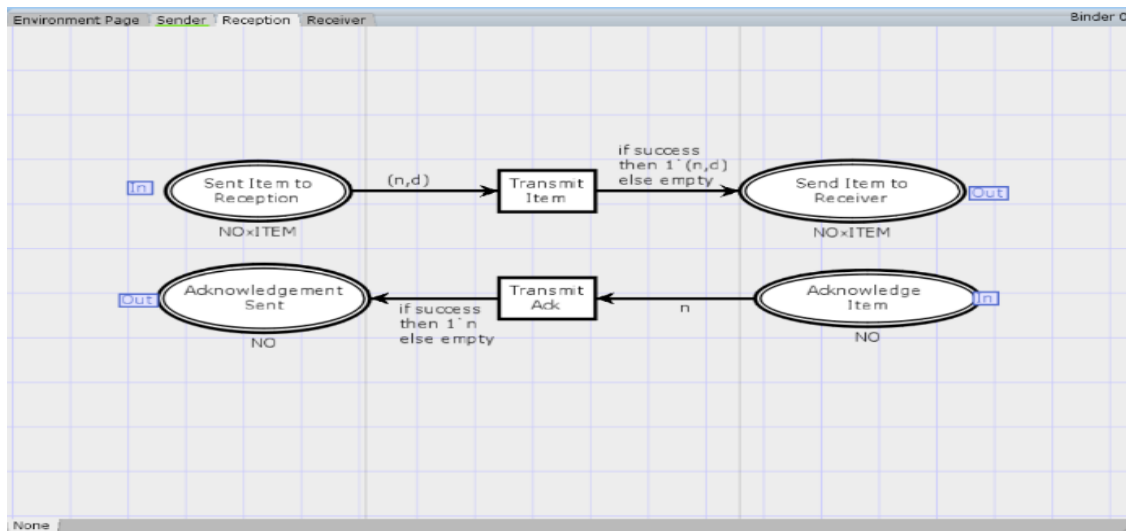


Figure 5: The reception subpage of the HTCPN Model

Figure 5 shows the reception subpage of the model. The reception receives all the items sent by the sender before transmitting the number of items to the receiver. Also, the

reception receives the acknowledgement of items collected by the receiver and transmits the acknowledgement of numbers of items collected to the sender.

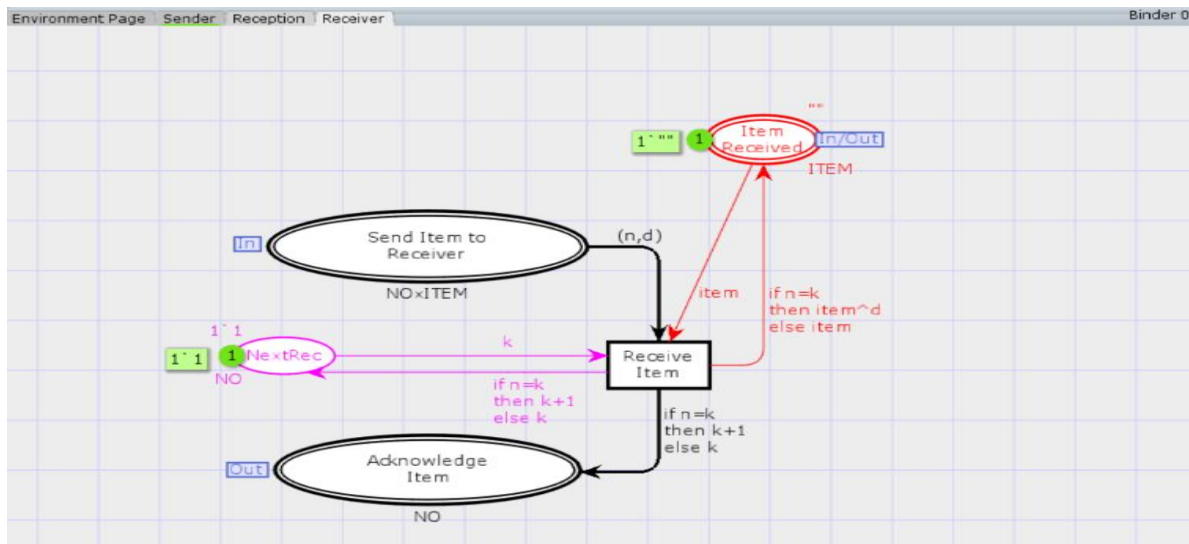


Figure 6: Receiver subpage of the developed HTCPN Model

Receiver subpage of the developed HTCPN Model" depicts the processes involved in item reception and acknowledgment within a Hierarchical Timed Coloured Petri Net (HTCPN) framework. It shows that when items are received, the receiver checks if there are items to send to the next step. If items are available, they are forwarded to the receiver, and a

corresponding acknowledgment is generated. The model includes conditional logic, where the receiver manages the count of items, adjusting the total based on successful receptions. This structure emphasizes the flow of items and the importance of acknowledgment in confirming successful item transfers within the system.

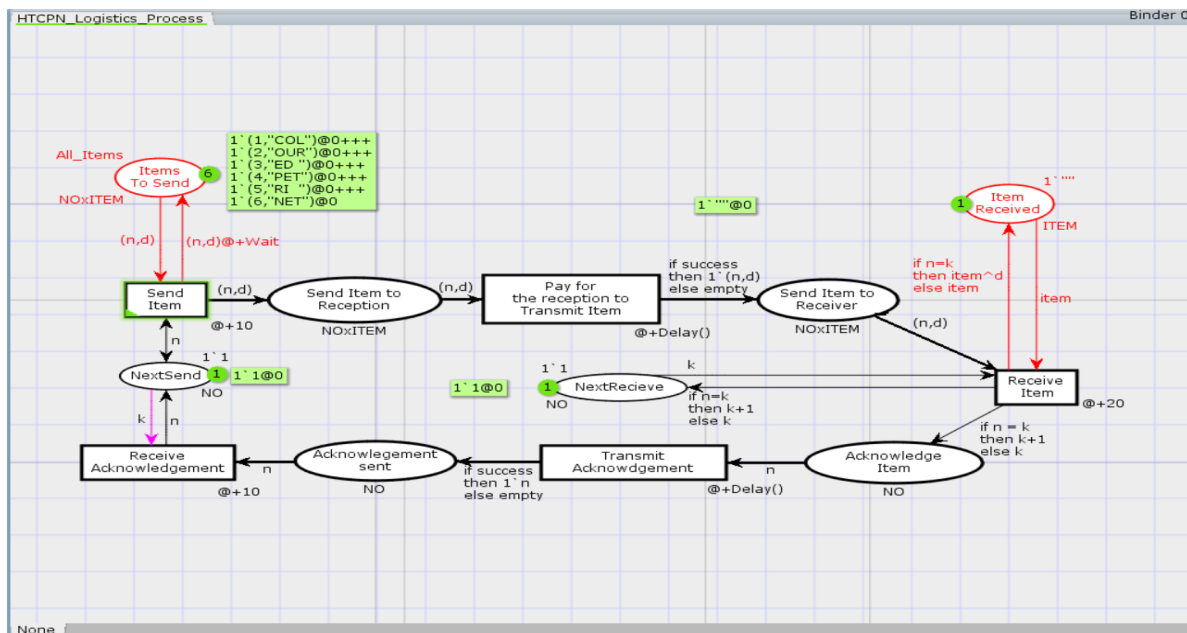


Figure 7: Integration of all subpages HTCPN Model

Figure 7 depicts an integration of all the subpages including sender, reception and receiver. The sender should not take more than 10 seconds to send all the items to the reception. There is a bi-directional arc for the next items to be sent. Payments are made by the sender, and reception transmits items to the receiver, this transition takes not more than 50 seconds delay time. Receivers receive the number of items

which should not take more than 20 seconds. There is a bi-directional arc for the next item to receive. Reception transmits acknowledgements of received items by the receiver, which should not take more than 50 seconds delay time. Acknowledgement of items received are transmitted by the reception to the sender, which does not take more than 10 seconds

Simulation Results and Outputs of the developed HTCPN Model

Results generated during Simulation of the developed HTCPN model are shown below:

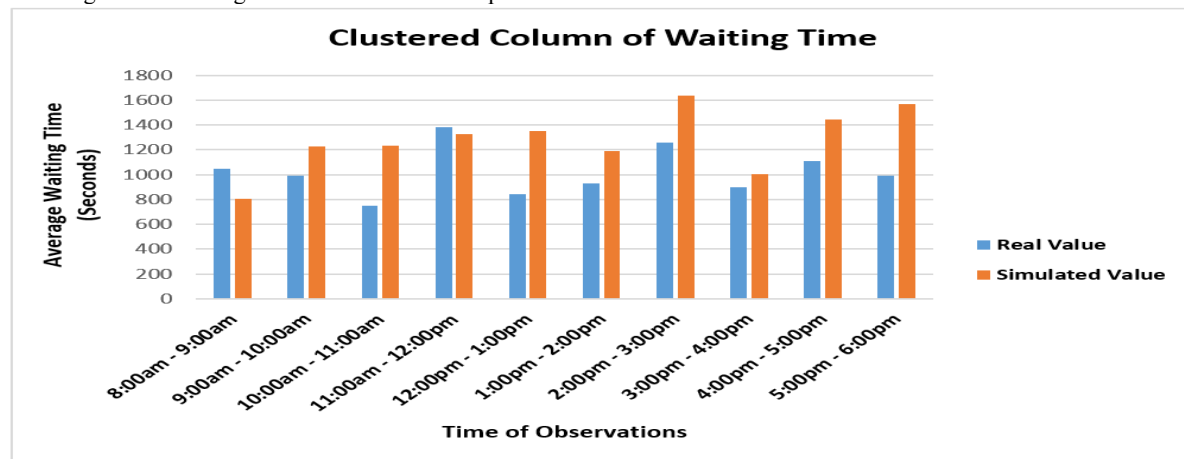


Figure 8: Clustered Column of Waiting Time

Clustered Column of Waiting Time" presents the simulation results and outputs from the developed Hierarchical Timed Coloured Petri Net (HTCPN) model. It features a clustered column chart comparing the average waiting times (in seconds) for different time intervals throughout the day, specifically from 8:00 AM to 5:00 PM. The chart distinguishes between two categories: the real values (actual

observed waiting times) and simulated values (predicted waiting times generated by the model). This visual representation allows for an easy comparison of the performance of the model against real-world data, highlighting any discrepancies or alignments in waiting times across the specified observation periods.

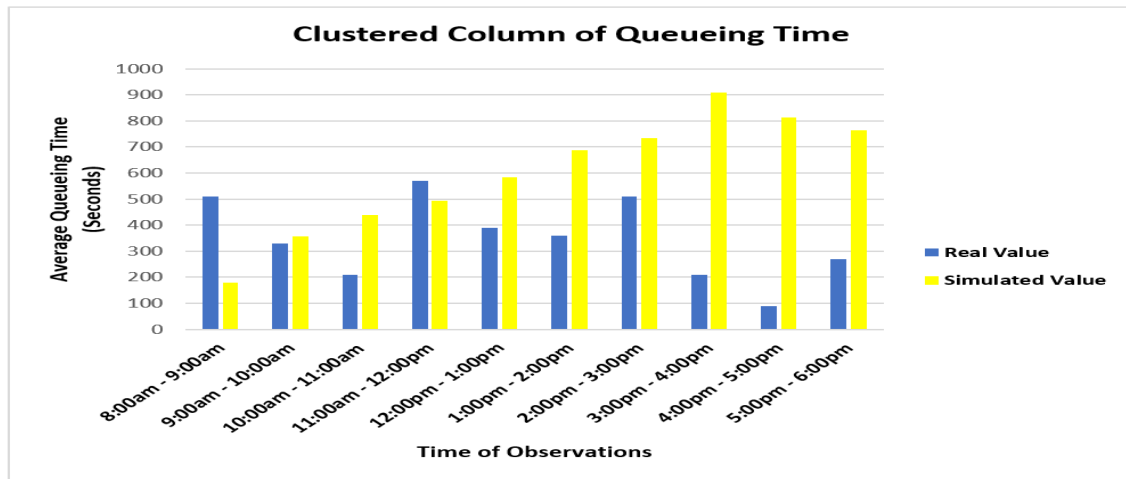


Figure 9: Clustered Column of Queueing Time

From the simulation outputs, it was discovered that with an increase in the number of reception personnel who are meant to attend to the customers (or senders), there is a corresponding reduction in the queueing time, resulting in a reduction of the waiting time by the customers. It is observed that the period of 8:00 am to 9:00 am has the lowest queueing time and waiting time was recorded.

This was attributed to the fact that this is usually when work commences, and the number of customers is not as much

compared to 3:00 pm to 4:00 pm, which recorded the highest number of customers. The number of receptions present from 8:00 am to 9:00 am was the highest, which resulted in the lowest queueing time and waiting time. This has shown that reception plays a vital role in ensuring that congestions are avoided at the Ekesson's Transport and Logistics Company. The simulation outputs of the developed HTCPN Model are provided below.

Table 3: Outputs of the developed HTCPN Model

Observation	Time of Observation	Average Number of Senders		Average Number of Receptions		Average Queueing Time (Seconds)		Average Waiting Time (Seconds)	
		Real Value	Simulated Value	Real Value	Simulated Value	Real Value	Simulated Value	Real Value	Simulated Value
1	8:00am - 9:00am	14	7	3	2	510	179	1050	807
2	9:00am - 10:00am	10	7	3	1	330	358	990	1224
3	10:00am - 11:00am	5	8	2	1	210	438	750	1235
4	11:00am - 12:00pm	7	8	2	1	570	495	1380	1326
5	12:00pm - 1:00pm	5	8	2	1	390	583	840	1354
6	1:00pm - 2:00pm	9	9	3	1	360	686	930	1191
7	2:00pm - 3:00pm	6	8	2	1	510	734	1260	1636
8	3:00pm - 4:00pm	9	10	3	2	210	908	900	1003
9	4:00pm - 5:00pm	6	9	2	1	90	814	1110	1442
10	5:00pm - 6:00pm	10	9	3	1	270	765	990	1567

Validation of the Developed HTCPN Model

Table 4: Bivariate Correlation of Simulated and Real Number of Senders

Criteria for Validation	No of Senders (Simulated)	No of Senders (Real)	Remarks
Correlation Coefficient (r)	1	-0.109	The r-value of the Simulated No of Senders shows a perfect positive correlation, while the real no of senders shows a weak negative correlation.
p-value	0.649	0.649	Since p-value > 0.05. Therefore, there is no significant difference between the Real and Simulated values for the No of Senders
N	20	20	The no of observations

Table 4. shows the p-value and correlation coefficient (r-value) between the values of the senders for both simulated and real system. Since p-value is greater than 0.05 level of

significance, it depicts that there is no significant difference between senders for both the simulated and real values. The r-value showed a weak negative correlation.

Table 5: Bivariate Correlation of Simulated and Real Number of Reception

Criteria for Validation	Number of Receptions (Simulated)	Number of Reception (Real)	Remarks
Correlation Coefficient (r)	1	0.611	The r-value of the Simulated number of receptions showed a perfect positive correlation, while the real number of receptions showed a moderate positive correlation.
p-value	0.04	0.04	Since p-value < 0.05. Therefore, there is a strong relationship between the Real and Simulated Values for the number of Receptions
N	20	20	The number of observations

Table 5 depicts the p-value and correlation coefficient (r-value) between the values of the reception for both simulated and real system. Since p-value is less than 0.05 level of

significance, it depicts that there is a strong relationship between receptions for both simulated and real values. The r-value showed a moderate positive correlation

Table 6: Bivariate Correlation of Simulated and Real Queueing Time

Criteria for Validation	Q Time Simulated	QTime (Real)	Remarks
Correlation Coefficient (r)	1	-0.479	The r-value of the Simulated Queueing Time showed a perfect positive correlation, while that of the Real Queueing Time showed a strong negative correlation.
p-value	0.033	0.033	Since p-value < 0.05. Therefore, there is a strong relationship between the Real and Simulated Values for Queueing Time.
N	20	20	The number of observations

Table 6 depicts the p-value and correlation coefficient (r-value) between the values of the waiting time for both simulated and real system. Since p-value is greater than 0.05

level of significance, it depicts that there is no significant difference between waiting time for both the simulated and real values. The r-value showed a weak positive correlation

Table 7: Bivariate Correlation of Simulated and Real Waiting Time

Criteria for Validation	Waiting Time (Simulated)	Waiting Time (Real)	Remarks
Correlation Coefficient (r)	1	0.173	The r-value of the Simulated Waiting Time (SWT) showed a perfect positive correlation, while that of the real waiting time showed a weak positive correlation
p-value	0.466	0.466	Since p-value > 0.05. Therefore, there is no significant difference between the Real and Simulated Values for the Waiting Time
N	20	20	The number of observations

From the given results of the bivariate correlation coefficient statistical analysis for direct real values and the simulated values. It has been shown that the simulated results are a representation of direct real values. Hence the Hierarchical Timed Coloured Petri Net Model for transport and logistics is valid and a representation of the real system

CONCLUSION

In the research, the hierarchical timed coloured petri net (HTCPN) model for transport and logistics process of items at Ekeson Transport and Logistics Company was developed, simulated and validated based on the queueing time and awaiting time of customers. Primary source of data was collected for the development of the HTCPN model for the transport and logistics process with attention on the delivery of items which consists of cargo, goods and parcels. Data on senders, receptions, queueing, and waiting times over ten working hours were collected and converted to seconds for accurate analysis.

The study simulated a Hierarchical Timed Coloured Petri Net (HTCPN) model for a transport and logistics system, evaluating four performance metrics of number of senders, number of receptions, queueing time and waiting time. The simulation results showed a strong correlation with real-world

values, validating the HTCPN model's accuracy in representing the actual system. This suggests the model can be used to analyze and optimize logistics processes effectively. Future work should focus on developing advanced logistics and transportation management systems that integrate HTCPNs with real-time data streams, optimizing fleet management, route planning, and resource allocation.

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