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Development of a Computational Model for Cassava Food Processing Using Coloured Petri Net

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Abstract: A food system is composed of a complex network of activities and processes for production, distribution, transportation and consumption, which interact with each other, thus leading to changeable behaviour. Most existing empirical studies on cassava processing have focused on the technical efficiency analysis of the cassava crop processing techniques among processors indicating that the modelling of the events and operations involved in the processing of the cassava crop is highly limited. In this context, different strategies have been used to solve difficult environmental and agro-informatic systems model-based problems such as system dynamics, agent based, rule-based knowledge and mathematical modeling. However, the structural comprehension and behavioral investigation of this modeling are constrained. In this regard, formal computational modeling is a method that enables modeling and simulation of the dynamical characteristics of these food systems to be examined. In this study, the system specification is designed using Unified Modelling language (UML) to show the structural process and system design modelled and simulated using Coloured Petri Net (CPN), a formal method for analyzing the behavioural properties of complex system because of its efficient analysis. For the purpose of observing and analyzing the behaviour of the cassava food process, a series of simulation runs was proposed.

Index Terms: Cassava, Simulation, Food System, Coloured Petri Net, Reachability, Garri, Lafun.

1. Introduction

A food system is composed of a complex network of activities and processes for production, distribution, transportation and consumption of food products, which interact with each other, thus leading to changeable behaviour. This involves not only the fundamental elements of how food products are transported from farm to fork but also all processes and facilities involved in meeting a population needs, that is, gathering, catching, growing, harvesting, storing, processing, consumption of food, and disposal of food [1, 2]. Food nutrition, accompanied by its security is an emergent and major global problem that relies on all people being properly supplied with healthy, affordable and nutritious fresh and processed foods in terms of using cutting-edge technology. The task of producing, processing and storing quality food products for the population would be partly addressed by using rising food production. But it will be important to reduce food losses across the supply chain from production to consumption and sustainable improvements in storage, nutrient quality, protection, food shelf-life, allowed by the food processing system [3].

Therefore, food processing is the transformation of agricultural products into food or one form of food into other food. This is because it includes several forms of processing food from grinding to complex industrial or automation methods used to make convenience food. As indicated by the national council of agricultural education food products and processing system, food production processing (FPP) is portrayed as the application of scientific standards, practices and methods in the preparing, stockpiling and improvement of sustenance food items. The council also established among the necessary art and know-how the application of science, technical know-how, engineering and mathematics to process, save a bundle and present sustenance and nourishment items available to be purchased and conveyed.

Literatures have shown that most of the studies on cassava processing have focused on the technical efficiency analysis of the cassava crop processing techniques among processors. This indicates that the existing knowledge on efficiency in wetland crops production especially the cassava production processing is highly substantial but the modelling of the events and operations involved in the processing of the cassava crop is highly limited. More so, the current simulation model did lack a formal method of description for model verification and analysis. However, this present work is unique since none of the previous works addressed the formal verification and analysis approach to confirm the accuracy of the cassava food system designed and modelled.

Different strategies have been used to solve difficult environmental and agro-informatic systems model-based problems. These include methods and their applications, such as Systems Dynamics. For instance, [4] looked into the combination of a quantitative model with rule-based knowledge to offer efficient decision making in a sensitive rural area. They used straightforward but broad mathematical frameworks in the investigation. The Agent-based approach, on the other hand, is a different methodology that made use of communication between freely programmable computing units [5]. On the other hand, networks and nets stand in for the fundamental structural elements of process models. In the systemic models, broad-ranging efforts have been done throughout the years to build and develop quantitative, time- and event-driven features

With the development in information and communication technology, there has been innovation and improvement by scholars in automation technology. According to [6], food production processes in today's world experience periodic change due to the rising cost of operation and the increasing demand by the abounding population as well as current transformation in industries, it is therefore necessary to offer automated solutions and computer technology tools that can help it become adaptable with fewer challenges. The automated solution substitutes manual task with computational technologies including computer-controlled devices, which decrease labour costs, reduce food losses, diminished roundabout work costs, improved cleanliness and a decrease in the number of modest errands and tasks performed by peoples, thereby enhancing production rates and output.

Modelling and simulation technology has been widely applied in all fields ranging from education, healthcare, space science, engineering to agriculture disciplines [7]. Moreover, the design and modelling of complex systems like food production system have become indispensable supporting techniques particularly with the development of science and technology, which is aimed at bringing convenience and efficiency to the food production process for people in terms of optimizing production process thus reducing food loss and improving food process quality costs

Today, the demand for food products, textiles, and oil products that rely on cassava product (e.g., starch) has been on the rise and still increasing daily [8]. Scholars have used mathematical modelling and simulation methodologies to investigate, improve and develop products and processes. [9] employed a thin-layer drying model to explain the process of drying irrespective of the controlling mechanism. Besides, [10] noted that a midilli model was incongruent with the data collected during the drying process of cassava pulp. Again, [11,12] used computational modelling technique to boost cassava Brown Streak disease surveillance to reduce losses and optimize as well as evaluate the collaborating and singular effects of the process and variables employed in the production of cassava starch-based film. Though, this approach is beneficial to perform. However, the difficulty of identifying and representing the biological process of the cassava production system is less exact and highly fragmented. Consequently, little understanding of the behaviour and dynamic nature of the system is known. Therefore, cassava-based farmers' economic efficiency and productivity could still be increased by using the most recent technology of computational modelling and simulation method available to represent the physical processes and events involved in the production of cassava product into an actual working system of which, the understanding of the system will lead to a hopefully better and more efficient system.

Computational modelling and simulation play an important role in food engineering and automation, particularly to provide digital representation, improve process automation, optimization and development, the visual simulation effects obtained. Therefore, the implementation of a computational simulation method in food processing engineering can provide a valuable solution to the understanding of the complex problem that theoretical or empirical approach can achieve. Different techniques with their tools have been used to model agricultural food processes. Different workflow process management systems tend to use a wide variety of work distribution concepts and a completely different term. [13] used an artificial neural network (ANN) for optimizing process parameters in feed manufacturing. The potential for the stochastic mathematical model has also increased exponentially over recent decades, but most systems are still complex to be analytically modelled or the computational solution is too costly to complete, requiring impractical time [14].

Among these simulation approaches, discrete simulation of event system has emerged as a paradigm of modelling and simulation capable of capturing a system whose state only changes at a discrete point in time. Recently, formal techniques like Process algebra, Petri nets, and temporal logic have recently have found their ways from academics to industry in several domains. [15] stated that the Petri net can be used for modelling the system and subsequently simulating the structural and behavioural properties of cassava food event process.

Similarly, [16] addressed the challenge of plug and play in terms of automation involved in the manufacturing system. In an attempt to achieve the objective of generating accurate result and behavioural properties. The authors designed a model and subsequently simulated the process using an event-oriented approach such as the use of Simulation tools such as SIMSCRIPT and others. Moreover, the result showed that the method of simulation and modelling supports decision making. However, Petri Net remains a formal and standardized specification tool that is widely accepted and used in continuous and discrete event system modelling and simulation. Also, the Petri net is designed specifically for representing the working construction of the complex system as they offer a pictorial illustration of events and processes involved in the simulation process.

This study is aimed at stimulating the cassava food production process using formal method. Hence, the objectives of the research are to examine the existing production processes employed in cassava food production, model and simulate the process behaviour using Unified modelling language and coloured Petri net model (CPN) and evaluate the behavioural properties of the model. Therefore, the paper presents a simulation of the coloured Petri net model of the cassava food process.

The organization of the paper is as follows. Section 2 provides an overview of cassava production processes and related works. Section 3 presents Petri net, Unified Modelling Language and CPN model methodology employed for the modelling of cassava production process operation with CPN tool. The simulation and the state space analysis reports are discussed in section 4, result and discussion in section 5 and the final section gives a concluding summary of the paper.

2. Literature Review

2.1. Overview of Cassava Production Processes

Cassava (Manihot esculenta) is one of sub-Saharan Africa's main staple food. According to [17]. It is African's second-largest food source grown after maize by households. Cassava is the basic food crop in the developing world, which gives the most essential human nutrition that helps the survival of over half a billion people [18]. According to [19, 20], cassava is regarded as one of the major farm crops planted by most farmers in Nigeria. In fact, Nigeria being the largest cultivator of cassava crop in Africa and is closely tailed by the Republic of Congo. The cassava plant is produced in its highest quantity, yielding about 38 million metric tons (MT) per annum thus producing three times much more than Brazil and twice the production capacity of Thailand and Indonesia with about 38 million metric tons (MT) per annum [21].

[22] asserted that cassava plant tuber is highly perishable and therefore important to process it almost immediately after harvest. Cassava roots are harvested at various time and seasons of the year and transported to the house or the processing sites for further processing or are transformed into different kinds of food products forms to prolong the shelf life of the products, assist the movement, promoting and distributing, reduce cyanide content and improve its pleasant-tasting to the consumers, improve profitability and increase the marketing margin of the processors. Generally, cassava tubers are prepared by different techniques into various staple nourishments and final consumable foods products which include Garri, Cassava, Fufu, Lafun, Starch, Tapioca, Bread, Prawn Crackers among others. Other methods are employed in processing cassava into numerous other products such as starch, gum which are used in various ways according to traditions and preferences [21]. However, the traditional processing techniques like drying, grating, pounding, boiling, soaking and fermentation are known to reduce the toxicity to a large extent [23].

[24] in the United Nations Environmental Programme International Resource Panel (IRP) categorized the classes of food processing system into three (3): traditional, modern and intermediate processing. The traditional method of processing uses input and traditional techniques to selling and processing the crop thereby yielding relatively low productivity while the modern processing technique requires varied external input to maximize production as well as the high technology system for storing, processing, etc. While the intermediate employs the features of the traditional and modern system. [25] illustrated the traditional and the improved methods used in cassava processing as shown in Table 1–4. The processes are as described, old method refers to the indigenous tool employed in the particular process while modern tools are used nowadays.

Table 1. Garri Processing Stages, Traditional Technology and Improved Technology.

Process	Traditional method	Improved technology
Peeling	Bamboo or flint knife	Mechanical peeler, Motorized peeler, hand peeler, hand rasper
Washing	Calabash	Plastic container
Grating	Coarse stone, prickly trunk of palms sheet / tin iron pierced with nail on one side	Mechanized grater, Motorized grater, hammer mill, disk grater, hand grater.
Dewatering	Heavy stone on heavy weighed cloth nylon bag (for several days)	Hydraulic jack press, screw press, parallel board press.
Sifting	Woven baskets	Improved bowl-shaped sieve
Roasting	Cast iron pan over wood fire	Improved roaster, solar dryer, kiln type dryer
Sifting	Knitted basket	Improved Sieve

Table 2. Lafun Processing Stages, Traditional Technology and Improved Technology.

Process	Traditional method	Improved technology
Peeling	Bamboo or flint knife	Mechanical peeler, Motorized peeler, Hand rasper
Washing	Mud pot	Plastic tank
Soaking	Mud pot	Plastic tank
Draining	Woven basket	Improved pulveriser
Drying	Spreading on hot hill to sun dry	Solar dryer
Milling	Mortar and pestle	Milling machine/grinder

Table 3. Starch Processing Stages, Traditional Technology and Improved Technology.

Process	Traditional method	Improved technology
Peeling	Bamboo knife	Machine -operated peeler, Cassava filter, Motorized peeler
Washing	Calabash/mud pot	Plastic container
Soaking	Calabash/pot	Plastic container
Sieving	Suspended transparent cloth holding mash	Improved pulverizer
Drying	Spreading on hot hill to sun dry	solar dryer
Milling	Mortar and pestle	Grinder/miller

Table 4. Fufu Processing Stages, Traditional Technology and Improved Technology.

Process	Traditional method	Improved technology
Peeling	Local knife bowl	Machine-operated peeler, cassava filter, motorized peeler
Washing	Mud pot	Plastic container
Soaking	Rough stone	Aluminum tank
Sieving	Suspended transparent cloth holding mash	Improved pulverizer

2.2. Related Works

[26] investigated the chaotic and deficiency involved in the production line of a bakery system. In an attempt to achieve the goal of providing an automated means of design the production lines processes, the processes were modelled and simulated using a simulation software tool called ARENA. [27] also addressed the challenge encountered in a food manufacturing system. The study was carried out to bridge the gap between the growth of food manufacturing and the quality of food products, thus enhancing the food manufacturing system. In the study, the process is modelled and analyzed to improve the performance of the process involved in the production of the system using simulation. Here, five (5) models were developed with modification. The result obtained showed that it assisted in management by helping in decision making. However, the improvement shown by using the model gives basic information about optimizing the system but could not reduce or simplify the concurrent processes involved in food processing. [28] worked on computational modelling in system engineering using cassava processing plant as a case study. The demonstration of the modelling of the cassava processing plant at five levels of abstractions was done using Automata theory and related techniques. The study developed a process difference diagram, a modelling tool and applied it in the analysis of process design and its dynamics. However, the study does not integrate analytical, numerical, qualitative and symbolic techniques within a unified framework which can cope with the intricacy and complexity of the real-world system such as the one modelled in this present work.

A fuzzy logic-based process control system was designed and simulated by [28] for a gari fermentation plant. The simulation was performed using the MATLAB 6.0 and CPN tool. Likewise, [29] worked on computational modelling in system engineering using cassava processing plant as a case study. The demonstration of the modelling of the cassava processing plant at five levels of abstractions was done using Automata theory and related techniques. The study developed a process difference diagram, a modelling tool and applied it in the analysis of process design and its dynamics. However, the study does not integrate analytical, numerical, qualitative and symbolic techniques within a unified framework which can cope with the intricacy and complexity of the real-world system. [30] used a Petri net tool to model Adire fabric production system to better understand how the production process could be improved. In order to model and simulate a multi-phase traffic light-controlled intersection for the T-type junction with an accompanying fixed signal timing plan to lessen traffic congestion and guarantee greater safety, [31] used the Timed Coloured Petri Nets (TCPN). Again [32] proposed a solution to the issue of patient-health-care break-continuity using the TCPN modeling approach to improve the flow process thereby saving lives. [33] applied the Hierarchical Coloured Timed Petri Net to simulate the Point of Sale (POS) cash deposit and Deposit Slip processes in Nigerian banks. However, the performance metrics to choose and assess the best simulation software for food processing, according to [34] include code reuse, modeling flexibility, and types of modeling structures.

Likewise, [35] investigated the challenge faced by the manufacturing system in terms of improving the production line processes in a food manufacturing system. To achieve the stated objective, a Modularized Hierarchical Timed Coloured Petri net model (HTCPN) was used to simulate the model designed for multi-food process production. The simulated design was verified at important stage using T-test. The outcome revealed that the model designed was effective for improving the process of making garri. [36] designed and developed models for the conventional and mechanized locust bean production process using HTCPN. [37] investigated the challenge of mechanisms of fluctuations and uncertainties realized in production-logistic in a dynamic production system. To address the problem identified, a timed petri net model method based on self-adaptive collaboration was presented. Similarly, the coloured petri net method was employed to validate the performance and the application of Petri net. The outcome revealed that the method used performed better than the event-driven method. [38] applied Coloured petri net methodology to industrial control system while [39] employed CPN model to check the equilibrium attained between the use and security on interactive information system design. Moreover, [40,41] in separate works used the CPN method to transform business pattern and verify the smart homes.

With the rapid growth and growing understanding of complex and dynamic systems, activities, states, practices and activities in the manufacturing and production systems, the whole lifecycle of each product produced draws attention, in particular, to the use of an approach that helps to address the problem discussed for food, clinical, biometric and identification as well as computational biology and chemistry. To improve the food production processes, Coloured Petri nets (CPN) have been adopted in this study for the design and implementation of cassava food processing as a means to improve its economic efficiency. The justification is the need to explore the usage of CPN for its possibility in the description of logical structure and behaviour of modelled systems. This paper focuses on proposing a computational simulation of cassava food process network together with the working performance of the formal specification method with a diagrammatical representation given by the simulation tool Coloured Petri net (CPN) tool.

3. Materials and Methods

3.1. *Petri Nets*

Petri nets (PN) is graphical, mathematical and analytical modelling formalism that has in recent years has gained wider recognition as a tool for representing the construction of complex and logical interactions among physical components of a system [42,43]. Petri nets are essentially bipartite weighted, labelled, directed graphs, with tokens that represent different changes as reactions take place in the graph, they can be used in the design and operations of batch processes in different ways [44]. In addition, petri net is a model-based tool that is characterized by its ability to describe the internal state of the system and by their focus on the description of how the operations of the system change that state. In addition to this, it specifies the behaviour of the system. Petri net as a model constructs a mathematical representation of the system that is being analyzed and studied. In the same context, [45] stated that the Petri net tool is a well-established abstract modelling language used to model and study system composition. Furthermore, the author emphasized the Petri net tool as a diagrammatic and executable technique for defining and analyzing concurrent, discrete event, and dynamic systems which facilitates the understanding of the behavioural properties of the system being studied.

There are many varieties of Petri Nets ranging from the simple net, known as low-level Petri Nets, which are conceptually simple and straightforward to analyze simple system constructs, to more complex Petri net known as Higher level Petri Nets, e.g., coloured petri net. However, the low-level Petri Nets experienced difficulty representing complex systems [46]. Therefore, to reduce the difficulty of representing complex system, coloured Petri Nets based method is employed [47]. [46] further observed that coloured Petri net method is being applied in several areas and field of knowledge [48]. In fact, coloured Petri net simulations serve as a modeling paradigm and a tool for a variety of applications, including performance assessment, decision-making support, and analysis of intricate and complex systems. like food, manufacturing, pharmaceuticals and many other production and processing systems implemented to help improve the knowledge of certain system model control flow processes [38, 49].

The exact and understandable portrayal of cassava production in terms of the conditions and events that result in the formation of cassava products is accomplished by using a petri net-based model approach. The modeling capabilities and mathematical formalization are its second advantage. Third, it is simple to examine and analyze whether system behaviors are proper and whether they have changed [50]. Fourth, using Petri nets could help a system designer and a system engineer analyze a system's actions at various design stages [29]. Fifth, through the associated modules for the multi-process food manufacturing system, the generated computational models might be altered to adapt for future adjustments [34]. As a result, the CPN approach and method are flexible and useful across a variety of domains, including IOT, nuclear power plants, modeling protocol behavior, information systems, business patterns, control systems of smart grids, and multi-process food manufacturing modeling, which is the primary motivation behind the proposed work. With the CPN technique, the proposed work intends to model the cassava food production system and evaluate its behaviours.

3.2. *System Design of Cassava Processing Techniques*

An object-oriented design and model-based approach formulated using Unified Modelling Language (UML diagrams) and Coloured Petri Nets (CPN) tools were employed in this study. The UML design for the cassava production process offers a standard way of showing the system's architectural blueprints as well as the structure and the logical flow of process or activities involved in the production process of the cassava products. Activity diagram was used during the design stage to document and understand the logical flow of the cassava food production system. Here, the activity diagram shows potential interactions between objects in the system being defined. This model was used for specifying and implementing the control aspects of the cassava production system as they send tubers of cassava to one another over time. Fig.1 illustrates the standard methods corresponding to the methods traditionally used in Nigeria for the processing of the four-cassava food product. The harvested cassava tubers from the farm are passed to a "Peel" process after which they are passed to the "Wash" process. After the cassava tubers are being washed, the process is then split for each of the products. The processes involved in making Starch include Cut, Soak, Drain, Decant, Dry, and Package. For Garri, the processes involve Grate, Dewater, Sieve, Roast, Sieve and Package. For Fufu, the processes include Soak, Mash, Sieve, Drain, Dewater, Dry and package. Also, for Lafun, the processes include Soak, Drain, Dewater, Dry, Mill and Package as illustrated in Fig. 1.

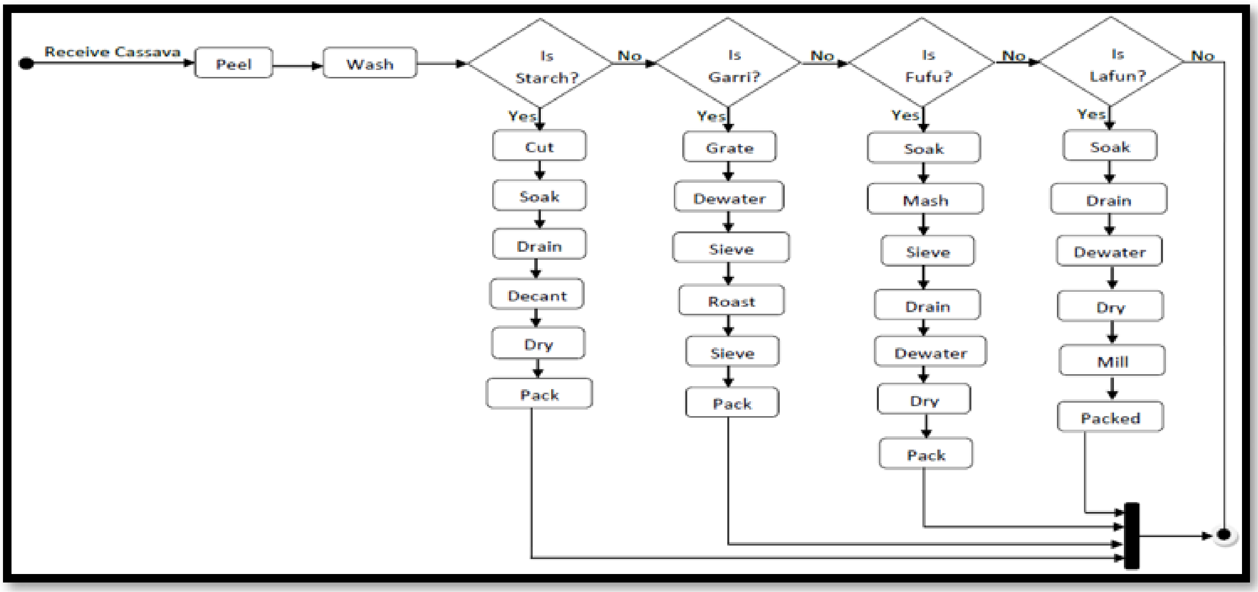

Fig.1. Activity Diagram for the Cassava Process Model.

Coloured Petri nets technique was used for the design, specification, digital construction and verification of both distributed and concurrent systems [43]. Its application is most desired in modelling systems be it simple or complex food system, where synchronization and resource sharing are essential. Simulations can be done during any stage of the entire design process, and not only at the very end. This also implies that it is possible to remove errors and implement necessary corrections at an initial stage of the design. CPN model defines the set of structures in which the state may be in a system, and the changes that occurs between those states in a system.

Coloured Petri nets allows its user in its continuous and discrete form to create aspect and components as Place (P) or state and Transition (T). Place is connected by an edge called an Arc with transition, and the transition (T) to Place (P). Moreso, the arc connects the place to transition and vice-versa thereby providing a causal relation description between the basic components of the food production system under investigation. The places (P) are denoted by a circle or ellipse, and a transition (T) denoted in this paper by R are represented as rectangles while the arc is denoted by an arrow. The word color set is used to label data types like integer, text, float, etc. Transitions from one place to another can only be activated if their input place contains tokens, therefore declaring color sets or data types to the nodes enables us to assign values known as tokens to the places. Green indicates that a transition is enabled. Similarly, the arcs are identified with labelled weights that are non-negative (positive) integer numbers. The place may hold or contain objects or a collection of tokens representing the discrete quantity each being an object representing a sub-process in the system.

Nevertheless, the basic properties of the petri net of this type follow from their dynamics of a state change which is about the change of state, which is connected to the movement of the token (s) that is being denoted by a black dot or sometimes represented with a non-negative integer from one place to another place through a transition. This corresponds to the flow of information through the cassava production system being modelled. However, the processing method for modelling cassava production requires the use of the concept of conditions and events in which places represent conditions and transitions represents events in the representation of interactions between the diverse structured processes involved in the production of the four cassava products from the cassava crop. Furthermore, the transitions that bear these tokens allocated to places are only enabled, thus indicating green. Following the creation of the CPN model, the designed model is simulated using a single- or multi-step debugging button. This debugging button enables us to see how the changes occurs in the state and its effects on each state. The simulated model is evaluated and verified to see the accuracy of the model through the use of the state space tool.

3.3. *CPN Modelling Approach of the Cassava Process*

In this section of the present work, CPN modelling approach used is briefly described. There is a typical characteristic of CPN that makes it possible for models to be organized into a number of related modules based on an ordered structural method of doing things which permits the use of bottom-up and top-down functioning ways. A complex system can consist of smaller ones which are sub modules of the main system. This characteristic makes the modelling of processes of these cassava products convenient. The model consists of one main module and four sub-modules: Fig. 2 shows the modelling of the main common processes, after each action that is, after each transition represented as rectangles the tubers assume a new state, represented as circles. After washing event the cassava tubers change to the washed state, at P_3 the model divides into four sub modules which represents the CPN modelling of the Lafun, Garri, Fufu and Starch processes respectively. This is the state where these tubers are distributed into the sub modules for further processing into corresponding products. Each of the modules carries out the relevant process tasks sequentially concurrently.

Coloured Petri net (CPN) tool was used to model and simulate the production processes of cassava in this paper. CPN for cassava process is defined computationally as a 7 tuple:

$$\mathrm{PN_{cassava}} \coloneqq (\mathrm{P, R, V, F, g, N, Mo}) \tag{1}$$

Where:

- P = {P1, P2..., Pn} is a finite set of Place
- R= {R1, R2…, Rn}is a finite set of Transition
- V= validation space {0,1}
- F ⊆ (S×R) ∪ (R × S) is the set of Arcs
- g is a binary mapping function used in determining whether the place is connected to the transition R*S→V
- N is the finite set of tokens and
- $M_{o:}$ P→ {0,1,2,3…}is the initial marking

3.4. *CPN model for Cassava Process*

Fig. 2 represents the coloured Petri net (CPN) model of the processes involved from turning cassava tuber to four end products: Garri, Lafun, Fufu, and Starch. The CPN model is a hierarchical structure showing the branching into each process after place P_3. The place P_1 models the unpeeled cassava tubers and the following transition models the peeling action of the cassava tubers which is the process of removing the cassava skin and the inner cortex. The peeled cassava is in place P_2 and ready to be washed in the next transition. At P_3 all the cassava tubers are washed and ready to be distributed into various other processes that will produce the different end products. Peeling and washing of cassava tubers are the common tasks in the cassava foods processes in Africa. These tasks have been identified to be labour-intensive. The places P_1, P_2, and P_3 and the transitions peel and wash represent the essential initial processes since they are all common to all cassava food products. The already peeled and washed tubers of cassava ready to be shared into different categories for further processing. The places P_1 (cassava), P_2 and P_3 have associated colour type string.

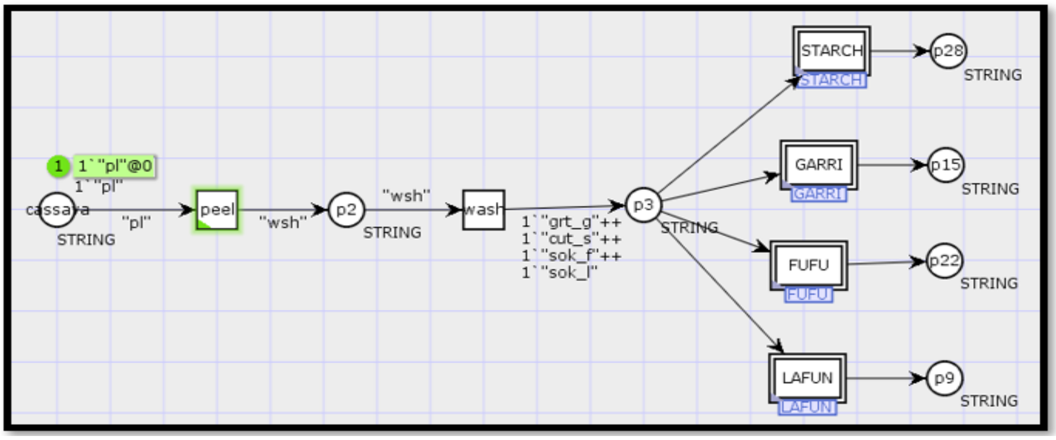

Fig.2. CPN Cassava Main Process Model.

A. *CPN Model for Lafun Processing*

The Lafun model consists of six states represented by places P_4, P_5, P_6, P_7, P_8 and P_9 as shown in Fig. 3. P_4 is the state of soaking the cassava tubers for fermentation. Fermentation is an automatic internal process which takes place as the processes proceeds so it is not represented as a transition. P_5 represents the drained state where the water was drained away from the soaked cassava. P_6 is the dewatered state after soaking and dewatering processes. The dewatering is a process whereby the soft cassava is tightly pressed to remove all the water. The state of sun drying follows after dewatering process and it is represented by P_7. Place P_8 models the state where the sundried cassava has been milled. Finally, P_9 models the packed Lafun powder ready for storage. Tables 5 summarizes the process places and the transitions for the Lafun processing. Similarly, there are five actions/events represented by the transitions in the Lafun model; these include five consecutive processes involved from the washed cassava to the final powder Lafun. They include soaking, draining, dewatering, drying, milling and packing.

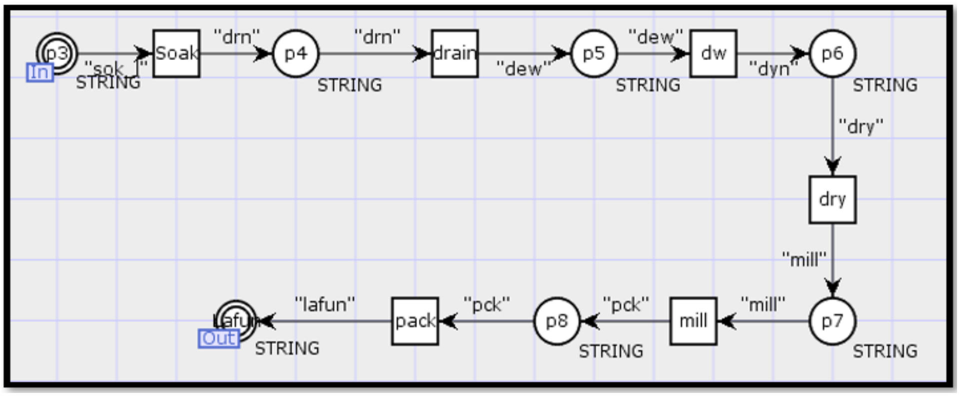

Fig.3. CPN Model for Lafun Processing.

Thus, coloured Petri net (CPN) model for Lafun is given

$P = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9)$
$R = \{r_1, r_2, r_3, r_4, r_5, r_6, r_7, r_8, r_9\}$
$V = \{0,1\}$
$F \subseteq (P \times T) \cup (T \times P)$
$f = P \text{ X}T \rightarrow V$
$f(P_1, t_1) = 1; f(P_2, t_2) = 1; f(P_3, t_3) = 1; f(P_4, t_4) = 1; f(P_5, t_5) = 1; f(P_6, t_6) = 1$
$f(P_7, t_7) = 1; f(P_8, t_8) = 1; f(P_9, t_9) = 1; g(P_1, t_1) = 0; g(P_2, t_2) = 0; g(P_3, t_3) = 0$
$g(P_4, t_4) = 0; g(P_5, t_5) = 0; g(P_6, t_6) = 0; g(P_7, t_7) = 0; g(P_8, t_8) = 0; g(P_9, t_9) = 0$
$N = (1,0,0,0,0,0,0,0)$
$M_0 = m(P_1), m(P_2), m(P_3), m(P_4), m(P_5), m(P_6), m(P_7), m(P_8), m(P_9)$

Table 5. Place Transition for Lafun Processing.

Places	Transitions
P_1=Raw Cassava	r1=
P_2=Peeled Cassava	r2=Peeling
P_4=Washed Cassava	r3=Washing
P_4=Cut	r4=Cutting
P_5=Soaked	r5=Soaking
P_6=Drained	r6=Draining
P_7=Dried	r_7=Drying
P_8=Milled	r_8=Milling
P_9=Sieved	r9=Sieving

B. *CPN Model for Garri Processing*

The Garri model is represented in Fig. 4. It is also made up of six (6) Places and six (6) transitions in addition to the common P_1, P_2 and P_3. The Places P_{10}, P_{11}, P_{12}, P_{13}. P_{14} and P_{15} represent the various states after each of the processes. Table 6 summarizes the process places and the transitions for the Garri processing. Similarly, there are five actions/events represented by the transitions in the Garri model; these include six consecutive processes involved from the grated cassava to the final Garri flour. They include grating, dewatering, sieving, roasting, sieving and packing.

The Petri net (PN) model for Garri is thus:

$P = \{P_1, P_2, P_3, P_{10}, P_{11}, P_{12}, P_{13}, P_{14},)$
$R = \{r_1, r_2, r_3, r_{10}, r_{11}, r_{12}, r_{13}, r_{14}\}$
$V = \{0,1\}$
$F \subseteq (P \times R) \cup (R \times P);$
$f = P \text{ X}R \rightarrow V$
$f(P_1, r_1) = 1; f(P_2, r_2) = 1; f(P_3, r_3) = 1; f(P_{10}, r_{10}) = 1; f(P_{11}, r_{11}) = 1$

$f(P_{12}, r_{12}) = 1$; $f(P_{13}, r_{13}) = 1$; $f(P_{14}, r_{14}) = 1$; $g(P_1, r_1) = 0$; $g(P_2, r_2) = 0$
$g(P_3, r_3) = 0$; $g(P_{10}, r_{10}) = 0$; $g(P_{11}, r_{11}) = 0$; $g(P_{13}, r_{13}) = 0$; $g(P_{14}, r_{14}) = 0$
$N = (1, 0,0,0,0,0,0,0)$
$M_0 = m(P_1), m(P_2), m(P_3), m(P_{10}), m(P_{11}), m(P_{12}), m(P_{13}), m(P_{14})$

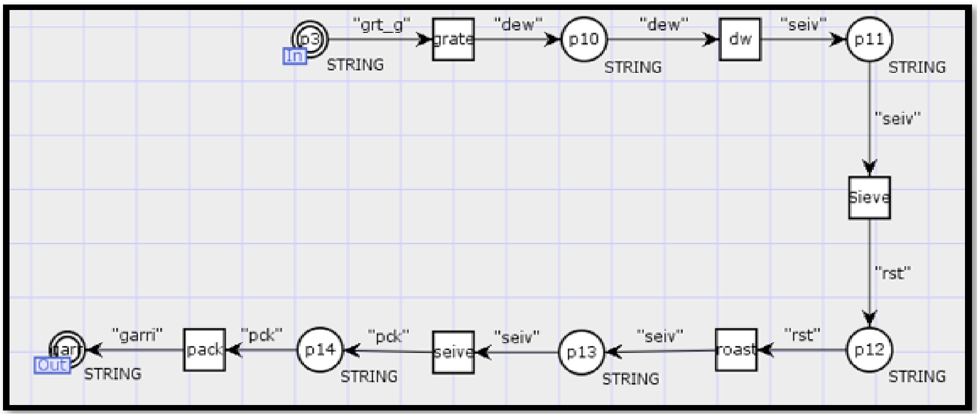

Fig.4. CPN Model for Garri Processing.

Table 6. Places (states) and Transitions for Garri Processing.

States(p1)	Transition
P_1 Raw Cassava	
P_2 Peeled cassava	Peeling (r_1)
P_3 Washed cassava	Washing (r_2)
P_{10} Grated	Grating(r_{10})
P_{11} Sieved	Sieving(r_{11})
P_{12} Dewatered	Dewatering (r_{12})
P_{13} fried	Frying (r_{13})
P_{14} sieved	Sieving (r_{14})

C. *CPN Model for Fufu Processing*

The Fufu model is shown in Fig. 5, which is made up of seven places and seven transitions, in addition to the existing three places. The transitions model the various processes. The processes include soaking, mashing, sieving, dewatering, drying and ends with packing. P_{16} through P_{22} represent the states after the transitions from each process with P_{16} being the initial that is, soaking and P_{22} as the final that is, packing ready for distribution or storage. Table 7 summarizes the process places and the transitions for the fufu processing. Similarly, there are seven actions/events represented by the transitions in the fufu model; these include five consecutive processes involved from the soaked cassava to the final fufu flour. They include soaking, mashing, sieving, draining, dewatering, drying and packing.

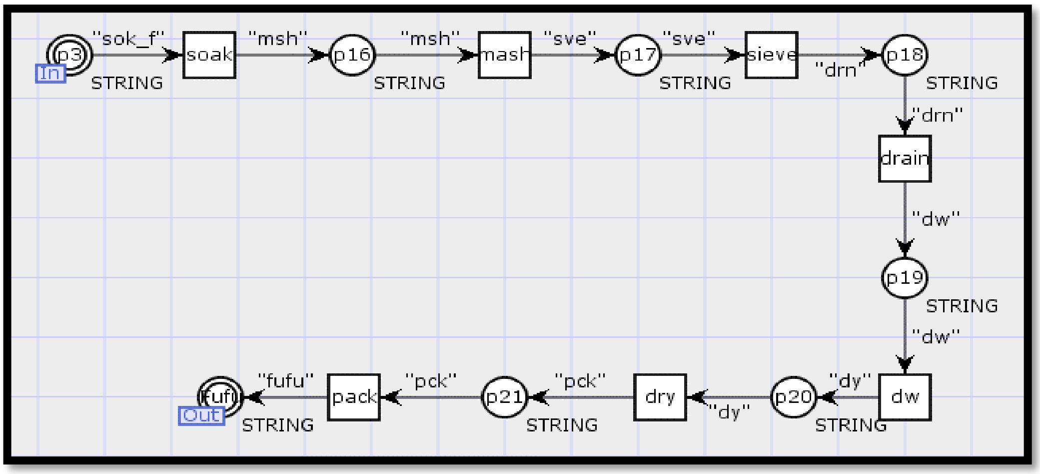

Fig.5. CPN model for Fufu Processing.

The petri net model for Fufu is:

$P = \{P_1, P_2, P_3, P_{16}, P_{17}, P_{18}, P_{19}, P_{20}, P_{21})$
$R = \{r_1, r_2, r_3, r_{16}, r_{17}, r_{18}, r_{19}, r_{20}, r_{21}\}$
$V = \{0,1\}$
$F \subseteq (P \times R) \cup (R \times P)$
$f = P * R \rightarrow V$
$f(P_1, r_1) = 1; f(P_2, r_2) = 1; f(P_3, r_3) = 1; f(P_{16}, r_{16}) = 1; f(P_{17}, r_{17}) = 1$
$f(P_{18}, r_{18}) = 1; f(P_{19}, r_{19}) = 1; f(P_{20}, r_{20}) = 1; f(P_{21}, r_{21}) = 1;$
$g(P_1, r_1) = 0; g(P_2, r_2) = 0; g(P_3, r_3) = 0; g(P_{16}, r_{16}) = 0$
$g(P_{17}, r_{17}) = 0; g(P_{18}, r_{18}) = 0; g(P_{19}, r_{19}) = 0; g(P_{20}, r_{20}) = 0$
$g(P_{21}, r_{21}) = 0;$
$N = (1, 0,0,0,0,0,0,0)$
$M_0 = m(P_1), m(P_2), m(P_3), m(P_{16}), m(P_{17}), m(P_{18}), m(P_{19}), m(P_{20}), m(P_{21})$

Table 7. Places (states) and Transitions for Fufu Processing.

Places	Transitions
P_1=Raw Cassava	r_1=
P_2=Peeled Cassava	r_2=Peeling
P_4=Washed Cassava	r_3=Washing
P_{16}=Cut cassava	r_{16}=Cutting
P_{17}=Soaked cassava	r_{17}=Soaking
P_{18}=Sift mash	r_{18}=Sifting
P_{19}=Drained	r_{19}=Draining
P_{20}=Dewatered	r_{20}=Dewatered
P_{21}=	r_{21}=

D. CPN Model for Starch Processing

The starch processes are represented by the CPN model in Fig. 6. The CPN model for starch processes consists of five (5) places P_{23}, P_{24}, P_{25}, P_{26}, P_{27}, and P_{28} in addition to the P_1, P_2 and P_3. It consists of six (6) transitions which model the various processes. This includes, cutting, soaking, draining, decanting, drying and packaging for distribution or storing as illustrated in Table 8.

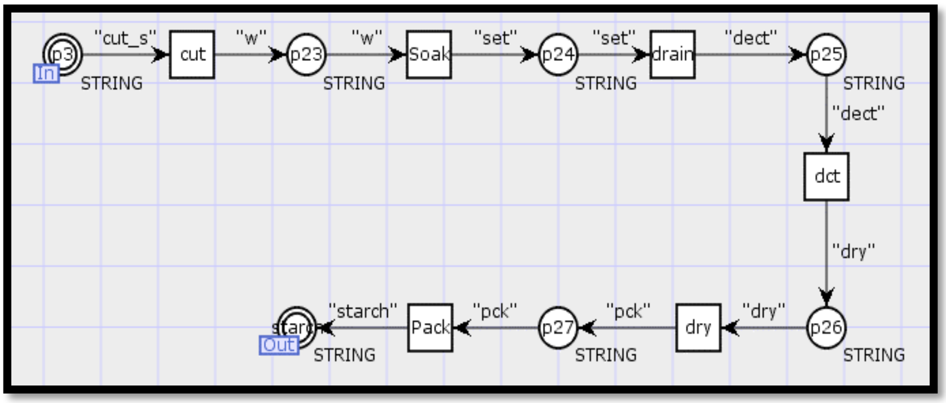

Fig.6. CPN Model for Starch Processing.

The Petri net (PN) model for the Starch processing is:

$P = \{P_1, P_2, P_3, P_{23}, P_{24}, P_{25}, P_{26}, P_{27})$
$R = \{r_1, r_2, r_3, r_{23}, r_{24}, r_{25}, r_{26}, r_{27}\}$
$V = \{0,1\}$
$F \subseteq (P \times R) \cup (R \times P)$
$f = P * R \rightarrow V$
$f(P_1, r_1) = 1; f(P_2, r_2) = 1; f(P_3, r_3) = 1; f(P_{23}, r_{23}) = 1; f(P_{24}, r_{24}) = 1$
$f(P_{25}, r_{25}) = 1; f(P_{26}, r_{26}) = 1; f(P_{27}, r_{27}) = 1; g(P_1, r_1) = 0; g(P_2, r_2) = 0$
$g(P_3, r_3) = 0; g(P_{23}, r_{23}) = 0; g(P_{24}, r_{24}) = 0; g(P_{25}, r_{25}) = 0; g(P_{26}, r_{26}) = 0$
$g(P_{27}, r_{27}) = 0;$

$N= (1,0,0,0,0,0,0,0)$

$M_0= m(P_1), m(P_2), m(P_3), m(P_{23}), m(P_{24}), m(P_{25}), m(P_{26}), m(P_{27})$

Table 8. Places (states) and Transitions for Starch Processing.

Places	Transitions
P_1=Raw Cassava	r_1=
P_2=Peeled Cassava	r_2=Peeling
P_4=Washed Cassava	r_3=Washing
P_{23}=Cut	r_{16}=Cutting
P_{24}=Soaked	r_{17}=Soaking
P_{25}=Sift mash	r_{18}=Sifting
P_{26}=Drained	r_{19}=Drain
P_{27}=Dried	r_{20}=Drying

4. State Space Analysis Result

This segment of the paper reveals the simulation report, which evaluates the behavioural properties of the cassava process model using a state space tool otherwise called occurrence graph. The occurrence graph determines and establishes the outcomes of the cassava CPN model. It determines the nodes' reachable states and state changes (arcs). In addition, it includes a list of standard behavioural properties including the state space's size, home marking, dead marking, instances of live and dead transitions, etc.

4.1. Model Evaluation

After modeling and analysis of the cassava production process operations, the simulation model and behavioural characteristics are assessed to confirm the accuracy of the cassava CPN modelled system. The dynamic state-space analysis, which is a one-time execution technique, is used to access the behavioural characteristics of the system, including boundedness, home qualities, liveness to confirm dead transitions and live transitions, and fairness. The CPN model's behavioural properties to be assessed are briefly discussed.

A. Home Marking

This is a property of CPN model that occurs when the marking ($M_0 = M_{home}$) which can be reached from any reachable marking. The state space report's home properties show no home marking, which suggests that the CPN model finishes someplace and does not go into an infinite loop. Fig.2 displays the markings that can be reached.

B. Dead Marking

This is a behavioural property that occurs when it has no enabled transition in the cassava food model. Hence, a marking (M_{dead}) of such no transition is considered to be dead.

C. Dead Transition Instance

According to the report produced by the state-space analysis and displayed in Table 9, this is a property which determines that the transition is not enabled.

D. Fairness

The fairness property of the cassava CPN model is determined by the presence of impartial transitions, which also implies the existence of infinite firing sequences (IFS), in which the transitions (peeling, washing, and other events) occur endlessly frequently.

4.2. Result of Analysis of Cassava Process Model

The state-space analysis report for the cassava main process model is shown in Table 9 (i.e., Fig.2). Using the State-space and Strongly Connected Components (SCC), the reachable states and loops included in the cassava process model can be identified as illustrated in Table 10, 11 and 12 respectively. The state-space report only generates/produces a partial/ an incomplete status for the cassava process model design/ configuration since state space calculations may be unduly complicated or take longer than usual for that configuration. It also takes into account that the nodes and arcs of the state-space and SCC graphs are similar, proving that the model is loop-free and that every node in the system can be reached from at least one other place. This is because, there is no home marking, keep in mind that the model finishes somewhere and does not go into an unending cycle.

Table 9. State-space Simulation Report for Cassava CPN Models.

1 0 peel @(1: Main Process)
2 0 wash @(1: Main Process)
3 0 cut @(1: STARCH)
4 0 Soak @(1: STARCH)
5 0 grate @(1: GARRI)
6 0 soak @(1: FUFU)
7 0 dw @(1: GARRI)
8 0 Soak @(1: LAFUN)
9 0 drain @(1: STARCH)
10 0 Sieve @(1: GARRI)
11 0 dct @(1: STARCH)
12 0 roast @(1: GARRI)
13 0 dry @(1: STARCH)
14 0 drain @(1: LAFUN)
15 0 dw @(1: LAFUN)
16 0 Pack @(1: STARCH)
17 0 sieve @(1: GARRI)
18 0 mash @(1: FUFU)
19 0 sieve @(1: FUFU)
20 0 drain @(1: FUFU)
21 0 dw @(1: FUFU)
22 0 pack @(1: GARRI)
23 0 dry @(1: FUFU)
24 0 pack @(1: FUFU)

Table 10. State Space Statistics for Cassava Process Model.

State Space Statistics

State Space	**SCC Graph**
Nodes: 1570	Nodes: 1570
Arcs: 5238	Arcs: 5238
Secs: 1	Secs: 0

Status: Full

Table 11. Table showing Home Properties.

Home Properties

Home Marking**s:** [1570]

Table 12. Table Showing Liveness Properties of the Cassava Process Model.

Liveness Properties

Dead Markings: [1570]
Dead Transition Instances: None
Live Transition Instances: None
Fairness Properties
No infinite occurrence sequences.

5. Results and Discussion

Coloured Petri net models for cassava processes are investigated using the state space tools. A fully automatic simulation of the model was executed. The simulation state space report produces a text file which gives a comprehensive information on all the occurred binding elements about the experiment. A report of the 24 transitions is listed in Table 9. The state space size determined for the cassava process model is shown in the state-space report or occurrence graph report. The state-space report obtained from the simulation experiment states explicitly the names of the state change-over that occur during the construction of a model to reproduce the characteristics of the exact system, or process as well as the module instances where the processes and events that happened are located. Likewise, the state space report of the model as depicted in Table 9 shows that the peel transition in the first instance of the Main Process module occurred in step 1 while the wash transition occurred in step 2. Other transitions in the first instance of each of the process modules as they occurred subsequently from step 3 to step 24 (see Table 9).

Similarly, the reachability graph was summed automatically by the CPN state space tools and the report which took 1seconds contains all the occurrences and the reachable markings was automatically generated. The state-space report for the cassava process model displays exactly the same nodes and arcs in their cassava process model graphs for the state space and strongly connected components as shown in Fig. 10. In addition, the reachability graph was automatically added by the CPN state space tools, and a report containing all occurrences and reachable markers was generated automatically. Both the state space statistics and the strongly connected components (SCC) graph, as shown in Table 11 have 1570 nodes and 5238 arcs, respectively, which correspond to the precise numbers of the nodes and arcs in the cassava model. This implies that the SCC covers all the state space nodes and as such, it is concluded that there was no infinite occurrence and the model terminates. The cassava CPN model has a single home marking (M_{home}) node represented by 1570, which can be reached from any reachable marking. Hence, all the occurrence sequences reach M_{home}, that is, the marking where the processes have been successfully completed.

In the same context, it is seen that the marking M_{1570} represented the state corresponding to successful completion of the transmission. Again, M_{1570} is the home marking which indicates that it is always possible to reach the desired final state. Moreover, the liveness properties such as the Dead Marking (M_{dead}) as depicted in Table 12 contains 1570 nodes representing the state corresponding to successful completion of the process. The live and dead transition instance t, produce no marking respectively as it is enabled from any reachable and disabled in all reachable marking. Similarly, the integer bound for the place in the cassava product process model contains a minimum number of tokens on the place sent in a reachable marking, However, the present study contradicts the claims of [37] who reported that the CPN model has no home marking (i.e., M_{home}= none) but holds a dead marking (M_{dead}) being M_{9331} and with deadlock situation having M_{7839}. Moreover, the Dead transition is single, indicating that it has no live transition instance despite the fact formal method: CPN tool is used. In addition, findings from the work of [34] revealed that the simulation runtime used for some quantities of garri to be processed was estimated to be in several minutes.

Nevertheless, the result presented by the present study is in consonance with the findings of [34, 37, 38,39, 40, 44], who in separate studies reported that petri net tool can be used in representing and simulation of discrete event and dynamic system, particularly complex systems which helps in the understanding, verification of the behavioural properties and correctness of the system being studied. Moreover, these features of ease of use (user-friendliness), reusability and its ability to be evaluated precisely highlights the gains of using the model approach in this present work.

6. Conclusion

With the development of a formal method of automation and verification of the behavioural properties of systems, there are more and more applications of petri net tool. This present work modelled and simulated cassava food production process using coloured petri net tool to understand and verify the behavioural characteristics of the complex production system. This work considers the modelling and simulation of four cassava products: Garri, lafun, fufu and Starch. The structural UML and CPN models for the cassava process is designed, examined, analyzed and evaluated using the state-space component tool incorporated in CPN tool to analyze its behavioural properties (liveness, dead and home markings, reachability and fairness) as wells as the accuracy of the modelled system. This indeed gives better understanding of estimating its liveness and dead state of interaction. The cassava process model is proposed to demonstrate the process of modeling and the benefits of this modelling approach are highlighted. These model approach display that this model approach is achievable, and the major objective of this paper is realized. This present work has represented the system design, modelling and simulation of a complex (cassava production process) system. It has also introduced to us the parallel production design process of food, which is essential to improve the processing efficiency of the products where there is sufficient raw material to meet such needs. Our future works focuses on verifying the correctness of biological and chemical systems.

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