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THE DYNAMICS OF ROAD MAINTENANCE IN OSUN STATE (FEDERAL ROADS IN FOCUS)

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A B S T R A C T

This research developed a road maintenance decision making system using System Dynamics (SD) Model. The SD model use the pavement deterioration, maintenance and optimization module to design road maintenance policies that would yield optimum cost-quality result. To calibrate this model, quality, cost and maintenance-measures related data were collected for twenty-four (24) road sections in Osun State from 2012 to 2018, and inputted into the SD System. The pattern observed from the data inputted, coupled with the optimum optimization parameters, were then used to simulate its own five (5) years maintenance structure ranging from 2019 to 2023, which was then compared with the structure administered on the study roads to ascertain its level of performance. The result showed the best-case optimization parameters of load related distress (LDR) threshold of 75 and highest prioritized maintenance measures as preventive maintenance (PM). The SD simulated maintenance structure outperformed that of the agency maintained with massive savings in cost. The health/usability of the SD simulated road sections at 2023 were also better than that obtained as a result of the maintenance management agency in seventeen (17) of the twenty-four (24) road sections used in this study. The two results were similar at three study road sections, while that maintained using the agencies system were better at four (4) road sections only. Also, using the trend from the data available, the budgeted, approved and SD generated maintenance cost were forecasted for 2024-2028. From the result, both budgeted and approved running maintenance cost were in billions while that of the SD generated running cost were in millions. This shows that application of the System Dynamics road maintenance system would lead to massive savings in cost at appreciable quality.

Keywords: System Dynamics, Road Maintenace, Federal Roads, Optimization, Cost, Maintenance Structure

1.0 INTRODUCTION

The annual amount of money spent on maintenance has increased, lives have been lost, and regular daily activities have been disrupted due to pavement breakdown [1]. One of the most popular forms of transportation is the road, which allows for the quick access to a vast array of social and economic services as well as the mobility of people, products, and services. Since paved roads give businesses a competitive advantage in the cost-effective transportation of goods, they offer an exceptional return on investment [2]. According to a number of studies, the transportation industry accounts for between 6% and 12% of the national gross domestic product in wealthier nations.

Nevertheless, despite the advantages of improvements in road infrastructure, a number of difficulties arise from the lack of comprehensive planning for both building and maintaining roads. Due to these difficulties, operations are often conducted inefficiently and in fragments, utilizing incompatible components. This results in waste and the inability to create appropriate plans, which eventually impedes development. Public policies have typically been implemented in response to symptoms rather than causes. When dealing with complex problems involving multiple actors, limited rationality, unpredictable behavior, and differing interpretations, such as those pertaining to transportation infrastructure and maintenance, traditional tools with limited capabilities to address causes and ignore the dynamic nature of the issues are doomed to failure [3]. A typical example is the budg*et al*located for road maintenance in Nigeria, which is an important aspect, limiting the progress of road maintenance in Nigeria. [4].

A method called System Dynamics (SD) helps improve learning in complicated systems. Jay Forrester of the Massachusetts Institute of Technology first presented it in the 1950s. This approach has been widely utilized to analyze operations system behavior. Understanding an operations system's dynamics and other complications is made easier with the aid of system dynamics. The technique, commonly referred to as SD, was created to investigate the connection between industrial activity policies and organizational structure. Owing to the method's success, housing, population growth, and commercial activity in an urban city were all studied using it. Currently, SD is applied to any research that examines how components of a system interact, from waste management [5], to industrial, transportation, logistics applications [6], and even urban planning [7].

This research believes that if a system dynamics approach were applied to inform the paved-road network construction and maintenance authorities, it could lead to improved sustainable paved road-network infrastructure construction and maintenance management, hence, the necessity to look into the dynamics of road maintenance, with emphasis on Osun state.

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2.0 METHODS

Study Areas and Roads

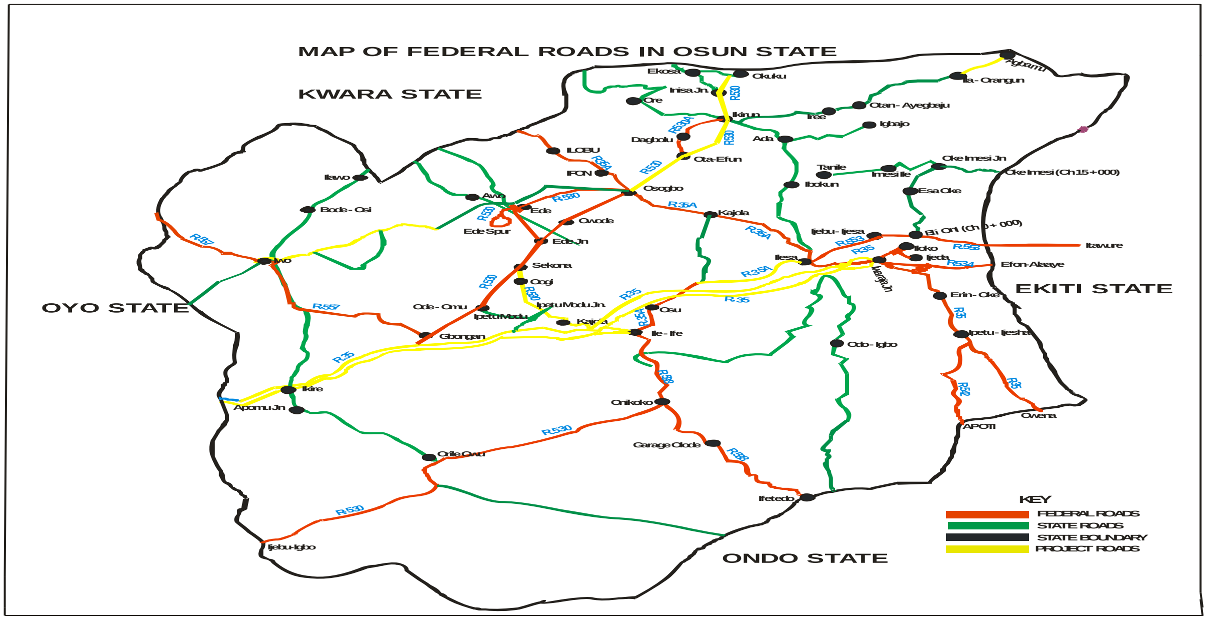

Figure 1: Map of the Study Area (Source: FERMA, Osogbo Field Office)

Osun state is a state in southwestern Nigeria; bounded to the east by Ekiti and Ondo states, to the north by Kwara State, to the south by Ogun State, and to the west by Oyo State. Osun State was named for the River Osun—a vital river that flows through the state—The state was formed from the southeast of Oyo State on 27 August 1991 and has its capital as the city of Osogbo. Based on the 2006 census (provisional result) the population of Osun State is about 3,416,959 people. Osun State has been a major centre Other important cities and towns include the ancient kingdom-capitals of Ila Orangun, Iragbiji, Ada, Ikirun, Oke-Ila Orangun, Ipetu-Ijesha, Ijebu-Jesa, Erin-Oke, Ipetumodu, Ede, Iwo, Ejigbo, Ibokun, Ode-Omu, Otan Ayegbaju, Ifetedo, Esa-Oke, Ilesa, Okuku, Otan-Ile and Igbajo. The state is located at 70 33′ 46″ N and 40 31′ 11″ E of Nigeria with 744 Km lengths of Federal roads, also the state has 30 Local Government Areas (LGAs). The agency responsible for road maintenance in Osun State is FERMA (Federal Road Maintenance Agency)

Twenty-four (24) federal road *sections* in Osun State was used in this study to investigate the effect of System Dynamics on its maintenance in terms of cost and quality. Data related to maintenance quality and cost on each of the twenty-four road sections were collected as follows:

a) Density of fatigue crack in meter square

b) Road pavement health evaluation agency report

c) The maintenance type conducted on each road section

d) The budgeted and approved maintenance cost of each road network

Road Maintenance System Dynamics Development Flow Chart

Figure 2 showed the SD simulated model designed for the road maintenance policies and analysis of the highways in Osun State. From figure 2, the simulated model consisted of two loops, the reinforcing loop (R1) which consist of the pavement distress deterioration rate and the balancing loop which is the required maintenance fix.

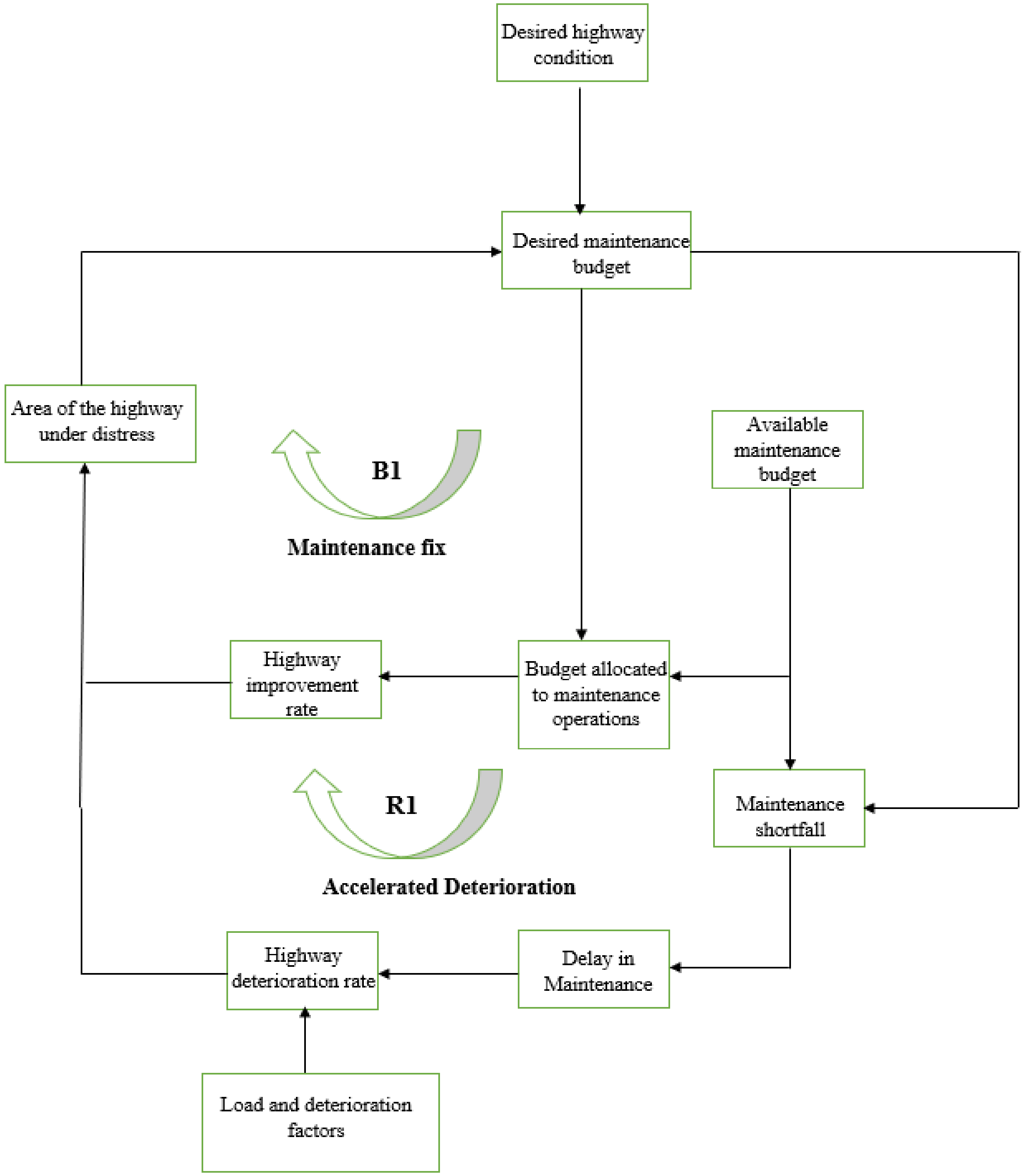

Figure 2: System Dynamics Road Maintenace Model Design Flow chart

SD Simulation Processes

The SD simulation was conducted using a simulation software, VENSIM v.9.0. This software makes use of three modules in determining the optimal road maintenance strategies in terms of cost and quality. These modules are the highway pavement deterioration module, maintenance module and the optimization module.

SD Simulation Pavement Deterioration Module

There are many types of pavement deterioration/distress, however this study focuses on the fatigue cracking pavement deterioration type. The two major computation in this module is the road pavement health/usability evaluation and the computation of the load related distress (LDR) of each road section

Road Pavement Usability Evaluation

The SD module uses the mechanistic–empirical (ME) models to capture the road deterioration process, which in turn lead to the road pavement health/usability evaluation. However, due to the limited data available to properly applied the mechanistic–empirical (ME) models, the square area (d) of the fatigue cracks on each road section was used to capture the state of the road.

$$Crack\ density\ (d) = crack\ length\ (l) \times crack\ width\ (w) \quad (1)$$

Table 1 showed the road pavement evaluation system used in this study, which was adapted from Fallah-Fini et al. (2020), and is applicable to the SD model. It evaluates each road sections in terms of severity(danger) and density (quantity). In order to capture the state of each road section in the evaluation system in table 1, expert judgement through the use of questionnaires and interviews were conducted to determine the range of crack density that would fit into each evaluation class in table 1. Table 2 showed the fatigue crack density thresholds and the road evaluation class each belongs to.

Table 1: Road Pavement Health/Usability Evaluation (Fallah-Fini *et al.,* 2020)

	Density Level		
Severity Level	Rare (R)	Occasional (O)	Frequent(F)
Not-Severe (NS)	NS-R	NS-O	NS-F
Severe (S)	S-R	S-O	S-F
Very-Severe (VS)	VS-R	VS-O	VS-F

Table 2: Density Threshold for the study road section pavement evaluation

Density Threshold(m^2)	Pavement Evaluation Category
1-10	NS-R(Not-Severe-Rare)
11-50	NS-O(Not-Severe-Occasional)
51-100	NS-F(Not-Severe-Frequent)
101-200	S-R(Severe-Rare)
201-400	S-O(Severe-Occasional)
401-600	S-F(Severe-Frequent)
601-900	VS-R(Very-Severe-Rare
901-1100	VS-O(Very-Severe-Occasional)
Above 1200	VS-F(Very-Severe-Frequent)

Load Related Distress (LDR) Index Computation

The load related distress (LDR) is an important parameter used by the SD Systems in selecting sections of the road to be maintained and is calculated as follows:

$$LDR = 100 - road\ pavement\ evaluation\ scorecard \quad (2)$$

The road pavement evaluation scorecard is a score in numbers assigned to the road evaluation performed on each road section. These scores were assigned using the Virgina Department of Transport Management (VDOT)'s Asset Management Division standard score for fatigue cracking, as it's what is available in the SD Systems, and also due to the absence of any developed Nigeria standard score card for the severity levels of the road sections. SD uses the load-related distress (LDR) index to reflect the condition of the road with respect to distresses.

LDR values range between 0 and 100, where an LDR of 100 represents a road section in perfect condition. To obtain the LDR for each road section, one subtracts from 100 the deduct value corresponding to each one of the nine possible road conditions presented in Table 1. Table 3 shows the standard values for fatigue cracking developed by VDOT's Asset Management Division (Fallah-Fini *et al.,* 2020).

Table 3: Fatigue Cracking Evaluation Scorecard

	Density Level		
Severity Level	Rare (R)	Occasional (O)	Frequent(F)
Not-Severe (NS)	10	20	30
Severe (S)	13	30	40
Very-Severe (VS)	16	38	52

SD Simulation Pavement Maintenance Module

The major computations in this SD module is the assignment of the pavement management measures to each road section evaluation and the average maintenance cost per square km of the road section. Also, pasts data on the budgeted and approved maintenance cost of the study road sections was also inputted into this module.

Road Pavement Management Measures

There are three major types of maintenance measures conducted on roads. These are Preventive Maintenance (PM), Corrective Maintenance (CM) and Restorative Maintenance (RM). Preventive maintenance (PM) refers to the treatments that are performed to reduce the rate of deterioration and preserve the existing pavement integrity. Corrective maintenance (CM) refers to the treatments that maintain the characteristics and structural integrity of an existing pavement for continued serviceability. Restorative maintenance (RM) refers to new surface layers that restore the pavement structure to a level similar to its original condition.

Table 4 showed the maintenance measures for each road evaluation metrics used for the study. Once the maintenance measures are applied, the next stage was to determine the cost of each management measures. NN means not needed

Table 4: Pavement Management Measures

	Density Level		
Severity Level	Rare (R)	Occasional (O)	Frequent(F)
Not-Severe (NS)	NN	NN	PM
Severe (S)	PM	PM	CM

Very-Severe (VS)	CM	CM	RM

Pavement Management Measures Cost

The cost of each pavement management measures (PM, CM and RM) were determined and inputted into the management module of the VENSIM software. It is difficult to peg a fixed price for each maintenance measures conducted as not all length of the study road sections would be filled with fatigue crack. Therefore, past data on the cost of each pavement management measures were used and the average cost per square km of the road for each pavement measures were determined and used as the cost of each management measures for the study. As a result, the maintenance measures cost was fixed as:

Preventive Maintenance - 1million per square km of road section

Corrective Maintenance - 3 million per square km of road section

Restorative Maintenance - 6 million per square km of road section

SD Simulation Optimization Module

The optimization module contains parameters which the SD system applies in assigning maintenance measures to the road section such that the optimal cost and quality fit (i.e. minimum cost at maximum quality) annually for the study road sections was achieved. These parameters include the LDR thresholds, pavement management measures profiling, crack density threshold and crack density values variations

SD System Calibration

Data were gotten for the twenty-four (24) road sections used in this study. The crack density and cost related data for the first seven (7) years ranging from 2012 to 2018 were inputted to calibrate and train the SD system. The function of the calibration is to detect patterns from the data inputted and then use this pattern, coupled with the optimization parameters to simulate its own five (5) years maintenance structure ranging from 2019 to 2023, which could then be compared with that of the data gotten from the various agencies to ascertain its level of performance. The patterns that were ascertained from the data used to train the system includes:

- Allowable number of load cycles
- Time btw transition from NS to S cracks
- Time btw transition from S to VS cracks
- Time delay btw maintenance and reappearance of cracks

SD System Validation

Performance related validation was used to ascertain the effectiveness level of the designed SD system in assigning maintenance measures and policies at low maintenance cost and good road quality. 2019-2023 maintenance structure was simulated from the SD, and its performance in terms of cost and road quality would be ascertained by comparison with the following:

- The 2019-2023 data of the study road sections from the maintenance policies of the Agency
- Other scenarios generated from using different optimization parameters
- Comparison of the 2023 state of health/usability of the study road sections for the simulated and that of the agency managed state of the road section
- Forecasted performance between SD, actual and budgeted for 2024 to 2028

3.0 Results and Discussion

Model Calibration Result

Table 5 showed the calibration result of the designed model as a result of five years (2012-2018) of road maintenance practices, cracks density, budgeted and approved maintenance cost of the four highways considered in this study.

From table 5, patterns were derived from the five-year data supplied to the SD model. The average time it takes for the study road pavement health to move from Not Severe (NS) to the Severe (S) stage measured from the density of cracks is approximately 34 months. However, that of the transition from Severe (S) to Very Severe (VS) stage took a shorter time of 22 months which is almost up to two years. Another pattern observed by the SD model is the time transition from the Not Severe and Rare (NS-R) pavement health stage from a recently conducted maintenance activities to the reappearance of cracks that transition to the next pavement health stage of Not Severe and Occasional (NS-O) as 11 months. Outliers are specific data points form a group of data with characteristics that are visibly not in sync with the general pattern observed from the group of data points. These are regular features of analysis involving data analysis. The SD model observed outliers from the data inputted as regards some particular road sections. These outliers were also shown in table 5

Table 5: The Developed SD Model Calibration Result

ROAD SECTION	PARAMETER	Estimated Value
	Allowable number of load cycles	100,000,000
	Time btw transition from NS to S cracks	34 months
	Time btw transition from S to VS cracks	22 month
	Time delay btw maintenance and reappearance of cracks	11 months
	OUTLIERS	
IFE-SEKONA ROAD, ROUTE 530	Time btw transition from NS to S cracks	12 months
IFE -ILESA DUAL CARRIAGEWAY (ILESA BOUND), ROUTE 35	Time btw transition from NS to S cracks	40 months
OSOGBO-ILESA ROAD, ROUTE 35A	Time btw transition from NS to S cracks	39 months
OSOGBO-ILOBU- OYSB ROAD, ROUTE 35A	Time btw transition from NS to S cracks	38 months

SD Model Optimization Result

Table 6 showed the designed SD optimization parameters that brought about the combinations that led to management choices that resulted in better maintenance quality at lower costs. From table 6, the load related distress (LDR) threshold chosen, which is an important parameter in selecting sections of the road to be maintained in a calendar year, based on the budget restrictions was pegged at 75. This meant that road sections with LDR value of 75 and below would be considered for maintenance activities while those above LDR values of 75 won't be considered for maintenance activities for the year in review. The LDR of 75 was considered as the best threshold to get maximum maintenance performance at the lowest cost for the study road sections in Osun State

After the road sections cracks to be corrected has been selected, the next stage is to prioritize the maintenance practices that would be applied to correct the selected cracks. From table 4.2, the highest priority was given to the preventive maintenance (PM), followed by corrective maintenance (CM) and lastly restorative maintenance (RM). This means from the approved maintenance amount, more funds would be allocated for preventive maintenance purpose, followed by corrective maintenance while the least funds would be for restorative maintenance.

Another optimization parameter from table 6 is the crack density threshold. Higher priority were given to threshold values higher than the median of the class of threshold to which they belonged to while lower priority were given to those lower than the median of their class of threshold. Lastly, the density values were left unchanged as its alteration might affect the quality of the output of the maintenance process.

Table 6: The Developed SD Model Best Case Optimization Parameters

Parameters considered in optimization	Values
LDR Threshold	75
PM, CM and RM Profiles	1st Priority: PM, 2nd Priority: CM, 3rd Priority: RM
Density Threshold (Higher Priority)	Values greater than the median for each threshold
Density Threshold (Lower Priority)	Values lower than the median for each threshold
Variations in Density Values	Unchanged

SD Model Performance Result

Figure 1 depicts the performance of the SD model in terms of cost as it showed the annual cost for the budgeted, actual and SD generated in a bar chart. Massive savings in cost would have been obtained from maintenance policies generated by the SD model, due to massive difference between it and both the actual and budgeted maintenance cost during the year 2021-2023, with the highest cost savings being recorded in the year 2022 when compared to actual, and year 2023, when compared with the budgeted cost. It was also observed from figure 1 that the budgeted cost increases with increase in number of years, while the SD simulated maintenance cost decrease with increase in the years, within the years under study.

Figure 2 is an area graph showing the density of cracks corrected by the SD simulated maintenance system and that of the one carried out by the agencies through their conventional maintenance policies. From figure 2, it was observed that the area of cracks covered by the agencies were higher than that covered by the SD simulated maintenance policies. This, however showed in terms of quality, the agencies were a bit higher than that of the SD simulated maintenance policies, but it comes at a higher cost. However, the purpose of the maintenance policies is to find the best fit in terms of cost and quality. While the agency structure were looking to fix all at a time, the system dynamics tends to distribute the maintenance fix optimally over the long run while ensuring that none of the road sections deteriorate into an unsafe stage before being amended, which as a result reduces the cost spent yearly on maintenance. This fit was better depicted in figure 3.

Figure 3 showed the graph of changes in cost and cracks for budgeted and actual, budgeted with SD simulated and actual with SD simulated. The smaller the difference in the crack area, which is a measure of quality and the larger the change in amount, which is a measure of cost, the more efficient the policies are. From figure 3, changes in budget with actual and budget with SD both undergo steep descent with the steepest being that of the budget with SD. This showed that budget with SD performed better in terms of quality. Also, both changes in budget with actual and budget with SD simulated, both ascend at the latter end of the years in focus, with that of the budget with SD ascending higher than that of budget with actual. This showed better performance in terms of cost of the budget with SD over that of budget with actual.

The graph showing that of changes in actual and SD however didn't show any significant features as observed from figure 3. This might be due to the fact that the actual budget is usually assigned based on the political climate and prerogative of the governor in charge, and doesn't follow any logical sequence while that of the SD is based on engineering logical dynamics, thereby leading to the disjointed graph shape encountered when plotted as shown in figure 3.

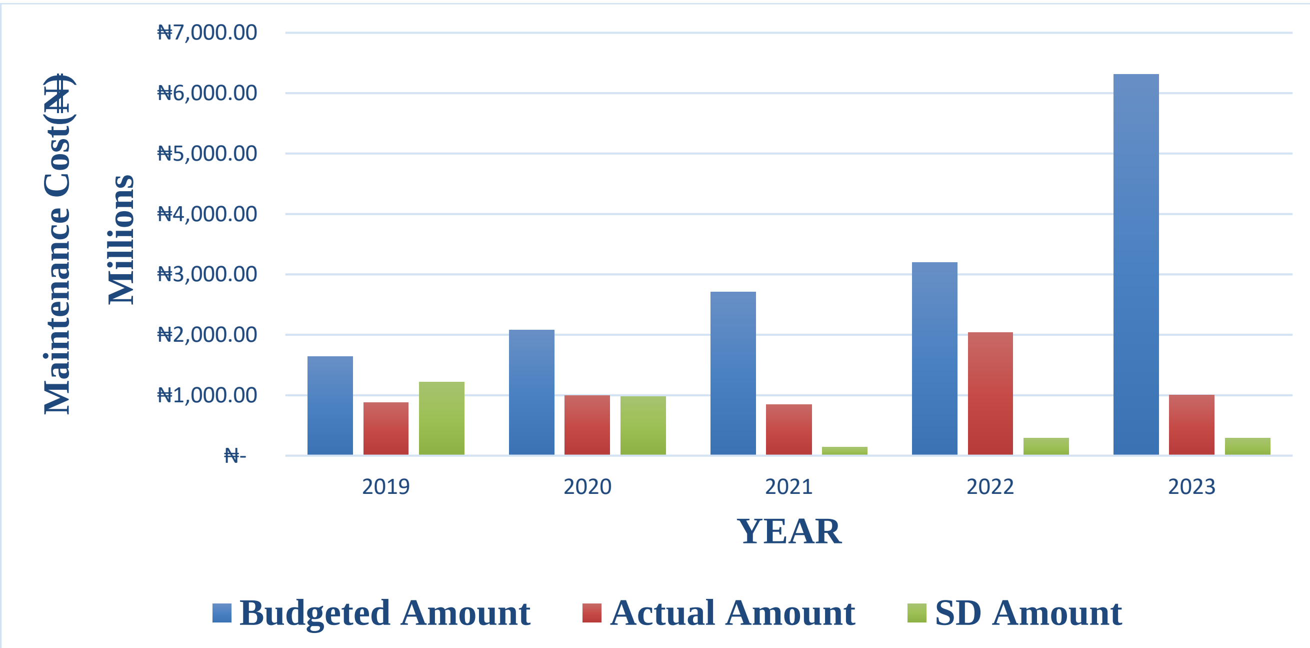

Figure 1: Bar Chart Showing Budgeted, Actual and SD simulated Maintenance Cost

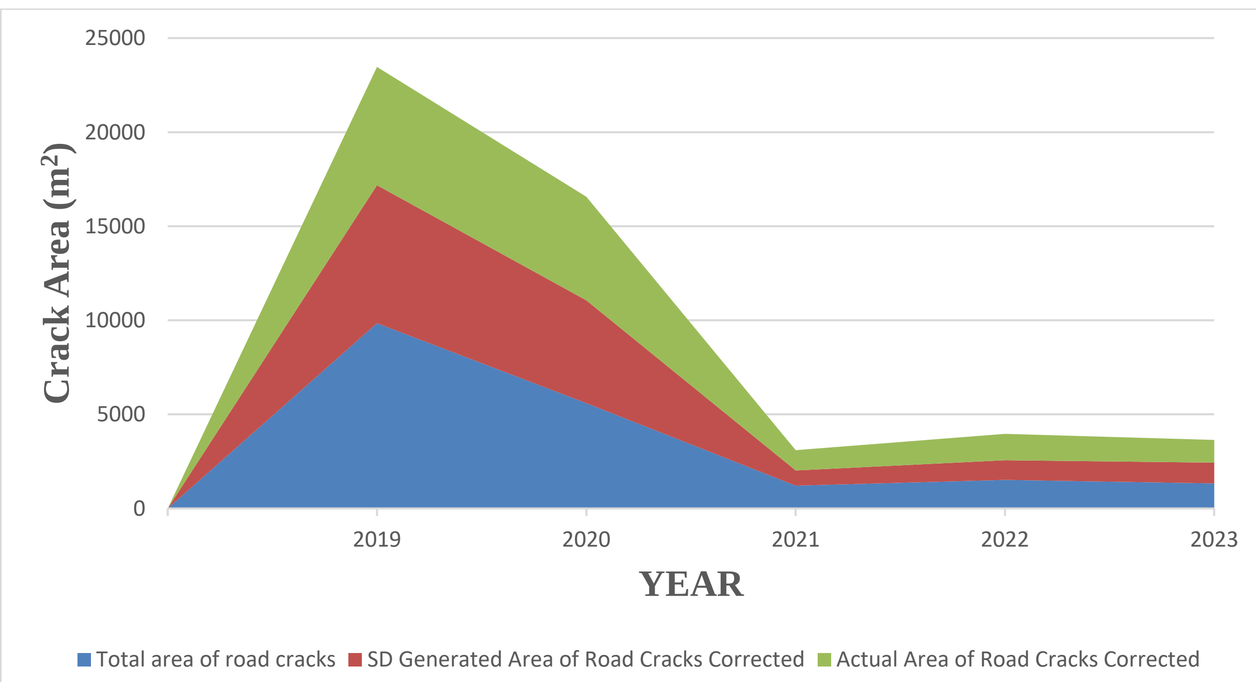

Figure 2: Graph of the SD Simulated and Agency Administered Area of Cracks Corrected

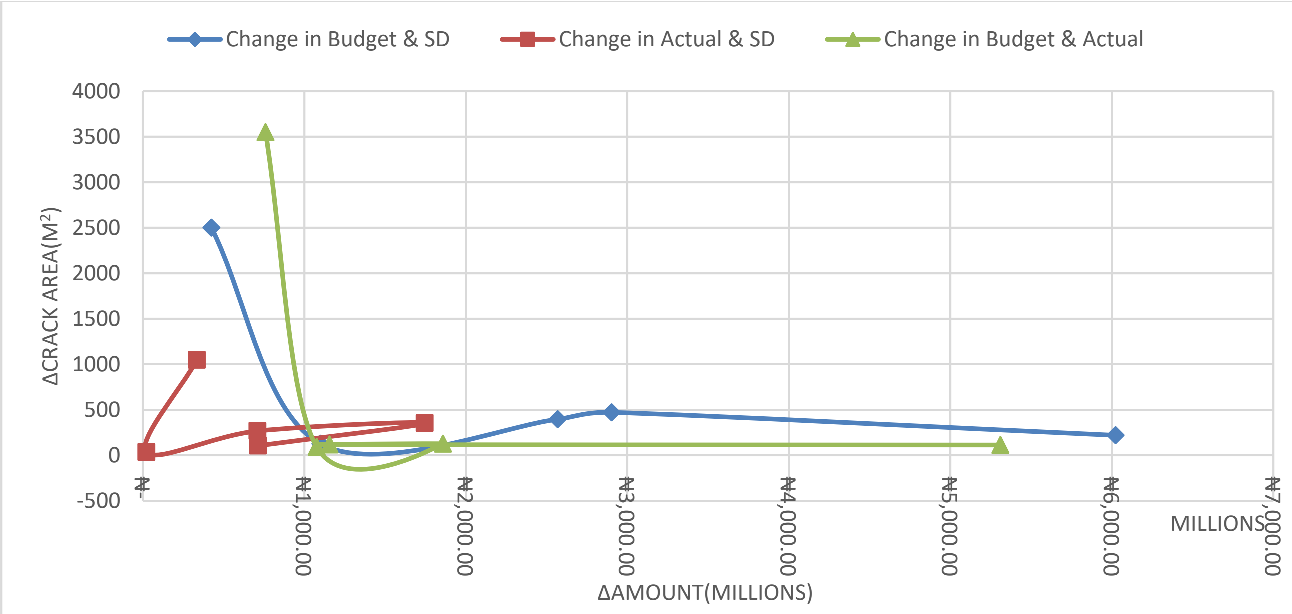

Figure 3: Cost and Quality Performance of the SD Simulated and Agency Administered with Budget

Performance against the 2023 Study Road Section State of Usage

Table 7 showed the study road section health as of the year 2023, from the maintenance policies conducted by the FERMA Osun State Field Headquarters and that of the SD simulated. From table 7, the SD Simulated Road section health was better than that obtained as a result of the maintenance management agencies in seventeen (17) of the twenty-four (24) road sections used in this study. The two results were similar at three study road sections which were the IPETU - JESA - APOTI - ODSB ROAD, ROUTE 542, ILESA-OWENA -ODSB, ROUTE 35 and OSU JUNCTION - ILESA IBL JUNCTION ROAD, ROUTE 35A. However, the road section health from that maintained using the agencies system were better than the SD simulated at four (4) road sections only with health status of NS-O (OSOGBO-ILOBU- OYSB ROAD, ROUTE 35A), NS-O(ILESA - ILOKO SPUR, ROUTE 35), NS-R (OSOGBO - OTA EFUN- IKIRUN (OLD OSOGBO - IKIRUN ROAD), ROUTE 530A) and NS-O (IFE - IFETEDO – ODSB ROAD, ROUTE 538) compared to SD simulated health status of NS-F, NS-F, NS-O and NS-F of the same road sections respectively.

Table 7: SD Simulated and Agency Maintained Study Road Section in 2023

		Agency Maintained			**SD Maintained**	
S/N	**ROAD**	**LENGTH (KM)**	**Severity**	**Density**	**Severity**	**Density**
1	OSOGBO-ILESA ROAD, ROUTE 35A	32.00	NS	F	NS	O
2	OSOGBO-ILOBU- OYSB ROAD, ROUTE 35A	20.50	NS	O	NS	F
3	IWARAJA-ERINMO EFON-ALAAYE ROAD, ROUTE 534	26.00	NS	F	NS	R

4	SEKONA-GBONGAN ROAD, ROUTE 557	22.00	NS	F	NS	R
		Agency Maintained			**SD Maintained**	
S/N	**ROAD**	**LENGTH (KM)**	**Severity**	**Density**	**Severity**	**Density**
5	GBONGAN-IWO - OYSB ROAD, ROUTE 557	46.00	S	F	NS	F
6	IFE-SEKONA ROAD, ROUTE 530	22.00	S	O	NS	O
7	OSOGBO-SEKONA ROAD, ROUTE 530	22.00	NS	O	NS	R
8	OSOGBO-OKUKU- KWSB, ROITE 530	40.00	NS	O	NS	R
9	ILESA-IJEBU-JESA-EKSB ROAD, ROUTE 553	18.00	NS	O	NS	F
10	ILESA-OWENA -ODSB, ROUTE 35	38.00	NS	R	NS	R
11	IBADAN - IFE ROAD (IFE BOUND), ROUTE 35	50.00	S	R	NS	R
12	IBADAN - IFE ROAD (IBADAN BOUND), ROUTE 35	50.00	S	O	NS	R
13	IFE -ILESA DUAL CARRIAGEWAY (ILESA BOUND), ROUTE 35	46.00	S	F	NS	F
14	IFE -ILESA DUAL CARRIAGEWAY (IFE BOUND), ROUTE 35	46.00	S	O	NS	F
15	ILESA - ILOKO SPUR, ROUTE 35	7.00	NS	O	NS	F
16	OSU JUNCTION - ILESA IBL JUNCTION ROAD, ROUTE 35A	20.00	NS	O	NS	O
17	IFE (MAYFAIR) - OSU JUNCTION ROAD, ROUTE 35A	21.00	NS	O	NS	R
18	IFE - IFETEDO – ODSB ROAD, ROUTE 538	45.00	NS	O	NS	F
19	IPETU - JESA - APOTI - ODSB ROAD, ROUTE 542	14.50	NS	F	NS	F
20	IFE (ONIKOKO) -ARAROMI ROAD, ROUTE 530	37.00	S	F	S	O
21	OSOGBO - OTA EFUN- IKIRUN (OLD OSOGBO - IKIRUN ROAD), ROUTE 530A	20.00	NS	R	NS	O
22	AKODA - EDE - AERO-DROME - OSOGBO ROAD, ROUTE 530	23.00	NS	O	NS	R
23	EDE -FED. POLY - TECHNIC SPUR,	7.00	VS	R	NS	F

24	IFE(GARAGE OLODE) - ARAROMI - OGSB ROAD, ROUTE 538A	97.00	VS	O	NS	F

Maintenance Cost Forecasting Result

Figure 4 showed the maintenance cost forecasted for five years between 2024-2028 from the pattern simulated from past data inputted into the SD system. The total budgeted, approved and SD simulated cost was forecasted for the study road section.

From figure 4, both the budgeted, SD and approved cost decreases with years up to the 2027 before experiencing an increase at year 2028. However, the difference in cost between the SD and that of the budget and approved were massive as shown in figure 4. The rate of decrease was also at the minimum at the SD simulated road management system compared to that practiced by the agency. That of the crack density, however, could not be forecasted, because the application of the approved funds is usually based on the prerogative of the administrator in charge, and no formal strategies are followed in that regard.

This shows that application of the System Dynamics Road maintenance system would cause massive savings in cost at appreciable quality in road usage and area of cracks covered and would reduce the overall depletion rate of the roads as its progressive application yearly would ensure that roads do not get too bad before it is attended to, no matter how much is budgeted and approved for the maintenance of the roads

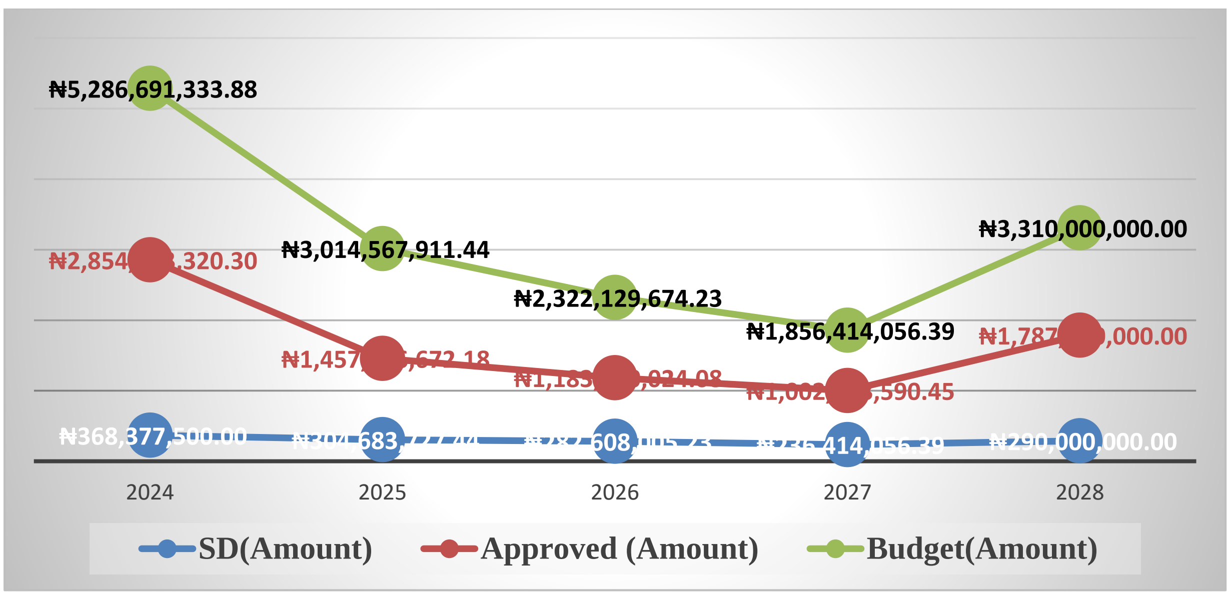

Figure 4: Forecasted Maintenance Cost

4.0 CONCLUSION

- The average time it takes for the study road pavement to move from Not Severe (NS) to the Severe (S) stage is approximately 34 months, while that of the transition from Severe (S) to Very Severe (VS) stage took a shorter time of 22 months
- The time transition from a recently conducted maintenance activities to the reappearance of cracks is 11 months.
- The optimal load related distress (LDR) threshold chosen, which is an important parameter in selecting sections of the

road to be maintained in a calendar year was 75.

- Massive savings in cost would have been obtained from maintenance policies generated by the SD model, due to massive difference between it and both the actual and budgeted maintenance cost during the year 2021-2023

- The area of cracks covered by the agencies were higher than that covered by the SD simulated maintenance policies, but comes at a higher cost

- From the maintenance cost forecasted for five years between 2024-2028, the difference in cost between the SD and that of the budget and approved were massive, with both budgeted and approved running maintenance cost in billions while that of the SD generated running cost were in millions

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