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Modeling of Sokoto Cement Production Process Using A Finite Automata Scheme: An Analysis Of The Detailed Model

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ABSTRACT
This researchintends to establish the detailed model and study the models as established in the compact scheme earlier on presented. In this case, the research focuses on the study of the algebraic theoretic properties and relationship between the processes of production viewed as sub-states of a designed automata scheme. The transitionswere then linked up in an algorithm that also specifies the movement from one state to another.A transition matrix was then generated from the resulting transition tableleading up to a construction of an optimal production model for the Sokoto Cement production system.

KEY WORDS: *Limestone, Cement, States, Finite Automata Scheme andTransitions matrix*

I. INTRODUCTION

Cement is a fine powder which sets after a few hours when mixed with water, and then hardens in a few days into a solid strong material, therefore, Cement is a hydraulic binder, which hardens when water is added to it [5].There are 27 types of common cement which can be grouped into 5 general categories and 3 strength classes: ordinary, high and very high. In addition, some special cements exist like sulphate resisting cement, low heat cement and calcium aluminate cement.Cement plants are usually located closely either to hot spots in the market or to areas with sufficient quantities of raw materials. The aim is to keep transportation costs low in taking thebasic constituents for cement (limestone and clay) from quarries to these areas.Basically, cement is produced in two steps: first, clinker is produced from raw materials and in the second step cement is produced from cement clinker. The first step can be a dry, wet, semi-dry or semi-wet process according to the state of the raw material.According to [2], the raw materials are delivered in bulk, crushed and homogenised into a mixture, which is fed into a rotary kiln, which is an enormous rotating pipe of 60 to 90 m long and up to 6 m in diameter. The kiln is heated by a 2000°C flame inside of it and is slightly inclined to allow for the materials to slowly reach the other end, where it is quickly cooled to 100-200°C for clinker formation. There are four basic oxides in the correct proportions that make cement clinker: calcium oxide (65%), silicon oxide (20%), alumina oxide (10%) and iron oxide (5%).

These elements mixed homogeneously (called “raw meal” or slurry) when heated by the flame at a temperature of approximately 1450°C to form thenew compounds: silicates, aluminates and ferrites of calcium responsible for the hydraulic hardening of cement through hydration of these compounds. These solid grains obtained as the final product of this phase is called “clinker” and are stored in huge silos for the next process. The second phase is handled in a cement grinding mill, which may be located in a different place to the clinker plant. Gypsum (calcium sulphates) and possibly additional cementitious (such as blastfurnace slag, coal fly ash, natural pozzolanas, etc.) or inert materials (limestone) are added to the clinker and grounded to produce a fine and homogenous powder called cement. The cement is then stored in silos before being dispatched either in bulk or bagged.

Portland cement

The American Society for Testing and Materials (ASTM) in [7], defines Portland cement as "hydraulic cement which not only hardens by reacting with water but also forms a water-resistant product, produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an inter-ground addition." The low cost and widespread availability of the limestone, shale, and other naturally occurring materials make Portland cement one of the lowest-cost materials widely used over the last century throughout the world.

Description of the Study Area

According to [1], the Iullemmeden Basin of West Africa covering anestimated area of 700,000km^{2}extends intonorthwestern Nigeria where it is referred to as the "SokotoBasin".The Sokoto Basin lies in the sub-Saharan Sudan belt ofWest Africa in zone of Savanna-type vegetation generallyclassified as semi-arid. It lies between latitudes 10° and14° N and longitudes 3° and 7°E and covering an area ofabout 65,000 square kilometres. The area isbounded on the north and west by Niger Republic and onthe southwest by Benin Republic. Although the SokotoBasin of Nigeria appears extensive in area extent, it onlyrepresents about one-tenth of the entire IullemmedenBasin of West Africa [1]. The basin broadlycovers an area underlain predominantly by crystalline rocksto the east and sedimentary terrain to the northwesternhalf. The cement plant (the Cement Company of Northern Nigeria) is located in Kalambaina,which is about 6 km from the capital – Sokoto and is (13^o 21' 16" N and 5^o 5' 37" E) in Wamakko local government area ofSokoto State,oneof the notable areas of the Sokoto Basin with the large deposits of limestone and otherminerals. The sedimentary rock in this study area is classified as Sokoto group, which included the Kalambaina formation made upof limestone (Adelana, Olasehinde and Vrbka, 2003).

1.3 Sokoto Cement

The Sokoto cement, produced by the Cement Company of Northern Nigeria, is a Portland cement and its production started from 1966. The Company is situated in Kalambaina area of Wamakko Local Government Area of Sokoto State where there is abundance of Limestone which constitutes the major raw materials. The first phase of its production is: Quarrying, Raw material preparation and Clinkering while the second phase which is the Cement milling consists of: Grinding and packaging.

II. APPLICATION OF FINITE AUTOMATA SCHEMES IN CEMENT PRODUCTION PROCESS

According to [4], the use of the word 'automata' harks back to the early days of the subject in the 1950's when they were viewed as abstract models of real circuits. The term 'finite automata' describes a class of models of computation that are characterized by having finite states. A Finite State Machine (FSM) or Finite-State Automaton (plural: automata), or simply a State Machine, is a mathematical model computation used to design both computer programs and sequential logic circuits. It is conceived as an abstract machine that can be in one of a finite number of states,the machine is in only one state at a time; the state it is in at any given time is called the current state. An automaton can change from one state to another when initiated by a triggering event or condition, this is called a transition. A particular finite state machine is defined by a list of its states, and the triggering condition for each transition.The fact that, automata models are abstract models of real circuits motivates me to use the model in design and analysis of the production system of Sokotocement on the ground that the system has finite states of production process with a finite link from one state to the other expressed in terms of machine sequence. A detailed approach to modeling a cement production process should include all stages of production and transitions from the raw material to the finished cement. In particular, finite automata models have been used to model and develop a control for manufacturing systems [8]. In cement production process, the state of machine changes after each instruction is executed, and each state is completely determined by the prior state and the input. The machine simply starts at an initial state, changes from state to state until it reaches the final state [6].

A typical production system is composed of multiple machines and workstations that perform various operations on a part of production, and a material handling system that interconnect these machines and workstations. Parts are processed to completion by transiting them through various machines and workstations according to their individual process plan. After processing is complete these parts leave the system and proceed to the next state until the final state of production is reached [9].For most manufacturing systems however, operation runs sequentially reaching desirable or pre-specified states. Each product goes through its own part of states until it reaches completion, i.e., the final state [3].

2.1 Notations

According to [4], a deterministic finite automaton (DFA) consists of;

[1] a finite set of states (often denoted Q)
[2] a finite set $\sum$ of symbols (alphabet)
[3] a transition function that takes as argument a state and asymbol and returns a state (often denoted δ)
[4] a start state often denoted q_0
[5] a set of final or accepting states (often denoted F)

[6] We have $q_0 \in Q$ and $F \subseteq Q$

So a DFA is mathematically represented as a 5-tuple $(Q, \sum, \delta, q_0, F)$
The transition function δ is a function in
$Q \times \sum \rightarrow Q$
$Q \times \sum$ is the set of 2-tuples (q, a) with $q \in Q$ and $a \in \sum$

Without loss of generality, we shall represent the detailed model of the cement production process using a finite automata scheme. This is to provide for an algebraic theoretic treatment and analysis of the model with a view to developing functional and ordered relations among the different components and subcomponents of the production systems as well as to undertake an optimization of the process. The model will therefore, be based on pre-defined assumptions of the deterministic automata having the following notational symbols:

qo_1 = at the quarry level
qo_2 = crushing of the lime stone
qo_3 = stock piling
qo_4 = raw mill
qo_5 = silo
$q1_1$ = preheating
$q1_2$ = rotary kiln
$q1_3$ = cooler
$q2_1$ = mixing with gypsum
$q2_2$ = grinding the mixture
$q2_3$ = the cement
$q3_1$ = packaging
$q3_2$ = store

$t1_1$ = Process to second state of production from quarry to crushing

$t1_2$ = Process to second state of production from crushing to stockpile

$t1_3$ = Process to second state of production from stockpile to raw mill

$t1_4$ = Process to second state of production from raw mill to the silo

$t1_5$ = Completely processing to second state of production

$t2_1$ = Process to third state of production from preheating to the rotary kiln

$t2_2$ = Process to third state of production from rotary kiln to cooler

$t2_3$ = Completely processing to the third state of production

$t3_1$ = Process to the final state of production from mixing with gypsum to grinding

$t3_2$ = Process to the final state of production from grinding to having the finished cement

$t3_3$ = Completely processing to the final state of production; cement being stored

$t3_4$ = Cement packaging

t_* = Impossible process

So that, $Q = (qo_1, qo_2, qo_3, qo_4, qo_5, q1_1, q1_2, q1_3, q2_1, q2_2, q2_3, q3_1, q3_2)$

$$\sum = (t1_1, t1_2, t1_3, t1_4, t1_5, t2_1, t2_2, t2_3, t3_1, t3_2, t3_3, t3_4)$$

The transition function of this scheme is denoted as:

$\delta : Q \ X \ \Sigma \rightarrow Q$, where δ, Q, Σ are as defined above.

It therefore, follows that the underlined model has the state parameters thus:

$\delta(qo_1, t1_1) = qo_2$
$\delta(qo_2, t1_2) = qo_3$
$\delta(qo_3, t1_3) = qo_4$
$\delta(qo_4, t1_3) = qo_5$
$\delta(q1_1, t2_1) = q1_2$
$\delta(q1_2, t2_2) = q1_3$
$\delta(q1_3, t2_3) = q2_1$
$\delta(q2_1, t3_1) = q2_2$
$\delta(q2_2, t3_2) = q2_3$
$\delta(q2_3, t3_3) = q3_1$
$\delta(q3_1, t3_4) = q3_2$

Construction of the Detailed Model of the Finite Automata for the Cement Production Process

The detailed model of the cement production process is obtained from compact model of the production system by taking into consideration additional processes and activities in line with the different components and subcomponents of the production system. As mentioned earlier, a state in the compact model has several sub statesin the production system. Therefore, the detailed model identifies these sub-states and incorporates them in the production complex.

The detailed model of the complete cement production process has thirteen (13) sub-states made up of the following:

[1] the raw material state
[2] clinker process state
[3] cement milling state
[4] finished cement state

The raw material state which is the initial stage of production has 5 sub-states comprising of quarry, crushing, stockpiling, raw milling and silo. The clinker state is the second stage and it has 3 sub-states of preheating, rotary kiln and cooling leading up to the third stage of production which is called the cement milling state.The milling state has 3 sub-states: mixing with additives, grinding and powdering. The finished cement state which is the final stage alsohas 2 sub-states that is packaging and storing.

Based on these defined parameters the detailed model of the Sokoto Cement production process can be designed using a finite automata scheme as in the fig. 1.

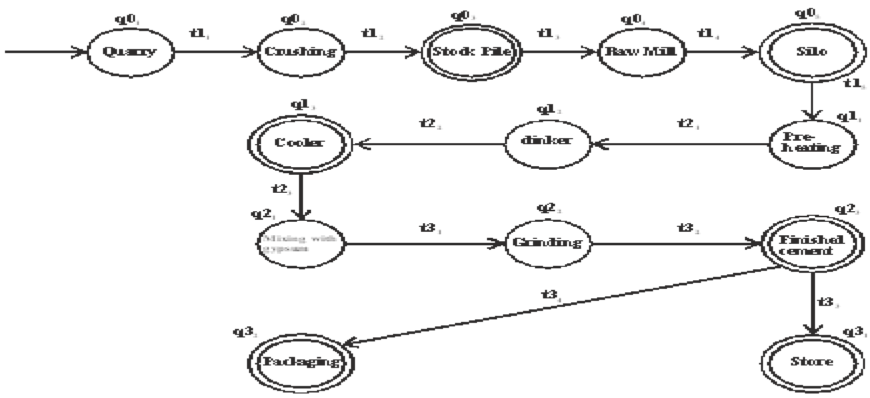

Fig 1. Detailed model of the SokotoCement production as a finite automata scheme

Figure 1, depicts the deterministic finite automata (DFA)modelwitha fixed number of states and wecan only be in one state at a timeand the transition table of the model is constructed using adjacency scheme as shown in table 1.

Table 1: the Transition Table of the detailed model of the SokotoCement production process

	$q0_1$	$q0_2$	$q0_3$	$q0_4$	$q0_5$	$q1_1$	$q1_2$	$q1_3$	$q2_1$	$q2_2$	$q2_3$	$q3_1$	$q3_2$
$q0_1$	1	$t1_1$	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*
$q0_2$	0	1	$t1_2$	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*
$q0_3$	0	0	1	$t1_3$	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*
$q0_4$	0	0	0	1	$t1_4$	t_*	t_*	t_*	t_*	t_*	t_*	t_*	t_*
$q0_5$	0	0	0	0	1	$t1_5$	t_*	t_*	t_*	t_*	t_*	t_*	t_*
$q1_1$	0	0	0	0	0	1	$t2_1$	t_*	t_*	t_*	t_*	t_*	t_*
$q1_2$	0	0	0	0	0	0	1	$t2_2$	t_*	t_*	t_*	t_*	t_*
$q1_3$	0	0	0	0	0	0	0	1	$t2_3$	t_*	t_*	t_*	t_*
$q2_1$	0	0	0	0	0	0	0	0	1	$t3_1$	t_*	t_*	t_*
$q2_2$	0	0	0	0	0	0	0	0	0	1	$t3_2$	t_*	t_*
$q2_3$	0	0	0	0	0	0	0	0	0	0	1	$t3_3$	t_*
$q3_1$	0	0	0	0	0	0	0	0	0	0	0	1	$t3_4$
$q3_2$	0	0	0	0	0	0	0	0	0	0	0	0	1

From the automata model of fig. 1one can observe in the adjacency matrix of table 1, as follows:

[1] That the upper diagonal elements are non-zero, indicating aone way directional connectivity of the respective process in the different stages of production.
[2] That the diagonal elements are 1s indicating there is a delay (time lag) in between processes.
[3] The lower diagonal elements are 0s indicating the non-reversibility of processes at this level of production.

2.3 The Transition Matrix of the Finite Automata Scheme of Sokoto Cement Production Process

Among the targets of this research work is to develop an optimal production model for Sokoto Cement. In view of this, a transition matrix is hereby generated from the transition table as in Table 1.This is done, first by developing an algorithm to generate elements of the transition matrix using the parameters of the automata model of fig. 1 and denoting all backward (reversed) operations act as ($t0_0$). The non-zero elements are those computed using the algorithm 2.4 which is used to construct the transition matrix in Table 2:

2.4 Algorithm

Assign: ti_j a transition from major production state to a sub-state, where $i =$ major state of production and $j =$ sub state of production.

Assign: $t_{rc}$is an element of the matrix where $r =$ row number and $c =$ column number

Then $t_{rc} = (i + j)r$ (1)

At $i = 1, compute\ t_{rc} = (i + j)r\ for\ j \leq 5$

At $i = 2, compute\ t_{rc} = (i + j)r\ for\ j \leq 3$

At $i = 3, compute\ t_{rc} = (i + j)r\ for\ j \leq 4$

end if i > 3
end.

Accordingly the following matrix is obtained.

Table 2: Transition Matrix of the Sokoto Cement Production Process

$$\begin{bmatrix} 1 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 20 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 30 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 18 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 28 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 40 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 36 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 50 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 66 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 84 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

III. DISCUSSION OF RESULT

From Table 2, taking the difference of the t_{rc} (ie, $t_{rn} - t_{rn-1}$)and summing up these differences we have.

$$\left.\begin{aligned} \sum_{r=1}^{5}(t_{rn}-t_{rn-1}) &= 30, \quad i=1 \\ \sum_{r=6}^{8}(t_{rn}-t_{rn-1}) &= 22, \quad i=2 \\ \sum_{r=9}^{12}(t_{rn}-t_{rn-1}) &= 48, \quad i=3 \end{aligned}\right\} \tag{2}$$

The summation of the three processes of production is 100 which indicate the attainment of complete production process.

$$\text{ie} \sum_{r=1}^{12}(t_{rn}-t_{rn-1}) = 100 \tag{3}$$

Now using equation (2), at i=1 yields 30% of production while putting i=2,3 yields 22% and 48% of production respectively. This signifies that any problem that causes a break in the chain of production will be measured with respect to the total production process. According to[9],in manufacturing process break in production process cannot be ruled out. In most cases the effect of this abnormality cannot be immediately ascertained by the manufacturers. This research will immediately show the extent of the break on the production process which analytically shows the manufacturer areas of concentration to optimize the process. The larger the percentage summation of a level of major state of production, the critical that level of production is. From this, the manufacturer knows exactly what is at stake at every level of production.

IV. CONCLUSION

The transition matrix generated from the resulting transition table lead to the construction of an optimal production model for the Sokoto Cement Production Process. However, for both the diagnosis and remedies to be more effective and timely, there is the need to consider further the detailed analysis of the sub-stages of the major sub-states of the cement production process or even look more critically into the languages of the individual state's automaton in future research.

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