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Highlights

Time Series Analysis Model

Implementation of Public Infrastructure

Conceptual Framework For Road

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Time Series Analysis Model for Annual Rainfall Data in Lower Kaduna Catchment Kaduna, Nigeria

By D.A. Attah , G.M.Bankole

Kaduna Polytechnic Kaduna, Nigeria

Abstract - Time series analysis and forecasting has become a major tool in many applications in water resources engineering and environmental management fields. The effects of climate change and variability on water demand in the 21st century makes the time series analysis of rainfall, a major replenishing source of water, more imperative than ever before. The major challenge of water demand management is the ability to effectively estimate the contribution of rainfall to the water budget of any given basin. Among the most effective approaches for time series analysis is the Box-Jenkins" Auto regressive Integrated Moving Average (ARIMA) model. In this study, the Box-Jenkins methodology was used to build an Auto regressive Moving Average (ARMA) model for the annual rainfall data taken from Kaduna South meteorological station within the Lower Kaduna catchment for a period of 47 years (1960 – 2006). From the analysis, the mean annual rainfall was 1385.2mm with a standard deviation of 313.8mm and coefficient of variation of 0.23 (low variation). The range for the period of study is 1407mm. The ARMA model identified is ARMA (1,1) which has Pearson Correlation Coefficient (R^2) of 0.969 and residual ACF and PACF that indicated no pattern. The model is therefore adequate and appropriate for the forecast of future annual rainfall values in the catchment which can help decision makers establish priorities in terms of water demand management..

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TIME SERIES ANALYSIS MODEL FOR ANNUAL RAINFALL DATA IN LOWER KADUNA CATCHMENT KADUNA, NIGERIA

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Time Series Analysis Model for Annual Rainfall Data in Lower Kaduna Catchment Kaduna, Nigeria

D.A. Attah^α, G.M. Bankole^β

Abstract - Time series analysis and forecasting has become a major tool in many applications in water resources engineering and environmental management fields. The effects of climate change and variability on water demand in the 21st century makes the time series analysis of rainfall, a major replenishing source of water, more imperative than ever before. The major challenge of water demand management is the ability to effectively estimate the contribution of rainfall to the water budget of any given basin. Among the most effective approaches for time series analysis is the Box-Jenkins' Auto regressive Integrated Moving Average (ARIMA) model. In this study, the Box-Jenkins methodology was used to build an Auto regressive Moving Average (ARMA) model for the annual rainfall data taken from Kaduna South meteorological station within the Lower Kaduna catchment for a period of 47 years (1960 – 2006). From the analysis, the mean annual rainfall was 1385.2mm with a standard deviation of 313.8mm and coefficient of variation of 0.23 (low variation). The range for the period of study is 1407mm. The ARMA model identified is ARMA (1,1) which has Pearson Correlation Coefficient (R^2) of 0.969 and residual ACF and PACF that indicated no pattern. The model is therefore adequate and appropriate for the forecast of future annual rainfall values in the catchment which can help decision makers establish priorities in terms of water demand management.

I. INTRODUCTION

Time series can be defined as an ordered sequence of values at equally spaced time intervals (Box et al, 2008). Time series models are mathematical representation of the time series. Time series models have been the basis for the study of behaviour of a process over a period of time. The application of time series models are manifold, including sales forecasting, weather forecasting, and inventory studies etc. In decisions that involve factor of uncertainty of the future, time series models have been found to be one of the most effective methods of forecasting. Most often, future course of actions and decisions for such processes will depend on what would be the anticipated results. The need for these anticipated results has encouraged organizations to develop forecasting techniques in order to be better prepared to face the seemingly uncertain future. The motivation to study time series models is twofold:

1. To obtain an understanding of the underlying forces and structure that produced the observed rainfall data in the Lower Kaduna catchment of Kaduna state of Nigeria.
2. To fit a model: this can be used for forecasting, monitoring or even feedback and feed forward control.

Time series analysis can be divided into two main categories depending on the type of model that can be fitted. The two categories are:

1. **Kinetic Model:** The data here is fitted as: $x_t = f(t)$. the measurements or observations are seen as function of time.
2. **Dynamic Model:** The data here is fitted as: $x_t = f(x_{t-1}, x_{t-2}, x_{t-3}, \dots \dots \dots)$.

Many methods and approaches for formulating forecasting models are available in literature. This study exclusively deals with Autoregressive Integrated Moving Average (ARIMA) time series models. These models are well described by Box et al (2008). The ARIMA models allow the manager who has only historic data of say rainfall, to forecast future values without having to search for other related time series data, for example, temperature. It also allows for the use of several time series to explain the behaviour of another time series if these other time series are correlated with variable of interest and if there appears to be some cause for correlation.

Box-Jenkins (ARIMA) modelling has been successfully applied in various water resources and environmental management applications (Nail & Momani, 2009). Time series analysis has become a major tool in hydrology. It is used for building mathematical models to generate synthetic hydrologic data, to forecast hydrologic events, to detect trends and shifts in hydrologic records and to fill in missing data and extend records. Time series analysis was used by Langu (1993) as cited by Nail and Momani (2009) to detect changes in rainfall and runoff patterns to search for significant changes in the components of a number of rainfall time series.

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II. MATERIALS AND METHODS

a) Data

The data for this study were obtained from Kaduna State Water Board, Hydro meteorological section and they include daily rainfall depths in millimeters for the period 1960 to 2006. The annual rainfall depths are the summation of the daily rainfall. The processed data for the time series analysis in the study area is, therefore, the annual rainfall depths. Descriptive statistical analysis and homogeneity test were then performed on these data to verify the integrity of the data. For the ARMA model building, the moving average (MA) values of these data were used.

b) Study Area

The Lower Kaduna catchment is located between latitude 10° 15' and 10° 45' North and between longitude 6° 15' and 7° 45' East with an area of 1547 square kilometers. It is within the highland climatic zone of Nigeria with a mean annual rainfall of 1230mm. The rainy season is between May and October when about 80% of the annual rainfall occurs. It is drained by River Kaduna.

Water resources in Lower Kaduna catchment are limited and with deteriorating quality due to urban development. Therefore, it is important to know the future water resources budget in order to help decision makers improve their decisions by taking into consideration the available and future water resources. Modelling and forecasting for future water resources have become possible with advances in forecasting methodologies such time series analysis.

c) Method of Analysis

Models used for the study of the variations in hydro-meteorological variables from year to year have not been based on the analysis of causal factors but on the decomposition of the time series into its basic components by means of the dynamic series model given as:

$$y(t) = u(t) + v(t) + s(t) + e(t)$$

Where: $u(t)$ = trend due to the action of \ permanent factors;

$v(t)$ = cyclic variations due to the action of rhythmic factors;

$s(t)$ = stochastic components assumed to follow an autoregressive moving average Process;

$e(t)$ = random component due to the action of random factors.

There is an obvious connection between these components of the series and the actual physical processes or situations. Thus, the general trends reflect the general direction of the dynamics of the phenomenon; the cyclic variations or component give the periodical fluctuations about the trend or mean; and the stochastic and the random components or

variations are as a result of the impacts of random factors on the natural development of the phenomenon (Haidu et al, 1987).

i. Trend

The general trend of the hydro-meteorological series can be ascribed to climate change or the influence of man's activities such as agriculture, deforestation and urbanization (Haidu et al, 1987) on the hydrologic system. The extraction of the trend component from the raw data series can be achieved by means of a polynomial fit given as:

$$u(t) = a_1 + a_2t + a_3t^2 + \dots \dots \dots + ant^{n-1}$$

For parsimony, (that is, using a model with the fewest possible number of parameters and greatest number of degrees of freedom among all models for adequate representation) the trend can be extracted by means of the basic statistical model for linear trend given as: $(t) = a + bt + e(t)$; Where a = intercept; b = slope of the regression line and $e(t)$ = random error component. The parameters a and b are estimated using the least square method if the error terms are uncorrelated. The principal complication with this method in the case of climate data is usually that the data are autocorrelated, in other words, the terms cannot be taken as independent (Smith, 2007).

After the elimination of the trend component, the dynamic series becomes:

$$R(t) = v(t) + s(t) + e(t).$$

In order to establish the general structure of the resulting series or residual series $R(t)$, the correlogram method is used. The autocorrelation coefficient γ_k , is determined as follows:

$$k = [\sum_{t=1}^{N-k} \{(Rt - Rm)(R(t+k) - Rm)\}] / \sum_{t=1}^N (Rt - Rm)^2$$

Where N = the length of the time series; k = the difference between two values of the series expressed in time units, Rm = mean value of the series.

The correlogram is obtained by graphical representation of the variations of γ_k with k . If the data series is random, the computed value of γ_k is other than that due, only, to internal (random) variation of the series, the points of the correlogram being very close to the horizontal axis. The confidence limit (CL) corresponding to a given significant level is expressed as: $CL(\gamma_k) = [-1 \pm Z_\alpha(N - k - 2)^{1/2}] / (N - k - 1)$, where Z_α = standard normal deviate corresponding to the probability α . For $\alpha = 5\%$, the significant level $Z_\alpha = 1.645$.

ii. Periodic Component

The determination of the periodic component is achieved by means of a Fourier series of the form:

$v(t) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty}(a_n \cos \frac{2\pi}{T}nt + b_n \sin \frac{2\pi}{T}nt)$, where n = the order of the harmonic corresponding to the period established by the analysis of the correlogram. $\frac{2\pi}{T}$ = the frequency of the oscillations. a_0, a_n, b_n = Fourier coefficients. The remainder of the dynamic series is given as $R(t) - v(t) = s(t) + e(t) =$

stochastic component. After eliminating the trend and periodic components from the original data series, the resulting series is a stochastic process which can be modelled by means of parametric models of an autoregressive moving average (ARMA) type (Haidu et al, 1987 and Box et al, 2008).

The general structure of a non-stationary ARIMA type (p, d, q) model is given as: $w_t = \phi_1 w_{t-1} + \dots + \phi_p w_{t-p} + a_t - \theta_1 a_{t-1} - \dots - \theta_q a_{t-q}$, where d = difference order; ϕ = parameters of the autoregressive process; θ = parameters of the moving average process; p = order of the autoregressive process; q = order of the moving average process; and a_t = current value of an independent random variable with zero mean and constant variance δ_a^2 (of the "white noise" type).

When $d = 0$, $w_t = s_t - \mu$, where s_t = the current value of the modelled series at moment t ; μ parameter that determines the level of the process, in

the case of stationary process μ is the mean of the series.

The steps necessary for establishing the ARIMA type model to describe, optimally, the data series are:

1. Estimation of the order p , q , and d of the model by the analysis of the autocorrelation (ACF) and partial autocorrelation (PACF) functions;
2. Determination of the parameters ϕ , and θ by means of the maximum likelihood and least square methods; and
3. Analysis of the structure of the residuals obtained after the application of the model in order to verify appropriateness of the chosen model. If the residuals obtained do not comply with the above mentioned criteria indicated for a_t , the model should be re-analyzed.

III. RESULTS AND DISCUSSION

The summary of the descriptive statistics of the annual rainfall data is presented in Figure 1 below. From the figure, it can be inferred that the mean annual rainfall of Lower Kaduna catchment is 1385.2mm and median is 1320mm. This indicates that the annual rainfall values are right skewed. The high standard deviation value can easily be correlated with the high range (1407mm) of the annual rainfall values

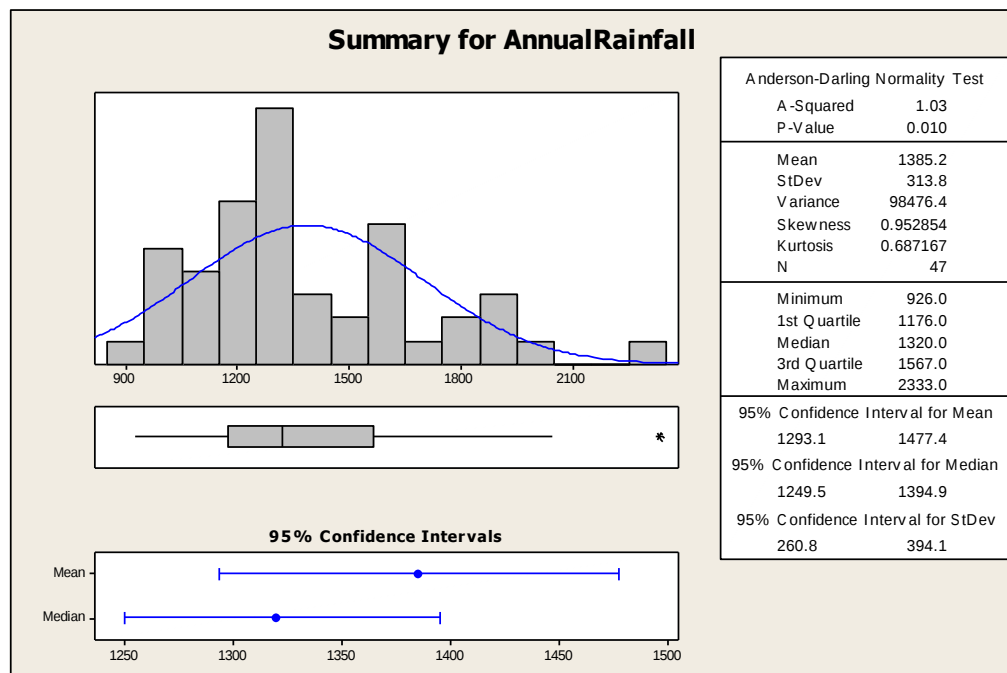


Figure: 1 Descriptive Statistics of Annual Rainfall

The range is the difference between the maximum and minimum annual rainfall values. The standard deviation and the range indicate the variability of the annual rainfall and hence denote how reliable the rainfall is in terms of its persistence as a constant and

stable replenishing source. The p-value is less than 0.05 indicating that the data is non-normal.

To test whether the annual rainfall data follow a normal distribution, the skewness and kurtosis were computed. Skewness measures symmetry or lack of

rainfall is in terms of its persistence as a constant and stable replenishing source. The p-value is less than 0.05 indicating that the data is non-normal.

To test whether the annual rainfall data follow a normal distribution, the skewness and kurtosis were computed. Skewness measures symmetry or lack of symmetry. The skewness for normal distribution is zero. Negative value of skewness indicates left skewness while positive value indicates right skewness. Kurtosis is a measure of data peakness or flatness relative to normal distribution. The normal standard distribution has zero kurtosis. Positive kurtosis indicates a peaked distribution and negative kurtosis indicates flat distribution. The annual rainfall exhibits right skewness and peaked distribution as indicated in Figure 1.

a) Homogeneity Test

A climate variable is said to be homogeneous when its variations are caused only by fluctuation in weather and climate. To test the homogeneity of the climate data time series, the "Run Test" was applied. The distribution of the number of Runs(R) approximates a normal distribution with the following mean (E) and variance ($Var.$):

$$E(R) = (N + 2)/2; \quad Var(R) = [N(N - 2)]/[4(N - 1)].$$

The Test statistics Z is defined as:

$Z = [R - E(R)]/\sqrt{Var(R)}$, for significant level of $\alpha = 0.01$ and $\alpha = 0.05$. The Null Hypothesis of homogeneity is verified if $|Z| \leq 2.58$ and $|Z| \leq 1.96$ respectively.

From the Run Test results, as presented in Table1, the Null hypothesis of homogeneity is not rejected.

Table 1: Run Test

	Annual Total Rainfall
Test Value	1320
Cases < Test Value	23
Cases > = Test Value	24
Total Cases	47
Number of Runs	19
Z	-1.472
Aymp.Sig. (2-tailed)	0.141

The plot of the original data, as shown in Figure 2, does not show any seasonal variation since the data is the annual rainfall total

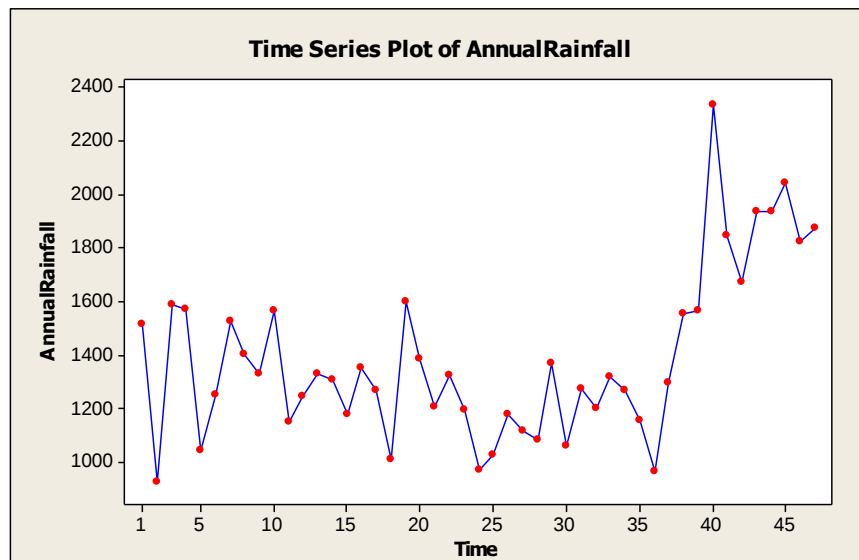


Figure 2: Time Series Plot of Annual Rainfall

The auto correlation function (ACF) and the partial auto correlation function (PACF) plots of the original data, as shown in Figure3, indicate that the annual rainfall data is stationary and therefore does not require differencing ($d=0$). That is, the annual rainfall series is serially independent.

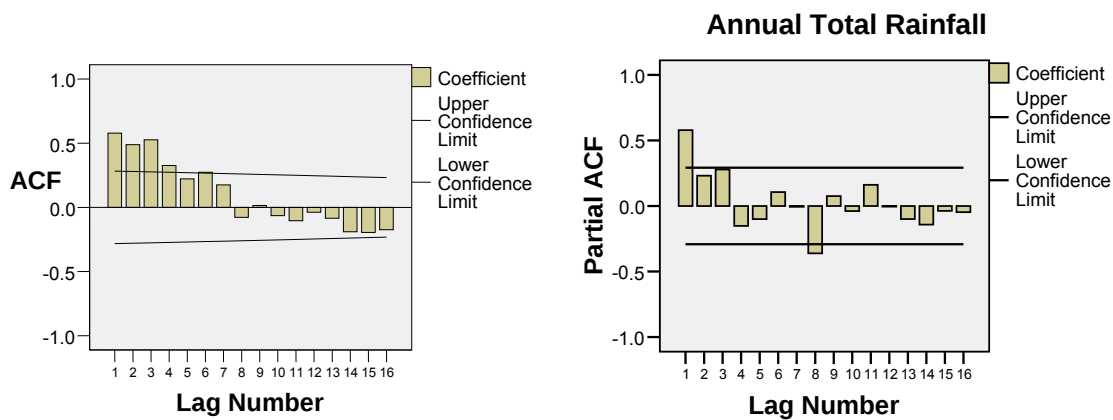


Figure 3 : ACF and PACF Plots of Annual Rainfall

From Figure3, it can be observed that there is only one significant pike in the PACF plot. This indicates that the autoregressive process would be of the order 1 ($p=1$) and the moving average process would also be of the order 1 ($q=1$). Therefore, the appropriate ARIMA model to fit the annual rainfall data would be an ARIMA (1, 0, 1) model which is equivalent to ARMA (1, 1).

After fitting the ARMA (1, 1) model, the model parameters were estimated from the following equation using the least sum-of- square of residuals method:

$$w_t = \phi_1 w_{t-1} + a_t - \theta_1 a_{t-1} \text{ or } X_t = \mu + \phi_1 X_{t-1} + \alpha_t - \theta_1 \alpha_{t-1}$$

The model fit statistics are presented in Table 2, while the estimated model parameters and their significant levels are presented in Table3. The estimated coefficients are all statistically significant at 5% level.

Table 2 : Model Fit Statistics

Model Statistics							
Model	Number of Predictors	Model Fit statistics		Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	R-squared	Statistics	DF	Sig.	
Ten Year Moving Average Annual Total Rainfall-Model_1	1	.969	.969	27.758	16	.034	1

Table 3 : Model Parameter Estimates

ARIMA Model Parameters					Estimate	SE	t	Sig.
Ten Year Moving Average Annual Total Rainfall-Model_1	Ten Year Moving Average Annual Total Rainfall	No Transformation	Constant		-17449.0	21796.890	-.801	.429
			AR Lag 1		.969	.065	14.966	.000
			MA Lag 1		-.600	.155	-3.869	.000
			Numerator Lag 0		9.527	11.009	.865	.393
	Year	No						

The model is validated by ACF and PACF plots of the residuals. A pattern less (white noise) ACF and PACF indicate a good fit. From ACF and PACF plot, as shown in figure 4, the ACF and PACF of the residuals have no pattern. Also, from Table 2, the Pearson product moment correlation coefficient (R^2) which measures the

linear association between individual pairs of forecasts and observations is very high (0.969) (for a perfect fit $R^2 = 1.0$). These indicate that the ARMA (1, 1) model identified is adequate for the forecast of future annual rainfall events in the study area.

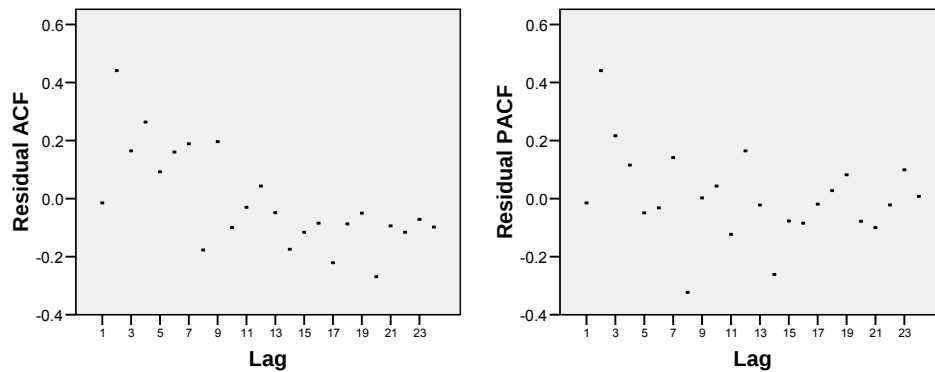


Figure 4: Residual ACF and PACF.

V. CONCLUSIONS

The ARMA (1, 1) model identified is adequate to represent the observed annual rainfall data and can be used to forecast future rainfall data. The ARMA (1, 1) model can be written as:

$$X_t = 1385.2 + 0.969X_{t-1} + \alpha_t - 0.6\alpha_{t-1}$$

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How Changes in Urban Form Influences Changes In Journey To Work Mode Choice ? (A Case Study of Sydney Metropolitan Region)

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Abstract - Suburbanization of employment and decentralization of residential workers experienced by most cities has contributed to more dependence on the car and a decreasing trend in public transportation share, leading to a less sustainable city over time. In order to overcome this condition, it is important to understand how changes in urban form influenced changes in mode choice of the residents. By using 1981-1996 Journey to Work Data for Sydney Metropolitan Region and applying multiple regression, this study investigates the relationship between changes in urban form and changes in commuting mode choices. The results indicated that the outer ring residents experienced a significantly higher increase in bus modal share compared to that of the inner and middle ring. On the other hand, the inner ring residents experienced a significantly greater increase in the proportion using train than that of the other regional rings. Local Government Areas (LGAs) with a greater increase in accessibility to jobs by bus and a greater increase in average job distances are associated with greater decrease in the proportion using car. Increasing the ratio of residential workers to jobs and accessibility to jobs by car was associated with decreases in the proportion using bus. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train.

Keywords : Urban form, mode choice, multiple regression.

GJRE-E Classification : FOR Code : 090599



HOW CHANGES IN URBAN FORM INFLUENCES CHANGES IN JOURNEY TO WORK MODE CHOICE ? A CASE STUDY OF SYDNEY METROPOLITAN REGION

Strictly as per the compliance and regulations of:



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Abstract—Suburbanization of employment and decentralization of residential workers experienced by most cities has contributed to more dependence on the car and a decreasing trend in public transportation share, leading to a less sustainable city over time. In order to overcome this condition, it is important to understand how changes in urban form influenced changes in mode choice of the residents. By using 1981-1996 Journey to Work Data for Sydney Metropolitan Region and applying multiple regression, this study investigates the relationship between changes in urban form and changes in commuting mode choices. The results indicated that the outer ring residents experienced a significantly higher increase in bus modal share compared to that of the inner and middle ring. On the other hand, the inner ring residents experienced a significantly greater increase in the proportion using train than that of the other regional rings. Local Government Areas (LGAs) with a greater increase in accessibility to jobs by bus and a greater increase in average job distances are associated with greater decrease in the proportion using car. Increasing the ratio of residential workers to jobs and accessibility to jobs by car was associated with decreases in the proportion using bus. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train.

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I. INTRODUCTION

Suburbanization of employment and decentralization of residential workers experienced by most cities has contributed to more dependence on the car and a decreasing trend in public transportation share, leading to a less sustainable city over time. In addition to the growth of vehicle numbers, the social development of more complex travel patterns (based on the car) have been seen as major limitations for the achievement of sustainable urban development (Newman and Kenworthy, 1999). Travel patterns are one component of environmentally sustainable transportation (EST) indicators. It has been suggested

that travel patterns such as Vehicle Kilometer of Travel (VKT), trip length and mode choice might be used as a proxy for energy consumption and transportation emissions (Stead, 2001).

Basically, the characteristics of urban form can influence population activities through trip behavior. Space form is an aggregate of various concepts and urban elements depicted in physical structure of the urban area. According to Kusumantoro et.al (2009), fringe area development or sprawl is a phenomenon that will continue to go on in the process of urban development. Un-readiness of spatial planning instruments in dealing with the problem has exacerbated the transportation problem in is connecting corridor, such as the problem of congestion. One effort that can be done is to conduct 'internalization of the orientation of the trip in the fringe area' so that the interaction of the fringe area with its core city can be reduced. However, before using urban form as a tool the first step in achieving sustainable transportation is to understand how urban form influences travel patterns.

At a macro level study, Giuliano and Dargay (2006) conducted international comparative analysis of relationships between car ownership, daily travel and urban form. Using travel diary data for the US and Great Britain, they estimated models of car ownership and daily travel distance. Both a structural model with daily travel conditional upon car ownership and a reduced form model for daily travel, excluding car ownership, were estimated. They found that differences in travel were explained by differences in demographics between the two countries, a lower household income in Great Britain, and differences in costs of car ownership and use and transport supply.

Gordon, et.al (2004) conducted a micro level study and he argued variations in public transit commuting were influenced by neighborhood type. They found a statistical link over a sample of all census tracts in the four largest California metro areas. They used statistical cluster analysis to identify twenty generic neighborhood types. The variables used in the analysis included broad indicators of location and population density, street design, transit access and highway

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access. They identified that the denser neighborhoods had higher transit use, whilst other things equal. In Germany, Vance and Hedel (2007) focused on individual automobile travel. They applied econometric models on a panel of travel-diary data collected in Germany between 1996 and 2003. They employed the two-part model (2PM): a procedure involving probit and OLS estimators. They found that urban form has a causative impact on car use. In Italian, Montis, et al. (2010) also found that similar commuting networks emerge in similar geographical settings.

Yang and Gakenheimer (2007) assessed the accessibility and mobility consequences of urban land transformation in expanding Chinese cities. They pointed out that appropriate accessibility and mobility objectives were not well considered in land development, and current development themes tend to lengthen trips and lead to increased congestion in the context of growth and motorization. Based on GIS modeling, Tang and Wang (2007) investigated the ways that four urban forms in the Macao Peninsula influenced vehicle transport and street environment. They stated that the urban forms in historical areas with narrower roads, complex road networks and a higher density of intersections lead to lower traffic volumes and thus lower noise pollution.

A research conducted in the fringe area of the Bandung City, Indonesia, by Kusmantoro et.al (2009) found that the compactness in an area does not have direct influence to the community pattern in having internal movement. Only several activities have direct influence, i.e. education and shopping trip. Not all of education and shopping trip have direct influence, they are only elementary school movement, junior high school movement, shop and supermarket. The rest of activities, such as working trip and health facility access do not show the relation of compactness and movement pattern. Another fringe area study was conducted by Kawabata et.al (2009) who analyzes travel behavior by car passengers and community buses in a mountainous under-populated region, Yamakoshi in the city of Nagaoka, Niigata in Japan. They estimated travel mode choice models using travel diary data to reveal the constraint factors of mobility for elderly people. They found that 'walking distance from home to a bus stop' influenced elderly people to shift travel mode from car passengers into an exclusive club bus system.

The strength of the relationship between urban form and mobility behavior is a longstanding question within the field of transportation demand management. Although several studies have identified a strong correlation between these variables, there is as yet scant evidence to support policy interventions that target land use as a means of influencing travel. For non-work trips, Zhang (2005) applied an activity-based time-use analysis of the relationship between urban form and non-work travel. Using data from the 1991

Activity-Travel Survey in Boston, he tested the role of spatial accessibility as a composite measure of urban form in explaining individuals' non-work activity participation, travel times, and travel frequencies. The results showed varying effects of modifying spatial accessibility on non-work activity participation and travel among different activity categories. However, according to Pooley and Turnbull (2000), the journey to work is one of the most commonly experienced forms of every-day travel, encompassing almost all transport modes, and making a substantial contribution to urban traffic congestion.

The weakness in most of the journey-to-work trip studies was the use of a static approach (i.e. the analysis was done at one point in time). This cross-sectional analysis using data at one point in time did not explain whether the changes in travel behavior of residents in a zone can be explained by the changes in urban form variables in that zone. There were substantial variations in travel behavior, urban form and socio-economic changes across the Sydney region. These variations provide a potential means of identifying the characteristics of urban form and socio-economic factors that are associated with changes in travel behavior. Using 1981-1996 Journey to Work data for the Sydney Metropolitan Region, the objective of this study is to investigate the relationship between changes in urban form and changes in travel behavior, especially mode choice.

The average change per 5 year of each variable for every zone (Local Government Area or LGA) over the period 1981 to 1996 is calculated and used in the analysis.

Several statistical analyses are employed including descriptive statistic, analysis of variance, correlation and multiple regression analysis.

II. DEFINITION OF URBAN FORM

Despite many factors influencing travel behavior, this research focuses on the influence of urban form on travel behavior. This section describes briefly the definition of urban form and archetypal urban form. Anderson (et al., 1996) defined urban form as 'the spatial configuration of fixed elements within metropolitan region'. According to Brunton and Brindle (1999) urban form is 'the generalized shape of an urban region, and the disposition of its major components (especially regional centers and major employment areas)'. In this study, urban form refers to physical arrangement of jobs-housing location. Urban form variables considered include density of population and employment, accessibility to jobs, average job distances, jobs-housing balance and distance from the CBD. Urban interaction is explained by the flow of goods, people and information across a city. However,

the flow of people (commuters, shoppers, etc.) is regarded as the most important movement in relation to the reduction of energy use and environmental emissions although the movement of goods also has significant impact.

Urban development is the result of many factors. Apart from geographical factors (rivers, mountains), the development of transportation infrastructure has influenced the size and the shape of cities. In Europe, before 1800, the physical expansion of a city was defined by the maximum distance people could comfortably walk to work. In that time, walking was the dominant mode of transportation. With the introduction of the new technology, passenger transportation modes (railways, trams) started replacing the walking mode and encouraged expansion outside the city (Hass-Klau, 1990). A similar situation was also experienced in Sydney with a steady progression from a compact "walking city" to a sprawling, car dependent city with low residential housing densities by world standards (Black, 1993). In addition to the influence of new technology, Newman and Kenworthy (1999) stated that the change in urban form is a result of a combination of factors including the market, government, and civil society.

The urban form is not simply determined by planners (Anderson, et al., 1996): the shape of the city has evolved over a long term period as a results of both public policies and free market forces. The construction of new transportation infrastructure leads to a more dispersed and inefficient pattern of land use development. Increasing numbers of people living in the outer areas requires more infrastructure to be developed. In turn, good infrastructure attracts more people to live in the outer ring.

III. METHODOLOGY

In order to analyze urban form change and travel patterns change across zones in Sydney Metropolitan Region, Journey to Work (JTW) census data and centroid to centroid distance matrix are used as input data. However, the values of the variables used are not the values for one point in time data but the average change per 5 years. Descriptive statistic is used to explain the change in urban form and mode choice across zones in Sydney over time. Following this descriptive analysis, analysis of variance (multiple comparison using Benferroni method) is used to compare the change in urban form and mode choice amongst LGAs located in the inner, middle and outer rings. Scatter-plot matrix is employed to visually inspect the relationship between independent and dependent variable and to check the linearity of the relationship. Correlation analysis is then used to examine the relationship between variables. A multiple regression analysis is conducted to predict the change in travel

mode choice. The change in urban form variables is used as independent variables. The analysis is also stratified into three regional rings – inner, middle and outer rings. The results are then used to draw policy implications on land-use development. Figure 1 and Table 1 shows Sydney zoning system.

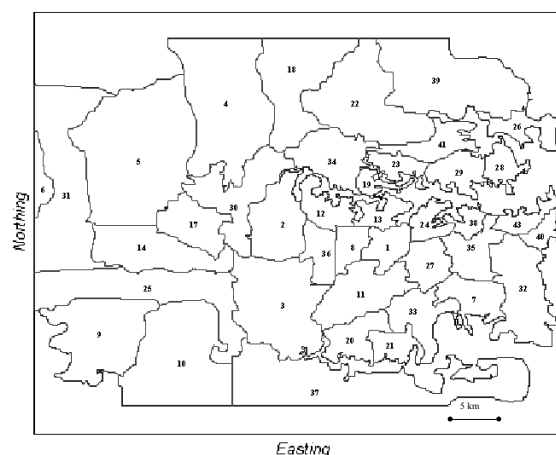


Figure 1: Sydney Zoning System

Table 1: Local Government Areas in Sydney and Zone Number

Region	Inner Ring				Middle Ring				Outer Ring			
	SLA	Zone Number	SLA	Zone Number	SLA	Zone Number	SLA	Zone Number	SLA	Zone Number	SLA	Zone Number
Central Zone	South Sydney	35	100	Middle South	Franklin	10	450	Outer South	Bathurst	37	100	
	Sydney (Inner)	38	101		Pydney	21	460	Outer South	Penrith	38	200	
	Sydney (Outer)	39	102		Roadville	31	470	Outer South	Geelong	39	300	
Inner Zone	Geelong	7	103	Middle South	Geelong	11	480		Geelong	40	400	
	Geelong	21	490	Outer South	Geelong	31	500		Geelong	41	500	
	Geelong	41	500	Middle West	Albury	2	200		Geelong	42	600	
Inner West	Geelong	40	500		Geelong	30	600	Outer West	Geelong	5	100	
	Geelong	24	400		Geelong	10	300		Geelong	6	200	
	Geelong	27	500		Geelong	8	300		Geelong	21	600	
Outer Zone	Albury	1	10		Geelong	36	700		Geelong	17	500	
	Geelong	15	200	Middle North	Geelong	34	600		Geelong	16	300	
	Geelong	25	400		Geelong	21	400	Outer North	Geelong	39	300	
Outer Zone	Geelong	25	500		Geelong	26	500		Geelong	4	10	
	Geelong	29	500		Geelong	41	500		Geelong	18	400	
					Geelong	19	400	Outer East	Geelong	44	300	
									Geelong	25	300	

The primary data source for this level of analysis were the 1981, 1991, and 1996 Journey-to-Work data for the Sydney Metropolitan Area. The Australian Bureau of Statistics (ABS) conducted the Census. The data are provided at the travel zone levels that have been aggregated from census tracts for the Statistical Local Area (SLA) levels and cover 44 Local Government Areas. The data that forms the basis for this research are the National Census of Population and Housing Journey-to-Work tabulations provided by the NSW Department of Transport, Transport Data Center (TDC).

Dependent variables describing LGA zonal travel behavior when stratified by transport mode were of three kinds: the proportion of journey-to-

work travel by the three major modes (car, bus and train); the total amount of travel, also stratified by mode; and the mean trip length, again also stratified by mode. Table 2 lists urban form as independent variables used in this study.

Table 2: Lists of urban form variables

No	Urban Form Variables
1	Proportion residential worker (%)
2	Proportion job (%)
3	Worker density (prs/km ²)
4	Job density (prs/km ²)
5	Ratio of residential worker to job
6	Proportion employed in CBD (%)
7	Proportion employed locally (%)
8	Average job distance (km)
9	Job accessibility by all mode
10	Job accessibility by car
11	Job accessibility by bus
12	Job accessibility by train
13	Separate dwelling (%)
14	Semi-detached dwelling (%)
15	Flat 1-3 storey (%)
16	Flat 4+ storey (%)
17	Road length per 1000 workers (km/1000workers)

IV. RESULTS AND DISCUSSIONS

a) Changes in Urban Form in Sydney

Table 3, 4 and 5 show changes in urban form variables in the inner, middle and outer ring of Sydney, respectively. The highest increase in the total number of jobs occurred in the outer ring (by about 3,664 persons per 5 years on average), whilst the middle ring LGAs experienced an increase of about 1,401 persons per 5 years but only 886 persons per 5 years for the inner ring. As with the total number of jobs, the outer ring LGAs also experience the greatest increase in total number of workers by about 4,658 persons per 5 years, in contrast to only 165 persons per 5 years in the inner ring. In spite of the absolute increase in total number of jobs and workers in the inner and middle ring, their metropolitan share of both jobs and residential workers has decreased. As jobs have continuously decentralized towards the outer ring, the inner ring LGAs have experienced the greatest increase in average jobs distances (by about 1.05 km per 5 years). Middle ring LGAs experienced an increase of about 0.77 km per 5 years. The increase is only 0.16 km in the outer ring.

A constant decrease in job density of about 170 persons per square kilometers per 5 years is experienced in the inner ring. On the other hand, the middle and outer ring experience increase by about 43 and 14 persons per square kilometers per 5 years, respectively. The average density of residential workers

increased in these three regional rings. In terms of dwellings, all of the regional rings experienced a decrease in the proportion of high-density dwellings and an increase in the proportion of semi-detached and separate dwellings. Moreover, the proportion of workers employed in the CBD and locally has decreased in all of these three regional rings indicating an increase in the suburb to suburb trips.

Table 3: Urban form variables changes per 5 years in the inner ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-494.36	138.71	13
CarAccess	2520.06	530.15	13
trainAccess	241.91	377.03	13
JobAccess	3874.32	1079.74	13
JOBDIS	1.05	0.09	13
TOTJOB	885.56	5881.22	13
TOTWRK	1088.46	2601.08	13
PROJOB	-0.14	0.68	13
PROPWRK	-0.03	0.19	13
RATIOJW	-0.05	0.13	13
WRKDEN	16.74	335.07	13
JOBDEN	-169.88	1194.13	13
%WRKCBD	-2.88	1.15	13
%WRKLOCAL	-0.13	1.22	13
%FLAT1+	-4.52	2.96	13
%SEMI	4.03	3.78	13
%Separate	0.48	1.26	13

Table 4: Urban form variables changes per 5 years in the middle ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-395.36	77.45	15
CarAccess	2748.60	438.53	15
TrainAccess	257.97	163.87	15
JobAccess	3931.18	519.46	15
JOBDIS	0.77	0.19	15
TOTJOB	1401.13	2111.90	15
TOTWRK	165.40	629.56	15
PROJOB	-0.03	0.12	15
PROPWRK	-0.12	0.11	15
RATIOJW	-0.04	0.07	15
WRKDEN	9.80	19.68	15
JOBDEN	43.05	68.72	15
%WRKCBD	-2.13	0.63	15
%WRKLOCAL	-0.35	1.20	15
%FLAT1+	-1.81	1.36	15
%SEMI	1.45	0.77	15
%Separate	0.36	1.44	15

Table 5 : Urban form variables changes per 5 years in the outer ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-148.91	64.42	16
CarAccess	1849.72	724.03	16
trainAccess	135.13	53.35	16
JobAccess	2676.81	961.11	16
JOBDIS	0.16	0.34	16
TOTJOB	3663.85	2532.24	16
TOTWRK	4657.50	3661.59	16
PROPJOB	0.14	0.16	16
PROPWRK	0.14	0.27	16
RATIOWJ	-0.01	0.11	16
WRKDEN	12.80	13.90	16
JOBDEN	13.92	17.15	16
%WRKCBD	-1.01	0.80	16
%WRKLOCAL	-1.19	2.39	16
%FLAT1+	-1.58	1.53	16
%SEMI	1.33	0.74	16
%Separate	0.25	1.07	16

b) Comparison in the Travel Mode Choice Changes

It has yet to be established whether significant differences exist in travel behavior between inner, middle and outer ring LGAs. This section compares travel behavior between these three regional rings in Sydney using analysis of variance, Benferroni method. Firstly, the comparison is performed using 1996 data only, it is then followed by the comparison of the average changes per 5 years. Table 6 shows the results of analysis of variance using 1996 data whilst Table 7 presents the results based on the average change per 5 years (during the 1981-1996 period).

Based on 1996 data, Table 6 shows that the proportion using car for inner ring residents is significantly lower by about 10.4 and 21.3 percent than that of middle and outer ring residents, respectively. The proportion using car for middle ring residents is significantly lower (by about 11 percent) than those in the outer ring. The inner ring residents have a significantly higher bus modal share by about 14.9 and 18.7 percent than that of middle and outer ring residents, respectively. However, there is no significant difference in the proportion using bus between the middle and outer ring residents. In terms of the proportion using train, there is no significant difference between the three regional rings.

Table 6: Comparison of Travel Behavior between Groups of LGAs in Sydney (1996)

Dependent Variables	(I) Ring	(J) Ring	Mean Difference (I-J)
%Car	1	2	-10.4*
		3	-21.3*
%Bus	2	1	10.4*
		3	-11*
%Train	1	2	14.9*
		3	18.7*
%Train	2	1	-14.9*
		3	3.8
%Train	1	2	-4.5
		3	2.6
%Train	2	1	4.5
		3	7.1
%Train	2	1	90237
		3	-439449*

1=inner, 2=middle, 3 =outer

* The mean difference is significant at 0.05 level

Furthermore, based on the average change per 5 years, Table 7 shows that there is no significant difference between the three regional rings in terms of proportion using car. The outer ring residents experienced a significantly higher increase in bus modal share (by about 1.43 percent) than the inner ring residents. On the other hand, the increase in the proportion using train in the inner ring is significantly higher by about 0.97 and 1.17 percent than the middle and outer ring, respectively.

Table 7: Comparison of Travel Behavior Between Groups of LGAs in Sydney (Average Change per 5 Years Data)

Dependent Variables	(I) Ring	(J) Ring	Mean Difference (I-J)
%Car	1	2	7.3E-03
		3	0.26
%Bus	2	1	-7.3E-03
		3	0.25
%Bus	1	2	-0.98
		3	-1.43*
%Train	2	1	0.98
		3	-0.45
%Train	1	2	0.97*
		3	1.17*
%Train	2	1	-0.97*
		3	-0.20
%Train	2	1	-2005
		3	-75339*

1=inner, 2=middle, 3 =outer

* The mean difference is significant at 0.05 level

c) Changes in the Mode Choice

For changes in mode choice, three transportation modes were considered – car, bus and train. The average change in the urban form variables per 5 years was expected to be associated with a

change in the proportion using car and public transportation.

d) Changes in the Proportion Using Car as Dependent Variable

Table 8 shows the result of multiple regression analysis for the average change in the proportion using car as the dependent variable. In the inner ring, only the average change in accessibility to jobs by bus entered the model with a negative association. The LGAs in the inner ring that had a greater increase in the accessibility to jobs by bus experienced a significant decrease in the proportion using car. The average change in accessibility to jobs by bus explains 38 percent of variation in the average change in proportion using car.

Two urban form variables entered the regression model for the middle ring, i.e. the average change in total number of residential workers (with a negative association) and the ratio of residential workers to jobs (with a positive association). This indicates that increasing the number of workers by about 1000 persons per 5 years is associated with about an 0.8 percent decrease in the proportion using car in the middle ring holding the average change in ratio of workers to jobs constant. A combination of these two variables explains 71 percent of variation in the average change in proportion using car.

Table 8: Regression Model for the Changes in Proportion Using Car as the Dependent Variable and Urban Form as the Independent Variables (Aggregate and by Rings)

Dependent Variable	Model	Unstandardised coeff.	Standardised coeff.	t	sig	Tolerance	VIF	
%Car (Inner)	Constant	-1.56		-1.27	0.230			R=0.62
	BusAccess	-0.0063	-0.619	-2.61	0.024	1	1	R ² =0.38
								F=6.83
								Sig.=0.024
%Car (Middle)	Constant	1.91		12.49	0.000			R=0.84
	TotWrk	-7.96E-04	-0.588	-3.67	0.003	0.946	1.057	R ² =0.71
	RatioWJ	5.75	0.482	3.01	0.011	0.946	1.057	Adj. R ² =0.66
								F=14.6
								Sig.=0.001
%Car (Outer)	Constant	0.71		2.41	0.030			R=0.62
	JobDen	0.041	0.623	2.98	0.010	1	1	R ² =0.39
								F=8.9
								Sig.=0.010
%Car (All ring)	Constant	0.58		1.80	0.079			R=0.52
	BusAccess	-5.26E-03	-0.828	-3.83	0.000	0.382	2.62	R ² =0.27
	JobDis	-1.43	-0.575	-2.66	0.011	0.382	2.62	Adj. R ² =0.23
								F=7.5
								Sig.=0.002

In the outer ring, only job density entered the regression model. The outer ring LGAs that had a greater increase in job density experienced a greater increase in the proportion using car. This finding suggests that increasing job density in the outer ring where there are plenty of parking spaces available, less congestion and a lack of public transportation services is not likely to reduce the use of car. The regression coefficient is statistically significant. However, the average change in job density only explains 39 percent of variation in the average change in the proportion using car.

When all LGAs are included, the average change in accessibility to jobs by bus and average job distances entered the model with a negative association. This indicates that LGAs with a greater increase in accessibility to jobs by bus and a greater

increase in average job distances are associated with greater decrease in the proportion using car. A combination of these two variables explains only 27 percent of variation in the average change in the proportion using car.

e) Changes in the Proportion Using Bus as Dependent Variable

Table 9 presents the result of multiple regression analysis using stepwise procedure between the average change in proportion using bus as the dependent variable and urban form change as the independent variable. The model is developed for all rings, and also for the inner, middle and outer rings. For each model, the regression coefficients, t-statistics, standardized coefficients (beta) and the significance are reported including collinearity test as given by tolerance

and variance inflation factor (VIF) values. Tolerance values of less than 0.1 or VIF more than 10 indicate a collinearity problem. Acceptable tolerance value is 0.1 or over while VIF value is less than 10. The beta coefficients reflect the relative importance of the association of the independent variable with the change in the proportion using bus. A beta coefficient may be interpreted as the effect of one standard error change in the independent variable on the dependent variable measured in unit equals to its standard error. A variable with a larger beta coefficient has a greater effect on the dependent variable than one with a smaller coefficient.

For the inner ring, only the average change in accessibility to jobs by bus (BusAccess) entered the model with a positive association. The LGAs in the inner ring with higher increases in their average accessibility to jobs by bus tended to have higher increases in the proportion using bus. Although the regression coefficient is statistically significant, it only explains 33 percent of variation in the average change in proportion using bus.

Table 9 : Regression Model for the Proportion Using Bus as the Dependent Variable And Urban Form as the Independent Variables

Dependent Variable	Model	Unstandardised coeff.	Standardised coeff.	t	Sig.	Tolerance	VIF	
%Bus (Inner)	Constant	1.81		1.10	0.294			R=0.58 R ² =0.33 F=5.5 Sig.=0.039
	BusAccess	0.00076	0.577	2.34	0.039	1	1	
%Bus (Middle)	Constant	-1.19		-9.84	0.000			R=0.75 R ² =0.56 F=16.75 Sig.=0.001
	RatioWJ	-6.039	-0.750	-4.09	0.001	1	1	
%Bus (Outer)	Constant	0.35		0.94	0.363			R=0.82 R ² =0.67 Adj. R ² =0.62 F=13.28 Sig.=0.001
	RatioWJ	-6.42	-1.013	-5.09	0.000	0.638	1.567	
	CarAccess	-4.66E-04	-0.480	-2.41	0.031	0.638	1.567	
%Bus (All ring)	Constant	0.21		0.70	0.491			R=0.71 R ² =0.50 Adj. R ² =0.48 F=20.8 Sig.=0.000
	BusAccess	0.00042	0.598	5.42	0.000	0.995	1.005	
	RatioWJ	-5.03	-0.428	-3.88	0.000	0.995	1.005	

The average change in accessibility to jobs by bus did not enter the regression model in the middle ring. Only the average change in ratio of residential workers to jobs entered the model (with a negative association). The negative association implies that increasing the ratio of residential workers to jobs in the middle ring is associated with decreases in the proportion using bus. The variable explains 56 percent of the variation in the average change in proportion using bus.

The average change in the ratio of residential workers to jobs also entered the regression model in the outer ring. In addition, accessibility to jobs by car entered the model with a negative sign. Increasing the ratio of residential workers to jobs and accessibility to jobs by car was associated with decreases in the proportion using bus. A combination of these two urban form variables explains 67 percent of variation in the average change in proportion using bus in the outer ring. When considering all LGAs in Sydney, two urban

form variables entered the regression model: the average change in accessibility to jobs by bus (with a positive association); and the ratio of residential workers to jobs (with a negative association).

f) Changes in the Proportion Using Train as Dependent Variable

The regression model given in Table 10 indicates that none of the urban form variables entered the regression model in the inner ring and only the average change in total number of residential workers entered the middle ring model with a positive association. Three urban form variables entered the regression model in the outer ring, i.e. the average change in proportion of workers employed in the CBD, job density and average job distance. Increasing the proportion of workers employed in the CBD by 10 percent was associated with the increase in train modal share by about 12 percent in the outer ring. On the other hand, increasing job density decreases the proportion

using train. This indicates that the role of train is to serve CBD work destinations for outer ring residents and it is not a competitive mode for local or suburb to suburb travel

Table 10: Regression Model for the Changes in Proportion Using Train as the Dependent Variable and Urban Form as the Independent Variables

Dependent Variable	Model	Unstandardised coeff.	Standardised coeff.	t	Sig	Tolerance	VIF	
%Train (Inner)	N/S (Not Significant)							
%Train (Middle)	Constant	-0.71		-6.50	0.000			R=0.73
	TotWrk	6.591E-04	0.726	3.80	0.002	1	1	R ² =0.53
								F=14.47
%Train (Outer)	Constant	0.64		2.63	0.022			Sig.=0.002
	WrkCBD	1.18	0.778	5.19	0.000	0.639	1.565	R=0.91
	JobDen	-0.032	-0.455	-3.60	0.004	0.900	1.111	R ² =0.83
	JobDis	1.25	0.355	2.45	0.031	0.684	1.462	Adj. R ² =0.79
								F=19.22
%Train (All ring)	Constant	-1.31		-3.87	0.000			Sig.=0.000
	JobDis	2.52	1.026	5.65	0.000	0.374	2.677	R=0.72
	WrkCBD	0.43	0.446	2.39	0.022	0.352	2.838	R ² =0.52
	PropWrk	1.93	0.398	2.97	0.005	0.688	1.454	Adj. R ² =0.47
	WrkLocal	-0.26	-0.415	-0.30	0.004	0.651	1.536	F=10.55
								Sig.=0.000

Four urban form variables entered the regression model for all LGAs, i.e. the average change in average jobs distance, proportion of workers employed in the CBD, proportion of residential workers and proportion of workers employed locally. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train. On the other hand, increasing the proportion of workers employed locally decreased the use of train. A combination of these four urban form variables explains 52 percent of variation in the average change in proportion using train with no problem of collinearity identified.

V. CONCLUSIONS

Changes in urban form variables in Sydney indicated that the highest increase in the total number of jobs occurred in the outer ring, followed by middle and inner ring. The outer ring LGAs also experienced the greatest increase in total number of workers. In spite of the absolute increase in total number of jobs and workers in the inner and middle ring, their metropolitan share of both jobs and residential workers has decreased. As jobs have continuously decentralized towards the outer ring, the inner ring LGAs have experienced the greatest increase in average jobs distances whilst the outer ring the lowest. A constant decrease in job density was experienced in the inner ring, while, the middle and outer ring experienced constant increase. The average density of residential

workers increased in these three regional rings. In terms of dwellings, all of the regional rings experienced a decrease in the proportion of high-density dwellings and an increase in the proportion of semi-detached and separate dwellings. Moreover, the proportion of workers employed in the CBD and locally has decreased in all of these three regional rings indicating an increase in the suburb to suburb trips.

Based on the average change per 5 years, analysis of variance comparing travel behavior between the inner, middle and outer rings indicated that there was no significant difference in the changes in proportion using car between these regional rings. The outer ring residents experienced a significantly higher increase in bus modal share compared to that of the inner and middle ring. On the other hand, the inner ring residents experienced a significantly greater increase in the proportion using train than that of the other regional rings.

Results of multiple regression analyses indicated that for the proportion using car as dependent variable, the average change in accessibility to jobs by bus and average job distances entered the model with a negative association. This indicated that LGAs with a greater increase in accessibility to jobs by bus and a greater increase in average job distances were associated with greater decrease in the proportion using car. Two urban form variables entered the regression model for the proportion using bus: the average change in accessibility to jobs by bus (with a positive association); and the ratio of residential workers to jobs (with a negative association). In the case of the

proportion using train, four urban form variables entered the model, i.e. the average change in average jobs distance, proportion of workers employed in the CBD, proportion of residential workers and proportion of workers employed locally. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train. On the other hand, increasing the proportion of workers employed locally decreased the use of train.

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El sistema Ctesiphonte.Evolucion de la estructura catenaria

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Abstract - La complicada situación de la España de los años de autarquía (1940-55), llevó a que algunos arquitectos propusieran soluciones sumamente económicas y de rápida construcción para tratar de solucionar el grave problema de la falta de vivienda. Entre esas propuestas llama especialmente la atención el sistema Ctesiphonte, basado en una catenaria estructural como único elemento que define el espacio. La solución se extenderá para otras funciones como la agropecuaria, pero igualmente llegará a utilizarse para edificios de uso social o religiosos.

Keywords : vivienda, catenaria, ctesiphonte, arquitectura social, estructura.

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El sistema Ctesiphonte. Evolución de la estructura catenaria

P. Rabasco

Resumen - La complicada situación de la España de los años de autarquía (1940-55), llevó a que algunos arquitectos propusieran soluciones sumamente económicas y de rápida construcción para tratar de solucionar el grave problema de la falta de vivienda. Entre esas propuestas llama especialmente la atención el sistema Ctesiphonte, basado en una catenaria estructural como único elemento que define el espacio. La solución se extenderá para otras funciones como la agropecuaria, pero igualmente llegará a utilizarse para edificios de uso social o religiosos.

Palabras Clave : vivienda, catenaria, ctesiphonte, arquitectura social, estructura.

Summary - The difficult situation in Spain during the autarchy years (1940-55) led some architects to propose extremely economic and rapid solutions in order to solve the serious problem generated by the lack of housing. One of these proposals, and of particular interest, is the Ctesiphon system, based on a catenary structure as the only element that defines the space. This solution was to be used later for agricultural, social and religious purposes.

Keywords: housing, catenary, ctesiphon, social architecture, structure

I. INTRODUCTION

En el año 1947, el arquitecto finlandés afincado en los Estados Unidos, Eero Saarinen, diseñaba junto al ingeniero de origen alemán Hanns Karl Bandel (1), el Jefferson National Expansion Memorial, en la ciudad de St. Louis, en el estado de Misouri. Nació así uno de los símbolos de la nueva arquitectura americana¹. Pero de una manera un tanto irónica, esta estructura no estaba diseñada por un arquitecto americano, y ni siquiera se trataba de un edificio. Era una expresión de alta tecnología de la construcción aplicable a la arquitectura, tal y como se demostró en la propia carrera de los Saarinen, pero también a la ingeniería y al arte. En unas fechas realmente combulsas, recién terminada la segunda guerra mundial, los Estados Unidos empezaban a tomar conciencia de su papel en un Nuevo orden mundial, y la arquitectura intentaba componer un nuevo lenguaje. Se trataba de adaptar las enseñanzas de los grandes maestros del Movimiento Moderno a una nueva realidad económica y social que no siempre posibilitaría los procesos ciertamente utópicos formulados en las décadas anteriores desde el viejo continente. (Figura 1)

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El gran monumento de St. Louis, edificado en memoria de la expansión territorial norteamericana, no era otra cosa que una estructura formada por una triple catenaria invertida que constituía una sección triangular para conseguir una altura de 192 m. Este gran despliegue de la tecnología, a otra escala tanto real como simbólica, estaba ya muy presente en Europa en



Figure 1. Jefferson National Expansion Memorial. Eero Saarinen (1947).

la ingeniería de puentes, de uso militar o en la aviación civil, pero contrastaba en esas mismas fechas con formas similares que a partir de una catenaria invertida describían una estructura autoportante creando un espacio habitable. Fue en 1944 cuando estas formas catenarias aparecieron en el sur de Inglaterra, dando cobijo a miles de soldados que se preparaban para desembarcar en Normandía (2). A partir de esos momentos, una forma que había estado asociada a la arquitectura de funciones singulares o altamente tecnificadas, pasa a ser considerada una forma aceptable de arquitectura económica y de rápida construcción, normalmente asociada a entornos y

espacios de usos secundarios (almacenes, establos...) pero que en el caso español llegará a conformarse como un ejemplo extremo de vivienda mínima.

A comienzo de la década de los 50 aparece en el panorama de la arquitectura española la necesidad de buscar nuevas tipologías que solucionen problemas concretos de una forma rápida y económica. Problemas que parecían concretarse en el diseño y planificación de viviendas de carácter social. El proceso, que busca adaptar las poco comprensibles pretensiones políticas a las escasas posibilidades tecnológicas desarrollables en una España recién salida del período de autarquía, es quizás el ejemplo más claro de un período donde la arquitectura, extremadamente dirigida e impuesta, choca con sus propias pretensiones, convirtiendo el resultado en una suerte de intentos que se sitúan en el mismo límite de la arquitectura habitable. Rafael de La Hoz, en su momento, analizó la situación de una manera muy acertada².

Entre estas nuevas formas llama especialmente la atención la presencia de la tipología Ctesiphonte, una forma que fue aplicada de manera sorprendente en edificios con finalidades tan dispares como la industrial, la vivienda o la religiosa, en una concentración de funciones que marcaron realmente un ejemplo sin precedentes en la historia de nuestra arquitectura⁽³⁾. Lo más destacable no es sin embargo que una tipología adopte funciones tan distintas, sino el hecho de resumir y acoger en una sola forma tendencias tipológicas que parecían inamovibles tanto en sus aspectos culturales, sociales o políticos ⁽⁴⁾.

La construcción tipo Ctesiphonte se desarrolla en España entre 1950 y 1965, en proyectos llevados a cabo por arquitectos como Alejandro de la Sota, Carlos de Miguel, José L. Picardo, Fernando Moreno Barberá o Rafael de La-Hoz. Tras este breve período de quince años, tiempo donde parece extenderse en un afán experimental sin precedentes, esta estructura desaparece y no vuelve a desarrollarse, al menos de la misma manera.

El desarrollo de esta forma de catenaria invertida y la adopción del nombre de Ctesiphonte por la cual la conocemos, parte del conocido arco que marca la entrada al palacio que lleva este mismo nombre, sede de la capital de los imperios parto (170 a 226 d.c.) y persa (226 a 650 d.c.). El palacio se encuentra en Salman Pak, en las cercanías de la ciudad de Bagdad.

Su curiosa forma y enormes proporciones han pasado a la historia de la arquitectura como el arco construido en ladrillo que alcanza mayores proporciones. Su traza de catenaria se describe a partir de una amplia base con siete metros de sección que va disminuyendo de grosor según va adquiriendo altura, hasta presentar en su punto más alto una mínima anchura, dando como

resultado la sensación de fragilidad que sugiere su imagen. A pesar de esta sensación y los pequeños ladrillos utilizados, se ha mostrado con el paso de los siglos como una estructura sumamente robusta. (Figura 2)



Figure 2. Palacio de Ctesiphonte, Salman Pak. Bagdad

Esta tipología se verá continuada en el tiempo, partiendo de tradiciones y usos indígenas sin que se registren influencias o modelos extranjeros directos en

¹ El Jefferson National Expansion Memorial, se ordena construir por; Executive Order 7523 de 21 de diciembre de 1935 bajo la responsabilidad del National Park Service.

² "El conflicto que como arquitectos hemos de solucionar estriba en la reducida superficie que disponemos para desarrollar tal programa. Stratemann lo resuelve con un mínimo de 83,28 m2 construidos. La UIOF aconseja 75,70 m2 útiles. Sin embargo, el acuerdo 22-1-59 Arrese-Solís establece, respectivamente, 50 m2 y 38m2 como máximo de dichas superficies; es decir, nuestras viviendas sociales deben desarrollarse en superficies que oscilen del 50 al 58 por cien de los límites lógicos.

Por otra parte, el coste unitario de la construcción de una vivienda de programa fijo es más elevado a medida que disminuye la superficie en que se desarrolla. La razón es obvia; por más que se comprima la vivienda, sus elementos caros, instalaciones de todo tipo, carpintería, etc.- permanecen invariables.

Por el contrario, las viviendas sociales hay que resolverlas en el límite más desfavorable del erróneo criterio opuesto, heredado por el MV del antiguo INV "cuando una vivienda disminuye de superficie, el coste de metro cuadrado lo hace proporcionalmente. Aceptando como real el valor oficial que corresponde a 76 m2, encontramos que el asignado a las viviendas de 50 m2 es un 50,5% del que realmente debe tener. El problema que la vivienda social plantea puede resumirse en construir una vivienda en la mitad de superficie universalmente considerada mínima, con la mitad de presupuesto que realmente se precisa". De la Hoz, R.: "La vivienda social". Arquitectura, nº 39, (1962). Este mismo texto lo incluye el autor en la Memoria para la construcción de 520 viviendas tipo social para la Obra Social Cordobesa Huertos Familiares, Córdoba Junio de 1959. Archivo del ministerio de la Vivienda, Delegación de Córdoba.

esta región. En otros edificios, como la iglesia de Ctesiphonte, construida entorno al año 600, vemos igualmente un desarrollo de esta forma donde desde la cabecera del templo arranca una catenaria que conforma el espacio (5). Los materiales son los mismos que observamos en toda la zona, básicamente ladrillo de adobe, a causa de la falta de piedra y los abundantes yacimientos de arcilla

El estudio y desarrollo de la catenaria como elemento arquitectónico ya en la época contemporánea aparece fuertemente unido a la obra y las investigaciones de Antoni Gaudí. Estas formas las vemos aplicadas en obras como la desaparecida Cascada de la Casa Vicens, en la Casa Milá, en el Colegio de las Teresianas, en la Finca Güell, el Palau Güell, en Bellesguard o en la Sagrada Familia. Pero su uso se vuelve especialmente trascendente y rotundo en la bohardilla de la Casa Batlló, a base de un sistema de repetición de arcadas en catenaria realizadas en ladrillo.

Pero como bien ha señalado Joseph Gómez-Serrano, Gaudí no desarrolló por si solo las aplicaciones arquitectónicas de esta forma, algunos estudios venían profundizando en este sentido durante todo el siglo XIX. Autores como Gabriel Lamé, Poncelet, Kart Culman, Luigi Cremona, Scheffler o Carl Ritter habían dejado toda una serie de estudios a los que el propio Gaudí llegaría a través del conocimiento de la obra de Scheffler (6).

Igualmente, hemos de tener en cuenta la aplicación de esta forma por parte de Robert Maillart en muchas de sus obras, y especialmente en la influencia que tuvo en Félix Candela, autor que desarrolla estas mismas formas en la década de los 50:

“Le conocí en Space, Time and Architecture de Giedion, y conseguí después el libro de Max Hill, con su inestimable colección de ensayos publicados por Maillart. Devoré sus artículos Diseño y Cálculo del Hormigón Armado, en el que diferencia claramente el significado de 2 ambos términos tratando de evitar la, más que semántica, confusión que prevalece, sobre todo en los países de habla inglesa, entre diseño y cálculo; El Ingeniero y las Autoridades, que expresa su posición respecto al establecimiento, y Masa y Calidad en las Estructuras de Hormigón Armado” (7)

El hecho es que en torno a ese año de 1950 se da en España la estructura de catenaria invertida como definidora del espacio. El arquitecto Rafael de la Hoz, uno de los nombres más importantes en el desarrollo de la vivienda social en la España del franquismo, trató de rastrear esta tipología e igualmente afirmó que su primera aplicación se produce al Sur de Inglaterra pocas semanas antes del día D, como construcción destinada a albergar al gran número de tropas allí concentrado (2). Al terminar la Guerra se siguió experimentando con este nuevo sistema; “Posteriormente, a la terminación de la guerra, se construyó por el Ministerio de Obras Públicas de la

Gran Bretaña, en el campo de pruebas del norte de Londres, un edificio Ctesiphon de 18,3 m. de luz por 61 m. de longitud.” Reafael de La Hoz comentaba en la descripción de esta tipología que “la idea del Ctesiphon modern tuvo su origen en la contemplación del arco de



Figure 3. Vivienda Ctesiphon. Ejercito Norteamericano (1944).

Ctesiphon. El primer arco ondulado fue construido en 1941, denominándolo, con bastante propiedad, el moderno Ctesiphon. Su luz fue de 6,1 m., y el espesor de la lámina de 3,1 cm., noconteniendo ninguna clase de refuerzos.” (9). (Figura 3) El mismo Félix Candela señalaba en referencia a los comienzos de esta estructura que el mismo realizara a partir de 1950 que “*Esto fue copiando un sistema que estaban haciendo en Inglaterra entonces; yo copaba todo lo que podía*” (10). La tipología la va a desarrollar el ejercito norteamericano en estas circunstancias y la utilizara tanto como edificio de almacenamiento, como vivienda de altos cargos militares. Pero ya se habian producido algunos ejemplos de esta forma como elemento único estructural que define el espacio, en construcciones de tipo industrial como los Hangares en Orly de Eugene Freyssinet, realizados entre 1916 y 1924. Freyssinet ya realizó estas estructuras durante el segundo período de

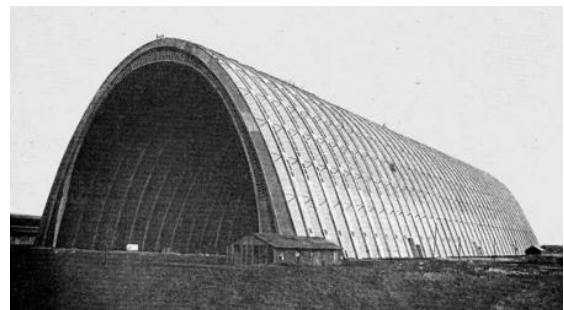


Figure 4. Hangares de Orly. Eugene Freyssinet (1916-1924).



Figure 5. Les Halles Centrales de Boulinguin, Reims. Emile Maigrot (1927- 28).

tiempo en que trabajó como ingeniero militar para el ejército francés entre 1914-18. (8). Igualmente lo aplica en estructuras abiertas como en el Tonneins Bridge, realizado entre 1919-22 (11). De la misma manera, otra obra muy interesante en este mismo sentido es Les Halles Centrales de Boulinguin en Reims, obra firmada por el arquitecto Emile Maigrot en 1927-28 bajo las propuestas del propio Freyssinet, (Figuras 4 y 5), (12, 13)³

Este sistema de membrana continua nace en sus primeros momentos como un concepto mixto, aplicable tanto a vivienda como a almacén aunque, cuando concluye el conflicto se potencia su uso industrial, hasta que se rescata la posibilidad de vivienda en circunstancias también extremas como las que se daban en la España de los 50. Habría que recordar que durante los primeros años de la década de los cincuenta aparecían en prensa especializada detalles de la construcción de prototipos siguiendo técnicas similares aunque aplicadas en estructuras de grandes dimensiones.

El período clave para el desarrollo de esta tipología surge en el momento en que, esta forma se considera como elemento suficientemente despegado de la semántica del ingeniero como para definir conceptos arquitectónicos y tipológicos tan importantes para la propia historia de la arquitectura como lo son la vivienda o el templo religioso.

En España ese momento se da en 1951, cuando de manera diferente, una serie de arquitectos parecen asumir una nueva y ponderosa función para esta tipología formal.

Por un lado, Alejandro de la Sota publicaba en el Boletín de Información de la Dirección General de Arquitectura (BIDGA), un artículo sobre el estado de la crítica arquitectónica (14). Se trataba de respetar nuevas formas y tipologías que por su formalidad pudieran sufrir rechazo por parte de la crítica más tradicional. Este artículo aparecía ilustrado con unos

dibujos a mano alzada donde el arquitecto mostraba ejemplos de estas nuevas arquitecturas, brillantes e incomprensibles. Entre los dibujos de estas formas novedosas e innovadoras aparecía una obra de arquitectura religiosa que utiliza la tipología Ctesiphonte, a modo de dos naves que se cruzan para conformar la cruz latina, todo resumido en una estructura de catenaria que arranca desde el nivel del suelo. Una idea similar, dentro del ambiente ambiguo que prevaleció durante la I Bienal de Arte Hispanoamericano, podemos contemplarla en el proyecto de Alfonso Gimeno para la Catedral bajo la advocación de San Isidro Labrador, donde encontramos desfasado el mismo tema propuesto e incluso las referencias excesivamente claras a la Sagrada Familia de Gaudí, pero que resulta muy moderno en la concepción espacial a través de una serie de catenarias que muestran además un arriesgado planteamiento en la iluminación cenital del espacio (15, 16). Esta misma concepción a otra escala la veríamos unos años más tarde en la Iglesia de Valdecañas, realizada por el arquitecto Fernando de Urrutia Usaola (17), por encargo del Instituto Nacional de Colonización algunos años después, en 1958, o en la iglesia del poblado de origen military de Campamento (Cádiz), obra de Francisco Echenegui (18). (Figuras 6, 7 y 8)

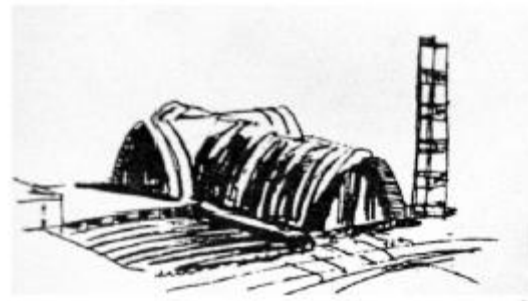


Figure 6. Dibujo de Alejandro de la Sota. Publicado en 1951 en el BGDA

³ Para ver la evolución de esta problemática en los años inmediatamente anteriores ver: Sambricio, C.: "La ingeniería en las revistas españolas de arquitectura: 1920-1936", en Informes de la Construcción, vol. 60, nº 510, 2008

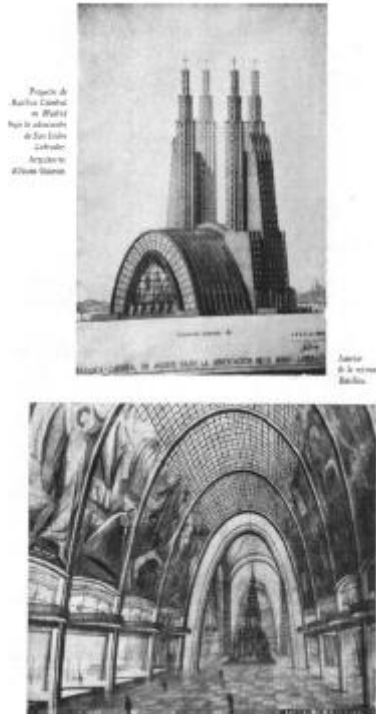


Figure 7. Proyecto de Basílica Catedral en Madrid. Alfonso Gimeno (1950).



Figure 8. Iglesia de Campamento, San Roque. (Cádiz).



Figure 9. Estructuras agropecuarias en las cercanías de Córdoba.

Se trata de un acercamiento conceptual a una serie de formas que se desarrollarían en los siguientes años, perdiendo ese concepto de arquitectura de calidad por el que apostaba De la Sota. (Figura, 9)

Carlos de Miguel y José L. Picardo la aplicaron en la construcción de unas naves de carácter industrial en el Centro Cívico para la Cofradía de Pescadores en Altea⁴. En este proyecto, la pareja de arquitectos colocaban un total de nueve construcciones utilizando el sistema Ctesiphonte, y aunque se centra en una serie de funciones de carácter más ligado a lo industrial, las proporciones se asemejan a los proyectos sociales que veremos a continuación. En este caso, los arquitectos proyectan nueve estructuras catenarias: dos como almacenes del Centro Cívico, cuatro depósitos para efectos navales y tres para depositar las redes que se sitúa a pie de embarcadero. Éstos se constituyen como construcciones auxiliares, pero realmente se incorporan correctamente al sentido general del proyecto. (Figura 10)

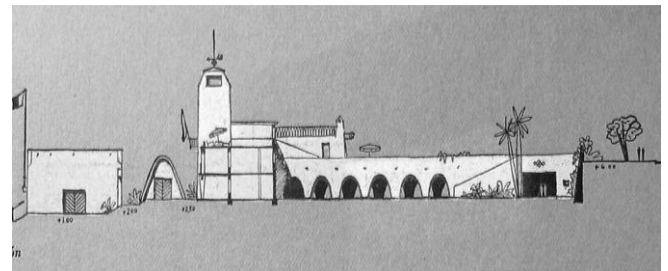


Figure 10. Centro Cívico para Cofradía de pescadores. Altea. Carlos de Miguel y José L. Picardo (1951).

Pocos meses después, el influyente arquitecto Fernando Moreno Barberá publica en la revista Informes de la Construcción un proyecto de viviendas unifamiliares siguiendo el sistema Ctesiphonte. (Figuras 11 y 12) En esta ocasión desarrolló la tipología como residencia vacacional (19). En este proyecto, Moreno Barberá plantea cuatro puntos en los que se apoya para defender las ventajas de utilizar este sistema constructivo, ventajas que van desde conceptos puramente técnicos hasta algunos de tipo

propagandístico y político, en un lenguaje de índole maquinista que se extiende en la España de los 50:

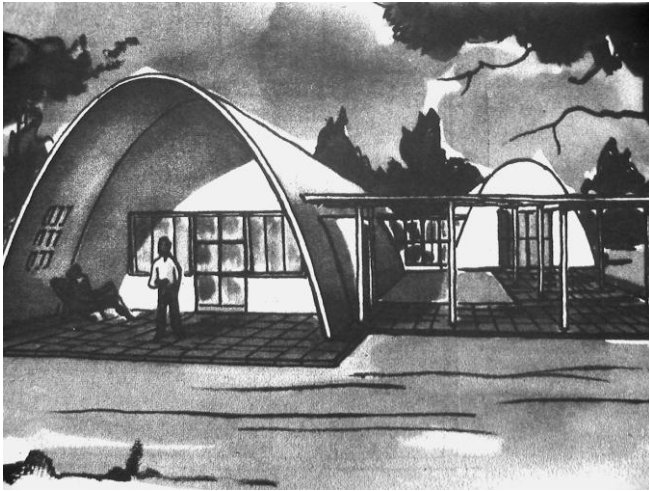


Figure 11. Proyecto de Fernando Moreno Barberá (1951).

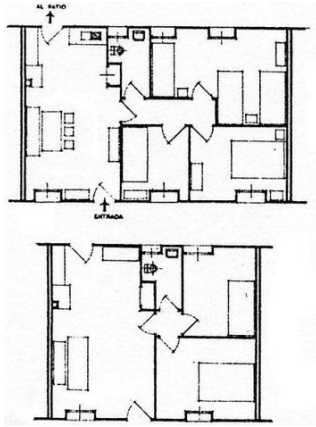


Figure 12. Plantas del conjunto residencial. Moreno Barberá (1951).

1º. Los materiales que se emplean son de la mejor calidad, análogos a los de las viviendas de alto precio.

2º. Por su especial sistema de construcción, las viviendas reúnen un buen aislamiento térmico, contando también con el debido confort como consecuencia de su estudiada distribución, e incluso su forma (empleada hoy en las ciudades atómicas de EE. UU.) es muy apropiada para resistir efectos de explosiones atómicas.

3º. Se eliminan en casi su totalidad los materiales hoy escasos o caros en España: madera de cubierta y hierro en forjados, herrajes y clavazón. El gasto de cemento es inferior por metro cuadrado al que requeriría una construcción normal de ladrillo y mortero de cemento.

4º. El especial sistema de construcción requiere un mínimo de horas de trabajo, base de su pequeño coste, y asimismo la intervención de un solo oficio – albañilería – para la total construcción de la estructura

En el punto primero el arquitecto presenta ya la estrategia económica como elemento vital, pero no la muestra como un valor propio sino como un valor comparativo de contraste hacia otro tipo de viviendas, y más específicamente hacia otras clases sociales.

Resulta realmente curioso observar cómo posteriormente trata de establecer las cualidades físicas no perceptibles visualmente de la vivienda, pero igualmente lo hace en una escala cuando menos aclaratoria de la situación; nos habla de la temperatura, el confort y, conjuntamente a estas cualidades, la define como “apropiada para resistir efectos de explosiones atómicas” (19), aunque este punto se presenta como una simple anécdota, contiene un mensaje importante pues, pone en relación el proyecto con la tecnología desarrollada en los EEUU; es aquí donde el arquitecto pretende llegar para enlazar con otra tendencia muy común en la actualidad de las revistas de arquitectura desde mediados de los años 40 pues, de cara al público, el sistema de apertura de la arquitectura española se muestra hacia el otro lado del océano como un referente tecnológico menos implicado en las tensiones políticas heredadas del conflicto.

Seguidamente, los puntos tercero y cuarto señalados en el texto, se convierten en un perfecto resumen de dos planteamientos muy comunes en estas fechas pero que fueron polémicos y, en ocasiones, contradictorios: el abaratamiento de los materiales y, lo que se presenta más discutible, la reducción de la mano de obra. El problema de esta reducción de la mano de obra se mezclaba con otro, el correspondiente inconveniente del aumento de paro en el sector de la construcción. Igualmente esto podía provocar una escasez de estos profesionales especializados y el descontento general en el sector. Conocemos que la cuestión es compleja pues la necesidad imperiosa de construcción de viviendas de bajo precio era de suma importancia para el nuevo régimen, pero cuando ya a partir de 1954 se necesita gran cantidad de mano de obra para proyectos de mayor envergadura, se tratará de corregir esta tendencia, que pasará a equilibrarse ante la necesidad de construcciones en altura que

⁴De Miguel, C., Picardo, J. L. “Centro Cívico para la Cofradía de Pescadores de Altea-Alicante”. Revista Nacional de Arquitectura, nº 115, (1951), pp. 36-38. Igualmente, en 1952 se publica; “Arcos de madera laminada”. Informes de la Construcción, (1952), transcripción de un artículo publicado en The National Builder titulado “Laminated Timber Arches”, que muestra el desarrollo del tipo Ctesiphonte como gran puerta de presentación al Festival Británico que en ese año se celebró junto a la estación de Waterloo.

abaraten el costo de urbanización y el del metro cuadrado, y no el de la mano de obra.

No podemos olvidar que el proyecto aquí presentado se muestra como experimental, sin hablar de localización concreta, y como tal se refuerza esta

orientación a través de la explicación de una serie de pruebas de Resistencia constructiva que se detallarán en el proyecto.

En cuanto a la descripción formal del proyecto hemos de partir de la cualidad constructiva que lo define, es decir, del hecho de que todos los elementos de la vivienda son fabricados en serie. El sistema constructivo se mostró bastante simple y rápido en su ejecución; se trataba en primer lugar de elegir un terreno óptimo y orientar correctamente la estructura en la medida de lo posible. Seguidamente se colocaba en el suelo una plataforma que se convierte en la base de la vivienda, se montan una serie de cimbras a lo largo de esta base que conforman el armazón y que servirá como molde-soporte de una serie de capas de cemento y de aislantes que una vez secas permiten retirar estas cimbras y dejar fijada la estructura definitiva de la vivienda. Las cimbras podían ser de diversos materiales; tubos de hierro, madera...la elección de estos vendrá por el precio del material en el momento de la ejecución del proyecto⁵.

En referencia a la forma descrita por este arco habría que establecer algunos parámetros interesantes que afectan al análisis de la obra. Por un lado se trata de una forma despegada de la tradición arquitectónica para su uso como vivienda. Se separa igualmente de los planteamientos más funcionales por la problemática en el aprovechamiento del espacio que puede presentar, tanto a nivel de mobiliario, que queda muy determinado por la forma curva de las paredes, como en la de los movimientos de los habitantes de la casa que quedan también, de alguna forma, más restringidos por las diferentes alturas. Igualmente se potencia el significado orgánico del hogar, que cambia el sentido de centralidad a partir de ángulos, pasando a una interpretación del espacio radial, que hace que una persona que se encuentre sentada en una de las habitaciones este siempre cerca del centro insinuado de la concepción tridimensional del espacio.

Si la relación interior/exterior del proyecto se presenta cuando menos interesante, la relación entre diversas estructuras plantea igualmente tensiones que preocupan a Moreno Barberá y a las cuales dedica especial atención, tanto en la redacción como en las ilustraciones explicativas de su proyecto.

El primer problema que se presenta es el de potenciar la vivienda aislada o, por el contrario, optar por una sucesión de elementos habitacionales compartiendo muro de medianera; el arquitecto parece

decantarse por este segundo, por economía en el uso de materiales y seguramente por la facilidad de urbanización del terreno aunque muestra la posibilidad de la construcción de residencias aisladas con este sistema.

Y aunque queda claro que el uso de estas viviendas se proyecta como segunda residencia y nunca como vivienda social, la distribución en planta de los tipos menores de 39,7 m², 42 m² y 51,6 m² respectivamente, plantea soluciones cercanas a las proporciones de lo social, y más concretamente en la elaboración de un mobiliario adaptado a su reducido tamaño y especial forma en el alzado. Afirmaciones como "todo los elementos complementarios pueden fabricarse en serie" (19), "cuando sea necesario, por medio de camas plegables y bancos-camas, como se detalla en los plano y será objeto de proyecto especial." o "Dos camas abatibles alojadas en nichos de fábrica, y en caso de necesidad el banco-arcón, sirven de dormitorio de hijos." (19), nos hablan de esa necesidad que posteriormente planteará Rafael de La-Hoz en el proyecto de Viviendas Ultrabarratas de Palma del Río (Córdoba, 1953) y que aplicará, al menos en el proyecto, en las viviendas del Grupo Francisco Solano de Montilla tres años más tarde, y que ahora se propone como una opción novedosa (3) (20).

Carlos de Miguel proyectaría algo más tarde un conjunto de viviendas para pescadores en este mismo sentido, pero con unas dimensiones y un sentido aun lejano a la arquitectura mínima pretendida por Rafael de la Hoz a partir de estas formas. En el Perellonet, en Valencia, dejaría un conjunto de 27 viviendas con unas superficies que oscilarían entre los 54 m² y los 42 m² (21). (Figura 13)

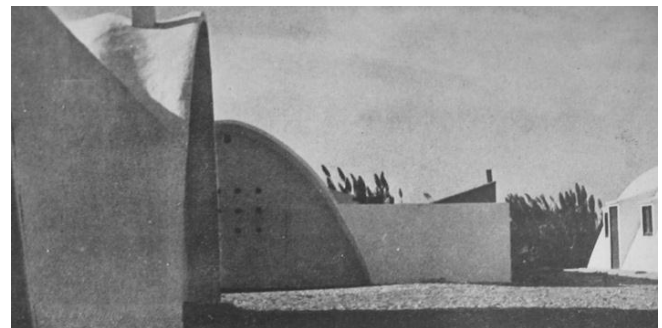


Figure 13. Viviendas de pescadores en el Perellonet, Valencia. Carlos de Miguel (1953).

Pero en 1951, Rafael de La-Hoz y J. M^a. García de Paredes utilizarán esta tipología como paradigma mínimo de vivienda de tipo social al que denominaría vivienda ultrabarrata. El número 135 de la Revista Nacional de Arquitectura, publicado en 1953, dedicaría una especial atención al proyecto en su artículo más extenso (22). El proyecto se debió comenzar en torno a 1951 puesto que en el texto publicado en la Revista Nacional de Arquitectura se hace referencia a que los

⁵ Según Moreno Barberá; "... se tienden sucesivamente tres capas de mortero de cemento de 2 cm. De espesor; a los siete días se retiran las cimbras o plantillas desmontables y se tiene formada la estructura". Moreno, F.: 1951.: "Proyecto de viviendas... op. cit.

arquitectos llevaban año y medio experimentando con estas formas. En el proyecto vemos la aportación más radical que hasta esas fechas se había realizado a la búsqueda y desarrollo de soluciones para solventar el problema de la vivienda. El tiempo se encargaría de no hacerlo tan radical, especialmente a partir del desarrollo de las tipologías de prefabricados en los albergues provisionales que se extienden por nuestras capitales en los primeros años de la década de los 60. (Figura 14)

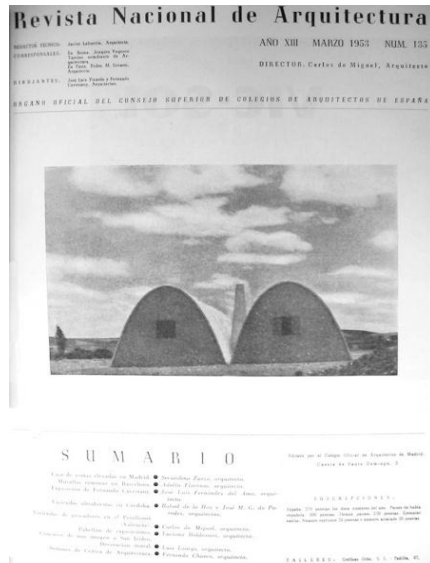


Figure 14. Portada interior nº 135 de la Revista Nacional de Arquitectura (1953).

Rafael de la Hoz tenía 30 años cuando realice el proyecto de Palma del Río. El arquitecto se había titulado en 1950 en la Escuela Superior de Arquitectura de Madrid y de inmediato se trasladó a Córdoba donde su padre, el arquitecto Rafael de la Hoz Saldaña venía desarrollando su carrera profesional.

Será durante estos primeros años de producción donde debemos rastrear el significado de sus proyectos dedicados a la arquitectura social y en especial el que aquí nos interesa. Desde su salida de Madrid y hasta 1956, año en que recibe el Premio Nacional de Arquitectura junto a García de Paredes por la madrileña Residencia Aquinas en la Ciudad Universitaria, se moldea la personalidad como arquitecto y cobra sentido de coherencia el conjunto de su producción.

En las viviendas ultrabaratitas que construye en Palma del Río (Córdoba), la superficie que ocupa cada vivienda se establece en 20 m², número resultante del cálculo de la renta posible que podía pagar cada familia. El sistema lo venía empleando el arquitecto desde el año 1951 aunque el proyecto de Palma del Río se presenta como una definición de la experiencia y de su aplicación a la vivienda de tipo 6. (Figuras 15 y 16)



Figure 15. Viviendas ultrabaratitas en Palma del Río. Rafael de la Hoz (1953).

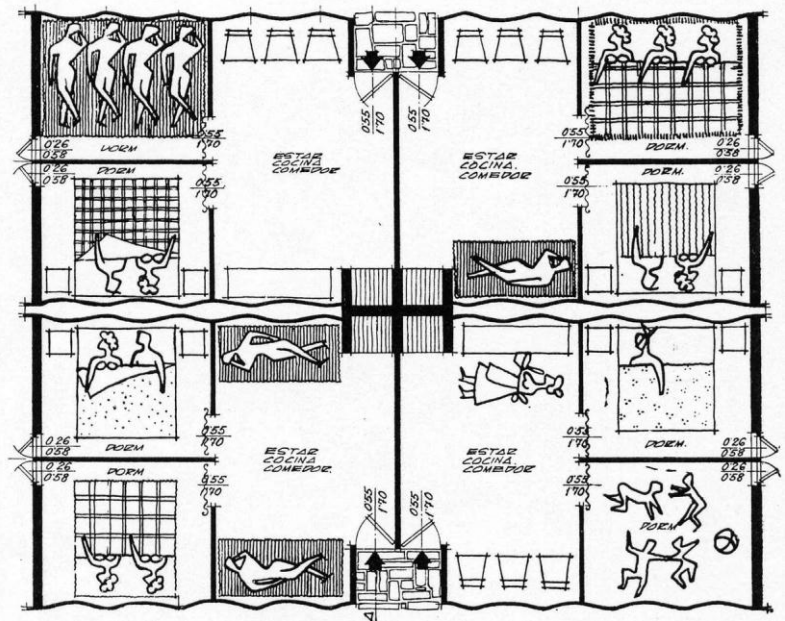


Figure 16. Viviendas ultrabaratitas. Plantas.

Las viviendas se disponen pareadas para formar un conjunto de cuatro con un pequeño espacio compartido que da entrada a cada vivienda. Ésta se compone de un espacio que hace las funciones de estar-cocina-comedor y dos dormitorios. La estancia principal tiene un hogar-chimenea y tan sólo presenta dos pequeños ventanucos en las habitaciones, con lo que la iluminación de la habitación principal se resuelve a través de la puerta de entrada, no quedando resuelto este punto ni el de la ventilación en el interior de la vivienda. El arquitecto se centró a la hora de la

⁶“Así, se ha realizado una sella experimental con sus cuatro viviendas de 3x4x5, cuyo valor, dentro de su extrema modestia, es el de solucionar realmente el problema de la vivienda para quienes sólo disponen de 20 pesetas mensuales para esta necesidad vital, y únicamente con la aportación interesada del capital privada.” De la Hoz, R.; García J. M^a: “Viviendas...”, op. cit.

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La habitabilidad se calcula con un número de seis habitantes por vivienda con lo que resulta un número de 3,2 m² por persona. Las cuestiones más estrictamente técnicas de uso de materiales fueron las siguientes según la expresaron los arquitectos: (Figuras 17, 18 y 19)

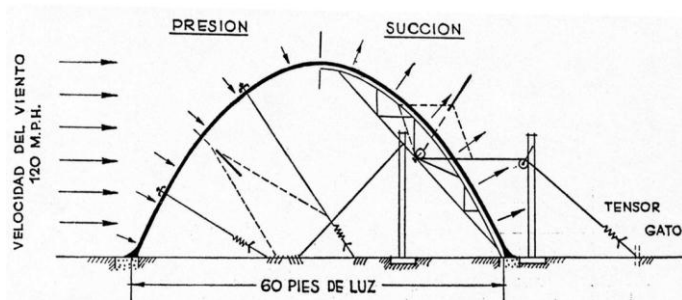


Figure 17. Viviendas ultrabaratas. Rafael de la Hoz. Detalles de la construcción.



Figure 18. Viviendas ultrabaratas. Rafael de la Hoz. Detalles de la construcción.



Figure 19. Viviendas ultrabaratas. Rafael de la Hoz. Detalles de la construcción.

Impermeabilidad. Perfecta, dado que la membrana está comprimida en todos sus puntos; una tela metálica ha absorbido las retracciones de fraguado, y juntas de dilatación impiden tracciones por variación térmica.

Falla en los siguientes casos: Cuando la arena del mortero contiene más de un 3 por 100 de arcilla (la solución es lavarla). Cuando el fraguado del mortero ha sido demasiado rápido (hay que mantenerlo húmedo unos seis días. Cuando no trabajan bien las juntas de dilatación (hoy las empleados, excelentes, del tipo piscina en cinc o plomo). Cuando sobrevienen asentamientos de la cimentación (conviene armarla con 4/8)

Aislamiento térmico. Ningún clima más duro en verano que el de Córdoba, y en esta provincia el de Palma del Río, con 68 grados al sol y 46 a la sombra. Pues bien: el resultado ha sido sorprendente. Es el tipo de construcción conocido más fresco en verano.

Las razones son las siguientes:

1ª. La superficie expuesta al sol es prácticamente la mínima posible.

2ª. El blanco de toda la superficie encalada actúa como aislante por reflexión, análogamente a los aislamientos por lámina de aluminio.

3ª. La gran conductividad térmica del hormigón hace que durante la noche se refrigere por completo, no almacenando calor de un día para los siguientes (la técnica del attic fan americano).

En resumen, equivale a una chaqueta blanca.

Contra el frío. El interior de estas bóvedas las enlucimos con mortero de yeso y paja machacada en un grueso total de 2,5 cm. Esta capa es un freno a las pérdidas de calor interior, que se mantiene regularmente. Sin embargo, dadas las temperaturas relativamente moderadas de nuestro invierno, sin

grandes continuidades en el frío, este aspecto deberá ser estudiado en otras regions españolas.

La única dificultad que el sistema presenta en invierno es que la humedad interior se condensa en las ventanas por las noches.- icómo se empañan los cristales!-, dificultad que se soluciona con el enlucido antes mencionado.

Características técnicas.

Una de las principales ventajas del hormigón es su propiedad de poder ser moldeado. Sin embargo, su utilización más frecuente, hasta la fecha, ha sido en formas semejantes a las adoptadas al utilizar en la construcción los materiales precedentes. El hormigón se diferencia de la madera y del hierro en su falta de capacidad para resistir a la extensión, de donde se deduce que en las estructuras prismáticas reticulares de hormigón armado una gran cantidad del hormigón tenga una función resistente inútil y cumpla solamente a la de cubrición de hierro.

Resulta complejo buscar la razón de ser de este tipo de proyecto en el ámbito de la España que sale del período de autarquía. Ciertamente, la trascendencia como modelo habitacional fue mínima, pero el hecho de que tuviera su presencia en los medios especialistas de divulgación nos hace pensar en una cierta tendencia que, tanto en Rafael de La-Hoz como en otros arquitectos del momento era valorada como una serie de aportaciones técnicas que, desarrollándose fuera de nuestras fronteras podían aplicarse a los problemas específicos de nuestro país. Y el caso es que en el espíritu general del texto notamos lo que posteriormente sería una constante en la postura de Rafael de la Hoz ante el problema de la vivienda. El arquitecto puede construir muy barato, estudiar los materiales más asequibles a la situación de nuestra industria de la construcción y las técnicas más económicas, pero también sabe que en ciertos momentos se está superando con creces el límite de habitabilidad de una forma innecesaria. Unos años después, Rafael de la Hoz se encontraría ante una problemática similar que cambia de escala. Ante la masiva e imperiosa necesidad de construcción de viviendas temporales, el arquitecto optará por soluciones acordes a una industria algo más desarrollada que posibilitaba la construcción en serie de elementos prefabricados, que permitían la construcción de grandes barriadas donde acoger a los desplazados de las zonas rurales. Personas que buscaban empleo y mejores condiciones de vida en las capitales de provincia. Así, entorno a los primeros años de la década de los 60, aparecerán grandes proyectos de urgencia social elaborados a partir de elementos prefabricados. En el caso de

Rafael de la Hoz, en Córdoba en 1963, llevó a cabo la construcción de 3.592 albergues provisionales en lo que fue, según la prensa local cordobesa, el mayor conjunto de viviendas prefabricadas que se había hecho hasta el momento en España. El proyecto se realiza a través del Ministerio de la Vivienda en colaboración con la Obra Sindical del Hogar, en colaboración con el arquitecto Gerardo Olivares en lo que formaba en esos momentos una de las parejas profesionales más brillantes y fructíferas.

Y aunque lo hemos citado anteriormente, no podemos olvidar que otro arquitecto español en esas mismas fechas estaba trabajando de una manera insistente en estas mismas formas. Félix Candela hizo de estos "cascarones" uno de los símbolos de crecimiento de su propia identidad como arquitecto, y aunque tuvo que llevar a cabo su carrera en México por la suerte del exilio, es cuando menos curioso observar cómo en estas mismas fechas está muy cercano a las estructuras Ctesiphontes aquí desarrolladas.

Quizás la obra que se encuentre más sorprendentemente ligada a las propuestas españolas sea el conocido Laboratorio de Rayos Cósmicos, realizado en México D.F. en 1952, donde junto al arquitecto Jorge González Reyna lleva a cabo una obra que en esta ocasión presenta una estructura autoportante de arcos hiperbólicos paraboloides, pero construida siguiendo un sistema muy similar al visto hasta ahora y en la misma línea de las propuestas vistas anteriormente (23, 24). Es su aportación más conocida desde la estructura autoportante, pero no la primera. En 1950 había construido en la Escuela Experimental en Ciudad Victoria (Tamauripas, Méjico) una nave Ctesiphonte de 6 metros de altura. Candela se refiere de esta manera a dicha obra: "Lo primero que hicimos fue una obrita muy chiquita, como de 6 m., que está hecha sin armadura, sin hierro y sin cimbra, de encofrado. Entre medias se pone tela de saco y



Figure 20. Félix Candela. Escuela Experimental en Ciudad Victoria, Tamauripas. Méjico, (1950).

después, si se puede, que está medio difícil, se va aplicando el mortero de cemento, que es difícil que no se caiga; pero al final los albañiles mejicanos son muy habilidosos y consiguieron que no se cayera. Luego quitamos las cimbras y ahí se quedó.” (10). (Figura 20)

La catenaria invertida se convirtió a partir de estas fechas en una solución aunque no de una forma mayoritaria, si que fue salpicando buena parte del territorio español para solucionar especialmente estructuras de uso agropecuario y de almacenaje.

En este sentido, cabría destacar la especial trascendencia de este concepto en los conjuntos residenciales que se llevan a cabo en Ifni y el Sahara españoles en los últimos años de control del territorio. En las ciudades de Sidi Ifni, El Aaiún o en Villa Cisneros aparecen viviendas y almacenes contruidos con la estructura de una forma ciertamente naturalizada. El especial tratamiento de las construcciones en estas poblaciones se debe a un alto nivel de experimentación al amparo de las especiales condiciones que allí se dieron: climáticas, residenciales, tanto para nativos como para colonizadores, y también por lo alejado del territorio peninsular. Todo esto posibilitó la aparición de estructuras novedosas, de extrañas conjunciones donde la modernidad, un cierto orientalismo y lo imperioso de la función-símbolo condicionaron algunas obras ciertamente destacables en el ámbito de la arquitectura y del urbanismo (25). (Figuras 21 y 22)



Figure 21. Viviendas Ctesiphonte. Calle del ejército, El Aaiun. Sahara Occidental.

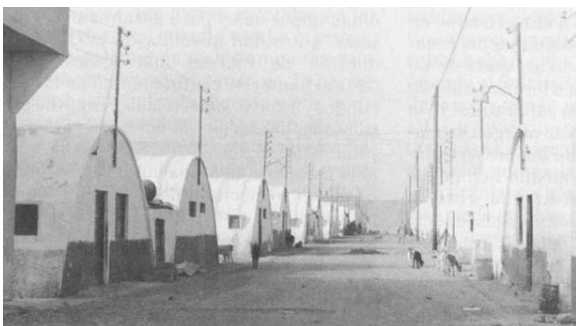


Figure 21. Interior de barracones militares en Villa Cisneros. Sahara. Occidental

Fueron utilizadas con más frecuencia en las zonas eparadas de acuartelamiento, para viviendas o comedores de los soldados de la tropa, pero también se construyeron angares de grandes dimensiones en los aeródromos militares. Pasando de servir como edificios secundarios, a describir formas simbólicas, como en el Cuartel General de El Aaiún, donde la entrada queda estructurada mediante un amplio arco de catenaria. En ocasiones se plantean dentro de la planificación urbana llevada a cabo ya en la década de los 60, y otras veces aparece como edificio marginal, en un contexto temporal muy diferente al desarrollo anterior. Son numerosos los conjuntos de viviendas encadenadas que se construyen a partir de la estructura Ctesiphonte en Ifni y en todo el Sahara español, formas que en estas latitudes se visibilizan con mayor naturalidad que en la península pues se acomodan al normal desarrollo de una arquitectura vernácula donde las cubriciones suelen resolverse medianate cúpulas visibles desde la calle. Podemos afirmar que será aquí, en la región del Sahara Occidental, donde la catenaria invertida tendrá una trascendencia más que notable, siendo una forma que se adaptará a la tradición vernácula, al afán experimental de los arquitectos españoles que trabajaban en la zona, y a las especiales condiciones económicas, constructivas y sociales.

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Factors Influencing the Implementation of Public Infrastructure in Nigeria

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Abstract - Nigerian infrastructure development depends substantially on public financing. However, projects budgeted for execution in most cases seems to be not fully implemented with the result that the projects are either partially implemented or abandoned. This situation has become worrisome in therecent time especially when private sector participation in the provision of infrastructure is only slowly forthcoming. This study assessed the implementation ofeducation, rural/urban electrification, health, transportation, water, and housing infrastructure projects budgeted for execution during the period of 1999-2008 in Osun State, South-western, Nigeria and the factors that impacted the level of implementation. Data for the study were collected through structured questionnaire administered on 74 construction professionals and 32 financial administrators in the public service of the State. In addition, field survey of 72 infrastructural projects budgeted for execution for 1999-2008 fiscal years was carried out. Data analyzed was done using percentage, mean score and relative significance index. Factors identified as critical to implementation of public financed infrastructure are those of slow disbursement of funds after budget approval, political will and commitment of government to execute projects, time of passage of budget, connectivity between budget size and proposed infrastructure projectsand level of involvement of the construction professionals in the budget preparation process

GJRE-E Classification : FOR Code : 090505, 090599



FACTORS INFLUENCING THE IMPLEMENTATION OF PUBLIC INFRASTRUCTURE IN NIGERIA

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Factors Influencing the Implementation of Public Infrastructure in Nigeria

Opawole, A.^α, Jagboro, G.O.^Ω, Babatunde, S.O.^β

Abstract - Nigerian infrastructure development depends substantially on public financing. However, projects budgeted for execution in most cases seems to be not fully implemented with the result that the projects are either partially implemented or abandoned. This situation has become worrisome in the recent time especially when private sector participation in the provision of infrastructure is only slowly forthcoming. This study assessed the implementation of education, rural/urban electrification, health, transportation, water, and housing infrastructure projects budgeted for execution during the period of 1999-2008 in Osun State, South-western, Nigeria and the factors that impacted the level of implementation. Data for the study were collected through structured questionnaire administered on 74 construction professionals and 32 financial administrators in the public service of the State. In addition, field survey of 72 infrastructural projects budgeted for execution for 1999-2008 fiscal years was carried out. Data analyzed was done using percentage, mean score and relative significance index. Factors identified as critical to implementation of public financed infrastructure are those of slow disbursement of funds after budget approval, political will and commitment of government to execute projects, time of passage of budget, connectivity between budget size and proposed infrastructure projects and level of involvement of the construction professionals in the budget preparation process

I. INTRODUCTION

Infrastructures projects are essential to economic growth and standard of living in a nation. These projects include housing, and others structures that provide shelter, transportation facilities, public services and utilities power plant, water resources, waste removal, minimization and control and environmental restoration (Oyegoke, 2005). Elementarily, infrastructure provides a number of basic needs. These include water for drinking; power for heating and lighting; telephone to interact with others who are at a distance; and transportation infrastructure which allows mobility. Infrastructure is crucial to every sector of a nation's macro-economy. For example, housing is crucial to public health (Ajanlekoko, 2001); transportation infrastructure enhances rural-urban integration and foreign trade (Zhou et al., 2007); electricity infrastructure provides base for commercial activities and

technological advancement (Adewoye, 2007; Sambo, 2008; and Subair and Oke, 2008); and education infrastructure is crucial to human capacity development, improved health, productivity and access to paid employment (Familoni, 2006).

Infrastructure procurement is basically through three financing options (Oyegoke, 2005; Ashworth and Hogg, 2007). These are public financing, private finance initiative (PFI), and public private partnership (PPP) initiatives. However, the level of private sector participation in infrastructure development is identified to be significantly low in Nigeria with progressive participation only in education and communication infrastructure (Ayodele, 2006; and Ilori, 2006). The Private-Public Partnership (PPP), likewise, is only in the recent gaining popularity in Nigeria (Tsema, 2008). Thus, the financing of infrastructure, like in most developing countries, is traditionally public task through public budgetary allocation in Nigeria. This situation makes public policy makers and the construction industry the major actors in infrastructure development in Nigeria.

It has, however, being worrisome over years in Nigeria that public infrastructure are poorly implemented. For example, between 1999-2007, Nigeria invested about one trillion naira on road construction while 65% of the roads still remain death traps. According to Olufidipe (2003), projects implementation in Nigeria has always being low, exemplified by huge budget deficits and poor physical performance. Significant number of projects contained in the annual budgets of governments at all levels in Nigeria are either partly implemented or not implemented at all in the fiscal year, thus resulting in wide divergence and persistent disparity between the actual and projected budget figure. This situation provides the basis for this study.

II. PREVIOUS STUDIES ON IMPLEMENTATION OF PUBLIC INFRASTRUCTURE IN NIGERIA

Literature abounds on micro-study of projects implementation in construction economics and management. However, limited studies on macro-study of infrastructure development, especially in the context of Nigeria, have correlated budgetary financing to level of execution of infrastructural projects.

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For example, Oforeh (2006) studied the role of the Nigerian Institute of Quantity Surveyors as an agent of economic development. The study asserted poor level profile of infrastructure projects implementation in Nigeria as resulting from low level input of construction professionals in infrastructure policy formulation at the macro-economic level. Mogbo (2001) and Frank (2003) identified infrastructure projects as projects of high capital outlay. Furthermore, Frank (2003) identified the major causes of poor performance of infrastructure in urban centers in Nigeria as factors relating to high cost of infrastructure provision, failure of government to adopt liberalization policies in dealing with urban infrastructure matters, and inadequate budgeting by the public sector. Similarly, Wahab (2000) and Babalola et al., (2010) asserted factors that are influential to poor implementation of infrastructure projects in Nigeria as inadequate investments, low capacity building, corruption and lack of political will by the government.

On the other hand, Mogbo (2001) posited that the low level implementation of infrastructure development in Nigeria could be correlated to level of contribution of the construction professionals in the budgeting process. Ogunsemi and Saka (2006) article on the New Partnership for Africa's Development (NEPAD) initiative and the challenge of efficient cost management of infrastructure development in Nigeria which was directed to ensuring efficient management of infrastructure projects through adequate professional of experts especially those of quantity surveyors and engineers inferred that poor level implementation of infrastructure projects in Nigeria is attributable to deficient cost management practice of projects and inadequate inputs of professionals as significant to poor implementation of infrastructure projects in Nigeria.

Challenges and problems of rural infrastructure development in Nigeria attracted the attention of Olayiwola and Adeleye (2005). The study, however, only highlighted the concept of rural infrastructural planning and examined the Nigerian rural infrastructural policies over the years 1960-1990. The major problems and challenges posed by the various rural infrastructural development identified include lack of spatial focus in rural development planning; lack of perceptual focus in the development plans; restriction of means of rural infrastructural provision to public funding; and lack of action and appropriate institutional arrangements for the execution of rural infrastructural programmes. All these studies, however, compromised in their efforts to make specific evaluation of factors that are significant to implementation of infrastructure projects in Nigeria and thus make this study imperative.

III. METHODOLOGY

The study area is Osun State in the southwestern Nigeria. The choice of Osun State is based on the fact that infrastructure development in the state depends majorly on public budgetary allocation (Opawole *et al.*, 2011). Respondents involved in the study were architects, quantity surveyors, builders, town planners, estate surveyors, engineers (civil, mechanical and electrical), accountants and economists in the public service of Osun State. A total of seventy-two (72) properly completed questionnaire by 6 architects, 4 quantity surveyor, 6 town planner, 5 estate surveyors, 4 builders, 21 engineers (mechanical, civil, and electrical) and 26 economists/accountants representing a response rate of 70% of total 104 copies of questionnaire administered, completed and returned for the analysis provided quantitative data for the study. The distribution of the respondents is shown in table 1. The questionnaire was of two parts. The first part identified the demographic features of the respondents; and the second part relates to the specific objectives of the study. The field survey covered 72 transportation, 4 water resources, 9 rural/urban electrification, 30 education, 4 housing, and 9 health care infrastructural projects. These were selected on the basis of adequate definition in term of either location or cost or both in the ten editions of Osun State budget between 1999-2008 from six (6) purposively selected local governments in the three (3) senatorial zones of the State. These comprised Oshogbo and Olorunda (Osun Central); Egbedore and Ede South (Osun West); and Ife Central and Ilesha West (Osun East) local governments.

IV. DATA ANALYSIS

The statistical tools used for data analysis were percentage and relative significance index (RSI). The formula for the relative significance index (RSI) is given as:

$$RSI = \frac{\sum_{i=1}^{n=5} n1k1}{\sum NXRh} \text{ i.e. } \frac{5n5+4n4+3n3+2n2+1n1}{\sum NXRh},$$

Where:

$\sum N$ is the total of questionnaire collected, and Rh is the highest value in ranking order.

V. DATA ANALYSIS

Table 1: Characteristics of Respondents

Respondents	Number administered	Frequency (F)	Percentage of Respondent (%)
Type			
Architects	8	6	8.3
Town Planners	7	6	8.3
Builders	8	4	5.6
Quantity Surveyors	4	4	5.6
Engineers	40	21	29.2
Estate Surveyors	7	5	6.9
Accountants/ Economist	32	26	36.1
Total	106	72	100.0
Academic Qualification			
Ph.D		1	1.4
M.Sc/M.Tech		19	26.4
B.Sc/B.Tech.		32	44.4
PGD (Post Graduate Diploma)		13	18.1
HND (Higher National Diploma)		7	9.7
Total		72	100
Working Experience			
	Midpoint (X)		FX
0-5	2.5	7	17.5
5-10	7.5	10	75.0
1-15	13.0	4	52.0
16-20	18.0	13	234.0
20- 25	22.5	27	607.5
Above 26	26.0	11	286
Total		72	1272
Professional Qualification			%
Nigerian Institute of Architects (NIA)		4	5.6
Nigerian Institute of Town Planners (TPL)		5	6.9
Nigerian Institute of Building (NIOB)		4	5.6
Nigerian Institute of Quantity Surveyors (NIQS)		4	5.6
Nigerian Society of Engineers (NSE)		19	26.4
Nigerian Institute of Estate Valuers and Surveyors (NIEVS)		5	6.9
Institute of Chartered Accountant (ICAN)/Association of National Accountants of Nigeria (ANAN)		25	34.7
Others		1	1.4
Non Professionally Qualified (NPQ)		5	6.9
Total		72	100

The percentage representation of the respondents are 8.3% for architects, 8.3% for town planners, 5.6% for builders, 5.6% for quantity surveyors, 29.2% for engineers, 6.9% for estate surveyors and 36.1% for economists/accountants. The mean work experience of respondents is estimated at 14 years, which represents the working experience of about 52% of the respondents. This shows that the respondents are at the middle of their carrier, and possess the experience to give reliable information. The minimum academic qualification of the respondents is Higher National

Diploma (HND) and this represents only 9.7% of the respondents. The result shows that all the respondents possess the minimum registration qualification of their various professional bodies in Nigeria and are of adequate academic training to supply reliable data for this study. Also, 67 respondents representing 93.1% of the total respondents are either associate or corporate members of their various professional bodies. This shows that the respondents possess adequate qualification and experience to supply reliable data for this study.

Table 2: Budgetary Allocation for Infrastructural Projects in Osun State (N, Millions)

Year	Total Budget	Capital Project	Budget Allocation to Infrastructure	Budget Allocation as % of Capital Budget (%)	Budget Allocation as % of Total Budget (%)
1999	4,790.00	1,530.00	850.40	55.58	17.75
2000	11,820.00	6,700.00	5,106.21	76.21	43.21
2001	20,480.00	12,040.00	8,100.75	67.22	39.57
2002	18,870.00	10,710.00	7,292.50	68.09	38.65
2003	14,530.00	4,830.00	2,976.57	61.69	20.48
2004	18,910.00	6,910.00	4,136.72	59.84	21.86
2005	25,220.00	11,630.00	7,085.00	61.00	28.09
2006	29,050.00	13,500.00	7,982.72	58.52	27.48
2007	34,770.00	17,790.00	11,491.68	64.51	33.05
2008	38,010.00	16,310.00	9,719.53	59.59	25.57
Mean	21,645.00	10,195.00	6474.21	63.23	29.57

Source: Osun State Budget (1999-2008)

N152 = 1\$

Table 3: Sectoral Budgetary Allocation for Infrastructure Projects in Osun State (N, Millions)

Year	Education	Rural/Urban Electrification	Transportation	Water	Health	Housing
1999	204.90	30.00	405.00	120.00	56.50	34.00
2000	422.70	60.00	1,060.00	3,260	250.02	53.49
2001	436.00	40.00	3,500	3,600	443.50	81.25
2002	1,260	185.00	2,430	2,230	1,200	187.50
2003	966.68	41.80	609.00	525.20	743.89	90.00
2004	1,300	188.00	724.00	972.50	796.50	155.72
2005	1,310	57.00	3,930	675.00	1,040	73.00
2006	1,920	179.00	4,170	506.70	1,120	87.02
2007	5,080	370.00	3,960	634.08	1,120	327.60
2008	3,560	516.40	3,800	593.94	993.00	256.19
Mean	1646.03	166.72	2458.80	1311.74	756.34	134.58

Source: Osun State Budget (1999-2008)

Table 4: Budgetary Allocation as Percentage of Capital Budget and Total Budget

Year	Education		Rural/Urban Electrification		Health		Transportation		Water		Housing	
	x (%)	y (%)	x (%)	y (%)	x (%)	y (%)	x (%)	y (%)	x (%)	y (%)	x (%)	y (%)
1999	13.38	4.28	1.96	0.63	3.69	1.18	26.44	8.46	7.83	2.51	2.22	0.71
2000	6.31	3.58	0.90	0.51	3.74	2.12	15.84	8.97	48.64	27.58	0.80	0.45
2001	3.62	2.13	0.33	0.20	3.68	2.17	29.02	17.09	29.89	17.58	0.68	0.400
2002	11.76	6.68	1.73	0.98	9.34	5.30	22.72	12.88	20.85	11.82	1.75	0.99
2003	20.03	6.65	0.87	0.29	15.42	5.12	12.62	4.19	10.88	3.61	1.87	0.62
2004	18.77	6.87	2.72	0.99	11.53	4.21	10.48	3.83	14.09	5.14	2.25	0.82
2005	11.30	5.19	0.49	0.22	8.97	4.12	33.81	15.58	5.80	2.68	0.63	0.29
2006	14.26	6.61	1.33	0.62	8.32	3.86	30.86	14.35	3.75	1.74	0.64	0.30
2007	28.53	14.61	2.08	1.06	6.27	3.22	22.23	11.39	3.56	1.82	1.84	0.94
2008	21.82	9.37	3.17	1.36	6.09	2.61	23.30	10.00	3.64	1.56	1.57	0.67
Mean	14.98	6.60	1.56	0.69	7.71	3.39	22.73	10.67	14.89	7.60	1.43	0.62

Source: Author's Calculation (2011)

x = % of Capital Budget; y = % of Total Budget.

Table 2 shows the trend of budgetary allocations for infrastructure development between 1999-2008 in Osun State while table 3 shows the sectoral budget allocations for education, rural/urban electrification, health, transportation, water, and housing. The mean budget allocation for infrastructure is established as N10, 195.0m which represents 63.2% of the mean capital budget and 47.1% of the mean total budget. The detail of the trend of budget allocation is illustrated in figures 1. Table 4 shows the mean budget allocation expressed as percentage of capital budget and total budget. The mean budget allocation expressed as percentage of capital budget for education, rural/urban electrification, health, transportation, water, and housing were established as 14.98%, 1.56%, 7.71%, 22.73%, 14.89%, and 1.43% respectively.

On the other hand, the mean budget allocations for education, rural/urban electrification, health, transportation, water, and housing expressed as percentage of total budget allocation were established as 6.60%, 0.69%, 3.39%, 3.39%, 10.67%, 7.60%, and 0.62% respectively. This is comparatively low, for example while comparing the budgetary allocations to education with UNESCO standard of 26% as against 14.98% obtained in this study. The results, however, almost agree with the findings of Oforeh (2006) and Ayodele (2008), who identified capital expenditure as staggering between 65-70% in the annual budgets of the three tiers of government in Nigeria, with allocation to infrastructure as often responsible for about 50% of the capital expenditure.

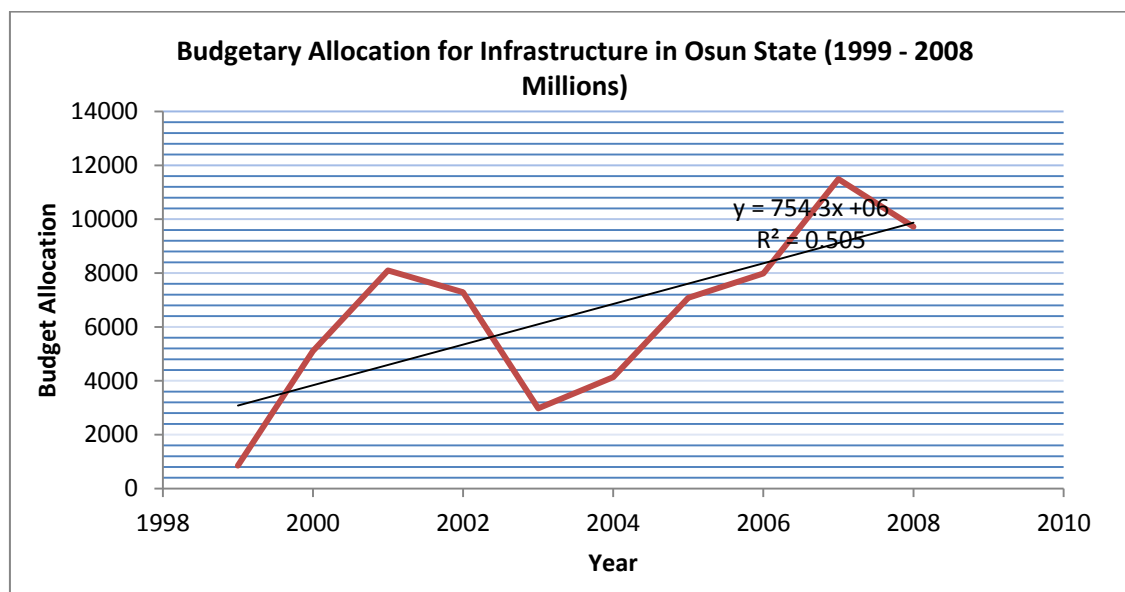


Figure 1: Trend of Budgetary Allocation for Infrastructure Projects in Osun State

The trend of budget allocations for infrastructure between the years 1999-2008 is as shown in figure 1. Going by the profile of the graph of allocation versus year, there was an upward increase from N850.4m in 1999 up to N8,100.21m in 2001 and a gradual declining pattern from N8,100.21m in 2001 to N2,976.57m in 2003. This downward trend was, however, reversed in 2003 and steadily climbed to N11,491.68m in 2008. The distortion of steady increase from 1999 to 2008 could be attributed to the fluctuation of the revenue in the same period in Osun State as exemplified by the decline of price of crude oil (Odularu, 2008). Another factor that could be responsible for this volatility is the fact that the political situation was still very much unstable transiting from military rule to civilian democracy. It would be noted that the 'due process' application to procurement of public was also heightened in this period. While these could be considered significant factors, other factors including need for better institutional framework, population growth and sustained commitment of the state government to improve the state infrastructure base could have been responsible for the trend.

While the best fit line revealed an average consistent trend defined by the value of R^2 ($R^2 = 0.505$),

it should be note that the value of R^2 (0.505) does not suggest or in any way indicate the adequacy of funding of infrastructure during this period. These results, however, presume commensurable projects implementation and better infrastructure development in the State during this period.

Table 5 shows the quantitative assessment of the level of implementation of housing, education, rural/urban electrification, health and transportation infrastructure projects financed by the budgetary allocations defined in tables 2-4. The assessment was based on the scale of 0-100% where 0 represents lowest ranking and 100 representing highest ranking. The table shows the highest mean implementation of 54.51% which indicate average implementation for health infrastructural projects. This is followed by education infrastructure with mean implementation of 53.69%. Housing, transportation; rural/urban electrification; and water infrastructure projects were rated as implemented at 36.69%, 45.33%, 46.44% and 49.36% respectively which are below average. These percentage implementations were compared with the result obtained from the physical survey of the projects..

Table 5: Implementation of Infrastructure Projects in Osun State

Infrastructure	Percentage Implementation (%)										TWV	Mean
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		
Rural/Urban Electrification	4	5	4	10	14	15	5	9	5	1	3554.00	49.36
Transportation	4	4	10	9	18	10	9	4	4	0	3264.00	45.33
Education	1	4	3	8	11	18	15	9	1	2	3865.50	53.69
Health	2	1	4	9	15	15	7	14	3	2	3925.00	54.51
Water	4	2	4	15	22	10	6	7	1	1	3344.00	46.44
Housing	9	10	12	5	18	10	3	4	1	0	2641.50	36.69

Thus, the level of execution of health, education, housing, transportation, rural/urban electrification and water infrastructure projects were established as 54.51%, 53.69%, 36.69%, 45.33%, 46.44% and 49.36% respectively. These results indicate that if this trend of levels of implementation continues, the state would

continue to witness declined trend of infrastructure development, the adverse effect of which may include reduced quality of education, poor health delivery and high risk of water related diseases among others. This will significantly reduce the standard of living and the economic development in the state

Table 6: Field Survey of Selected Infrastructure Projects Budgeted for Execution (1999-2008)

Projects	Total Number	Completed		Not constructed/Suspended/ Abandoned		Under construction	
		Number	%	Number	%	Number	%
Transportation	17	5	29.41	10	58.82	2	11.76
Rural/Urban Electrification	8	5	62.50	3	37.50	0	0.00
Health	9	3	33.33	5	55.56	1	11.11
Housing	4	0	0.00	4	100.00	0	0.00
Water	4	2	50.00	1	25.00	1	25.00
Educational	30	17	56.67	10	33.33	3	10.00

The filed survey in table 6 covered 72 infrastructure projects (transportation, rural/urban electrification, water, health, housing and educational projects). In the case of transportation projects, 58.82% out of seventeen (17) road projects surveyed were not completed or abandoned or suspended; 29.41% were completed and 11.76% were still under construction. In the case of

rural/urban electrification projects, 62.50% of the total eight (8) projects were completed while 37.50% were not constructed or suspended or abandoned and none were under construction. Only 33.33% out of nine (9) health infrastructure projects were completed; 55.56% were not constructed or suspended or abandoned and 11.11% were still under construction.

Table 7: Factors Influencing the Implementation of Infrastructural Projects in Nigeria

Factors	Construction Professionals	Financial Administrators	Overall	Ranking	Effect Level
	RSI	RSI	RSI	R	
Adequacy of budgetary allocation for infrastructure projects	3.70	3.19	0.70	7	S
Connectivity between budget size and proposed infrastructure projects	3.76	3.23	0.73	6	S
Level of pre-budgetary technical evaluation of infrastructure projects	3.35	3.42	0.68	14	S
Level of pre-budgetary cost assessment of infrastructure projects	3.52	3.23	0.68	11	S
Level of involvement of the construction professionals in the budget preparation process for infrastructure projects	3.78	3.38	0.73	5	S
Time of passage of budget	3.78	3.62	0.74	4	MS
Disbursement of funds from the federal government to the state after budget approval	3.96	4.12	0.82	1	MS
Disbursement of funds from the state government to the project implementation ministry/agencies/departments	3.76	3.81	0.77	3	MS
Political will and commitment of government to execute projects budgeted for	4.24	3.23	0.80	2	S
Corruption in contract award procedure of infrastructure projects	3.41	3.15	0.68	13	S

Level of follow up by spending ministry/agencies/departments on infrastructure contracts they have awarded	3.63	3.08	0.69	8	S
Level of controls at each stage of the expenditure cycle	3.50	3.12	0.68	12	S
Extent of physical performance report on projects	3.57	3.08	0.69	9	S
Corruption in the infrastructure projects procurement process	3.57	3.04	0.69	9	S
Level of post-budgetary project monitoring and cost control	3.43	3.12	0.67	15	S
Existence of system for managing multi-year contracts	3.13	2.65	0.61	16	S

Significance Scale: VS = Very Significant (5), MS = More Significant (4), S = Significant (3), LS = Less Significant (2), NS = Not Significant (1).

All (4 housing estates) the projects in housing infrastructure projects were not completed, suspended or abandoned. In the case of water projects, 50.00% out of four (4) projects surveyed were completed while 25.00% were still under construction and 25.00% also were not completed or suspended or abandoned. Out of thirty (30) educational infrastructure projects surveyed, 56.67% were completed, 33.33% were not completed or suspended or abandoned and 10.00% were under construction at the time of the field survey.

The results reveal the highest level of execution in rural/urban electrification projects and educational infrastructural projects relative to transportation and housing, and health projects. This, however, does not indicate a very good execution of rural/urban electrification projects and educational infrastructural projects. Followed closely is water project. It could be noted that substantial numbers of these projects were either not commenced in the budget year or are unreasonably extended to some years after. This is particular with transportation infrastructure. The least level of execution was observed in housing infrastructure with relatively poor level of execution. While the results obtainable in the field survey compared favourably with those obtained in the questionnaire survey on the implementation of the projects, the results obtained in rural/urban electrification could be adjudged better and there seems to be a little interpolation in the case of rural/urban electrification and health infrastructure in the result obtained in the field survey and the questionnaire survey on the implementation.

An important scenario that was noted in the budgetary allocations is an inconsistent pattern of the allocations. This is worst in the case of transportation infrastructure. For example, one among the road rehabilitation that was surveyed (Osogbo-Iwo Road projects) received budgetary allocations in the trend of 150m, 210m, 50m, 200m, 22m, 45m, 70m over 2000, 2002, 2003, 2005, 2006, 2007, 2008 budget years.

Adjudging by the inflationary trend in Nigeria, the allocations would be expected to increase from 2000 to 2008 if the allocations were based on procedural approach. The inconsistent pattern could be traced to inadequate technical evaluation of the project during budgeting presumably as a result of low contribution of the construction professional as indicated by Oforeh (2006). This result indicates that budgetary allocations to infrastructure projects in the State are arbitrarily based on non-procedural approach.

The results of the field survey on the overall indicate low level execution of the five categories of projects. This could be attributed to the factors which among others include poor connectivity between the projects and the budget size; adequacy of the budget allocation; fund disbursement chain and lack of political will by the government to execute the projects. It would be noted that despite the fact that the rehabilitation of Osogbo-Iwo road projects has received budgetary attention for the seven year, the road is still yet to be constructed as at the time of the field survey.

Table 7 shows the factors that influence the implementation of infrastructural projects in Nigeria. Disbursement of funds from the federal government to the state after budget approval ranks highest with RSI of 4.08 which indicate significant factor on the scale of significance of the factors. The table reveals the mean of the range 3.03–4.08 which indicate either 'significant' or 'more significant' on the scale of significance of the factors, thus indicating the significance of all the identified factors to implementation of infrastructural projects in Nigeria. Disbursement of funds from the federal government to the state after budget approval is followed by political will and commitment of government to execute projects budgeted for with RSI of 4.01. Disbursement of funds from the State government to the project implementation ministry/agencies/departments was ranked third with RSI of 3.85. Next to these are time of passage of budget; and level of involvement of the

construction professionals in the budget preparation process, and connectivity between budget size and proposed infrastructure projects; and adequacy of budgetary allocation for infrastructure projects with RSI of 3.72, 3.64, 3.63, and 3.51 respectively. The least significant factors are existence of system for managing multi-year contracts; level of post-budgetary project monitoring and cost control and level of pre-budgetary technical evaluation of infrastructure projects with respective RSI of 3.03, 3.36, and 3.38.

These results show the factors that are significant to implementation of infrastructure projects are more of funds related, that is, connectivity between budget size and proposed infrastructure projects and level of involvement of the construction professionals in the budget preparation process, and political will and commitment of government to execute projects budgeted for. The results reveals that absence of system for managing multi-year contracts, though, a significant factor does not have the magnitude of affecting the level of implementation of projects. The least ranking of the level of post-budgetary project monitoring and cost control; and level of pre-budgetary technical evaluation of infrastructure projects as factors that are significant to implementation of infrastructure projects presumes that adequate contribution of the construction professionals in infrastructure procurement process are involved at post-budgetary process and pre-budgetary technical evaluation process.

Contrary, however, to the findings of Wahab (2000) and Babalola *et al* (2010) that corruption in the infrastructure projects procurement is the most significant factors affecting infrastructural development in Nigeria, corruption in the infrastructure projects procurement process, though was ranked a significant factor, received the ninth rank with RSI of 3.44. Reason for this may include the introduction of due process application in public procurement process in this period based on recommendation of findings of Wahab (2000), and the establishment of Anti-Corruption Agencies, that is, Independent Corrupt Practices and other Offences Commission (ICPC), and Economic and Financial Crime Commission (EFCC) by the Federal government of Nigeria during this period.

VI. CONCLUSIONS

The study reveals the mean budget allocations expressed as percentage of capital budget for education, rural/urban electrification, health, transportation, water, and housing in Nigeria as 14.98%, 1.56%, 7.71%, 22.73%, 14.89%, and 1.43% respectively. On the other hand, the mean budget allocations for education, rural/urban electrification, health, transportation, water, and housing expressed as percentage of total budget allocation were established as 6.60%, 0.69%, 3.39%, 3.39%, 10.67%, 7.60%, and

0.62% respectively. Also the study reveals the level of implementation of health, education, housing, transportation, rural/urban electrification and water infrastructure projects as 54.51%, 53.69%, 36.69%, 45.33%, 46.44% and 49.36% respectively. The factors identified as critical to implementation of these projects are slow disbursement of funds after budget approval, political will and commitment of government to execute projects, time of passage of budget, connectivity between budget size and proposed infrastructure projects and level of involvement of the construction professionals in the budget preparation process. Findings from the study suggests that if the present trends of levels of implementation continue, the State would continue to witness declined trend of infrastructure development, the adverse effect of which may include reduced quality of education, poor health delivery, poor rural urban integration and high risk of water related diseases among others. This will significantly reduce the standard of living and the economic development in the state.

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Conceptual Framework for Road Pavement Monitoring and Evaluation

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Abstract - For the effective maintenance of roads, appropriate procedures for pavement monitoring and evaluation are required. Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to criteria that define the pavement condition based on which the pavement “health” is perceived, helping decide whether there is the need or not to intervene in the pavement. The present paper presents a conceptual framework for the development of a procedure for Pavement Monitoring and Evaluation (PAME) that is outlined by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis in order to determine the optimum section strategies and priority interventions.

Keywords : *pavement, non destructive, monitoring, evaluation, criteria.*

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Conceptual Framework for Road Pavement Monitoring and Evaluation

Christina Plati^α, Panos Georgiou^Ω, Aggeliki Armeni^β

Abstract- For the effective maintenance of roads, appropriate procedures for pavement monitoring and evaluation are required. Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to criteria that define the pavement condition based on which the pavement "health" is perceived, helping decide whether there is the need or not to intervene in the pavement. The present paper presents a conceptual framework for the development of a procedure for Pavement Monitoring and Evaluation (PAME) that is outlined by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis in order to determine the optimum section strategies and priority interventions.

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I. INTRODUCTION

In road maintenance activities, the selection and prioritization of appropriate remedial treatments facilitates the development of a projected rolling works program over a given timeframe. Methodologies used are mainly based on engineering-driven criteria based upon road condition data available at the time of the assessment. They include pavement condition assessment, performance prediction and needs analysis, which are three sequential yet interconnected processes (Shekharan et al., 2010). These processes aim to assess the appropriate maintenance and rehabilitation strategies on the basis of given budget constraints, identifying life-cycle cost alternatives and determining the optimum scheduling for pavement maintenance and rehabilitation interventions in terms of pavement preservation. Preserving pavements in an appropriate manner, extends their service life, and most importantly improves users' safety and saves

public resources (FHWA, 2003; FHWA, 2006). and evaluation, which are important in many areas of pavement engineering, especially in the case of Long Life Pavements (LLP) (Loizos, 2006). Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to trigger values (criteria) that define the pavement condition, based on which the pavement "health" is perceived, helping decide whether there is the need or not for pavement intervention. This definition appoints required management activities for preserving pavements in favor not only of the involved highway/road agencies but also users' satisfaction.

In order to support effectively the implementation of pavement management activities, often there is the need to apply a framework for pavement monitoring and evaluation that agencies can adapt depending on the situation. For this purpose the present research concerns a conceptual framework for the development of a practical procedure for Pavement Monitoring and Evaluation (PAME) that can be described by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis along an approximately 80 km highway using individual data i.e. traffic (ESALs), layers thickness, deflections and roughness in order to determine the optimum section strategies and priority interventions. Thickness data is determined using the Ground Penetrating Radar (GPR) technique (Al-Qadi et al., 2005), deflections are recorded using Falling Weight Deflectometer (FWD) testing (Aalavi et al., 2008) and roughness data collection is accomplished utilizing a highway inertial profiler (Perera & Kohn, 2002).

The implementation of the developed procedure to support pavement management activities demonstrates multiple advantages that include its simplicity in application, economic benefits and familiarity. It is representative of circumstance where limited resources and minimal information is available. The present paper demonstrates the implementation of the proposed procedure and related results.

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II. DEVELOPED PROCEDURE

a) Required data

The main objective of the developed procedure is the periodic evaluation of both the structural and functional condition of an existing pavement. Based on this, the pavement performance affected by environmental changes and the accumulation of traffic loads can be predicted. Thus, an accurate and reasonable evaluation is important, in order, to increase the pavement service life through adequate rehabilitation. For this purpose, various data needs to be collected taking into consideration that "good" data is extremely important in providing effective pavement management. For the structural pavement evaluation, the minimum individual data required includes traffic information, pavement layer thicknesses and pavement deflection records. For the pavement functional evaluation, it is necessary to collect roughness data that best reflects the public's perception of the overall condition of the pavement section. Functional evaluation may, of course, benefit from additional data, including rutting measurements or surface distress records to support pavement management activities; roughness data, however, is considered as the minimum required data, addressing the simplicity of the developed procedure.

All necessary pavement data is gathered using NDT techniques. GPR (ASTM, 2010) allows the acquisition of accurate, continuous pavement layer thicknesses data. The GPR system consists of an antenna unit, a transmission/reception unit, a control unit and a storage/display unit. The antenna unit can be a single antenna that transmits and receives radar signals or two separate antennas one for transmission and one for reception. In both cases the antennas must be lightweight and manoeuvrable so that they can be easily positioned over the area under investigation. The transmission/reception unit consists of a transmitter for signal generation, a receiver for signal detection and timing electronics for synchronizing the transmitter and the receiver. The control unit is the operator interface that controls the overall operation of the GPR system and sends the received data to the data storage and display unit.

Utilizing the GPR techniques 'black' spots can be identified and these locations can be further examined with FWD testing or coring. In addition, the GPR technique is able to provide thickness data to be used in the pavement mechanistic analysis models incorporated within the FWD technique to addresses the evaluation of the physical properties of the pavement structure.

FWD generates a load pulse by dropping a weight on a damped spring system mounted on a loading plate. The falling mass, the spring system (rubber buffers) and drop height can each be adjusted

to achieve the desired impact loading on the pavement. Vertical deflection peaks are measured at the centre of the loading plate and at multiple radial positions by a series of deflection sensors. The impulse load acting on the pavement causes a "wave front" of recoverable deformations, or deflections, that spread out from the centre of the load. Both the peak impulse load (force) and maximum vertical deflections of the "wave front" are measured at multiple radial distances from the load centre. These deflections, considered as a function of the applied impulse load, provide an indication of the structural strength of the pavement. Taking into account available traffic information and considering the GPR thicknesses, FWD deflections are analyzed to estimate the pavement bearing capacity, to determine the necessity for repairs.

For roughness data collection, high speed inertial profilers, which are the most technologically advanced and most widely used systems, are incorporated into the developed procedure. These systems are able to record the characteristics of the pavement surface profile at regular traffic speeds using accelerometers and sensors (lasers), which measure the vertical distance between the accelerometer and the surface. Profilers usually have a beam as a basic unit that has integrated electronic laser sensors and accelerometers. The beam is able to be mounted on the front or rear of a suitably modified vehicle, to provide a planar surface for the installation of the sensors. The profiler scans the surface and the measured parameters are processed and analyzed, in order to produce a longitudinal surface profile of the surveyed pavement and determine the International Roughness Index (IRI) (Hajek et al., 1998; Perera & Kohn, 2002).

In summarization the proposed procedure for pavement monitoring and evaluation involves both the pavement structural capacity and user-related roughness factors to determine the optimum section strategies and priority interventions in an optimal way.

b) Setting pavement monitoring and evaluation parameters

In order to describe the developed procedure for pavement monitoring and evaluation it is essential to address two sub-procedures related to the structural and functional condition of the investigated pavement(s). In addition, trigger values (criteria) to indicate when detailed evaluation at project level is needed are of major importance. These trigger values are based on individual indicators keeping in mind that a detailed evaluation should be triggered in time for optimum maintenance (Fig. 1) (Thom, 2008).

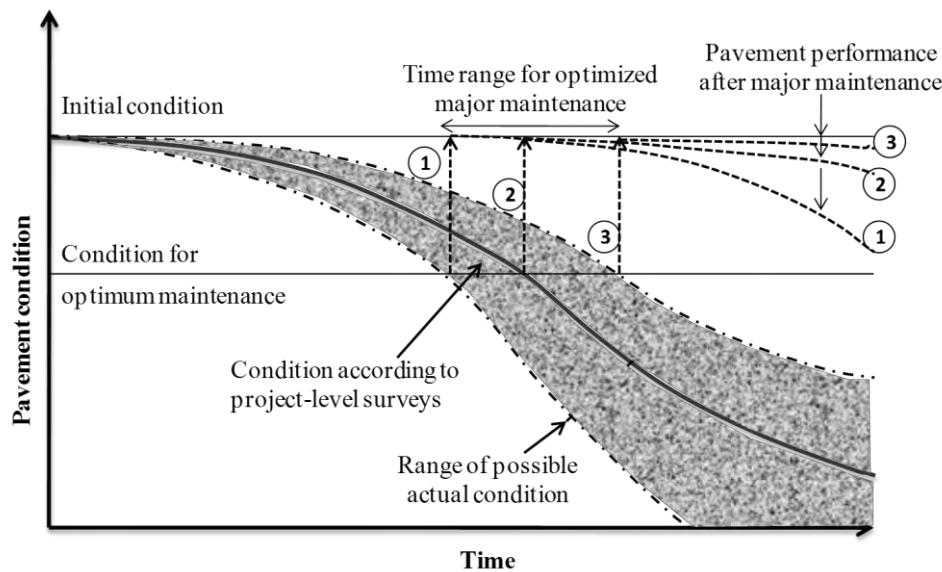


Fig. 1. Concept for pavement maintenance.

Investigation of the structural condition of the pavement may be performed, based on guidelines (COST-336, 1998). Initially, the section under investigation is divided into homogeneous subsections, based on pavement layer thicknesses, traffic and deflection data. The final segmentation of the section is a combination of the intermediate divisions (Fig. 2).

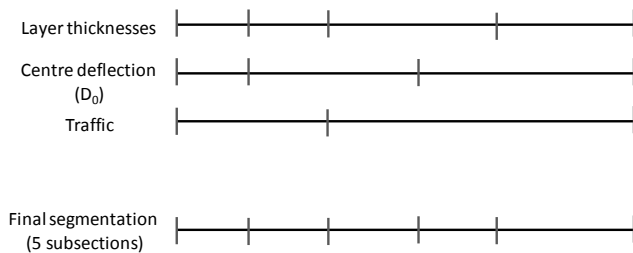


Fig. 2. Road section segmentation.

For the section division based on deflection data, an internationally used index (D_0 index) derived from FWD measurements is utilized (COST-336, 1998; Hakim et al., 2002). The D_0 index is based on the maximum center deflection measured by the FWD and represents the overall structural condition of a pavement. For the estimation of this index, the measured deflection should be normalized to the target test load and reference temperature (usually 20° C) using suitable international factors (COST-336, 1998). Normalization is required, as the mechanical characteristics and behavior of the asphalt mixes are significantly influenced by temperature and deflections are dependent on the imparted load.

In order to divide the section into homogeneous subsections based on the three parameters mentioned above, multiple statistical techniques may be employed.

The cumulative sum (Cum Sum) method is one such technique. The method requires the plot of the cumulative sums of the deviations from the mean of a parameter and indicated homogeneity when the slope of the line connecting all cumulative sum values changes. However the difference between two adjacent sections may not be significant and the statistical difference of adjacent sections can be checked with the T-test. For each subsection, the number of measurements, the average, the median and variance are calculated. By estimating the weighted variance of two adjacent subsections, their homogeneity can be determined.

After the final segmentation of the main section into homogeneous subsections, an evaluation of the structural condition of each individual uniform subsection can be performed, utilizing international experience and practice (Brunton et al., 1992; COST-336, 1998; Hakim et al., 2002). Among these procedures, it is believed that by setting the 85th percentile of the D_0 values (only 15% of the values are higher) as representative of the in subject subsection we are able to achieve a more objective design analysis for reinforcement (i.e. overlay thickness). Road authorities may, of course, perform the analysis for higher percentile values, but are not advised to use lower values.

The reinforcement design results (overlay needs) are followed by the longitudinal profile evaluation of the pavement surfaces for each subsection, based on statistical analysis of the measured IRI values, which specifies the users' perception of ride quality. IRI is a widely used and well established roughness index and is considered to be a good indicator of pavement condition in regards to road roughness (Sayers et al., 1986). IRI is accepted as a key decision criterion for the selection of deficient roads and is also accepted as an

index for quality control purposes in new construction (Ong et al., 2010).

Three criteria are established, based on three critical IRI values for particular characteristic variables and confidence levels (i.e. IRI_{cr1} , IRI_{cr2} , IRI_{cr3}). It should be mentioned that the characteristic critical values are dependent on the road class classification, as defined by the traffic level (i.e. Average Annual Daily Traffic, % trucks, ESALs). For the purpose of the present evaluation the IRI critical values address highway specifications (Table 1). The statistical analysis determines the theoretical distribution function that best fits the distribution of the obtained IRI data and the calculation of the characteristic variable values at the relevant confidence levels (i.e. IRI_{85} , IRI_{95} , IRI_{100}) (Table 2).

Characteristic base variables		Recommended values and confidence levels	
Symbol	Definition	Value	Percentile
IRI_{cr1}	Characteristic acceptability limit value	1.1	85%
IRI_{cr2}	Upper limit value of a confidence interval	1.8	95%
IRI_{cr3}	Fit for use – limit value	2.5	100%

Table 1. Characteristic variables, suggested values and confidence levels.

Criteria for longitudinal roughness evaluation	Condition	Confidence level
Criterion 1	$IRI_{85} \leq IRI_{cr1}$	85%
Criterion 2	$IRI_{95} \leq IRI_{cr2}$	95%
Criterion 3	$IRI_{100} = IRI_{cr3}$	100%

Table 2. Criteria for longitudinal roughness evaluation

Through the three criteria above, the required interventions can be determined. More precisely, there are three types of evaluation outcomes (Fig. 3), the first corresponding to no required intervention and other two signifying warning procedures of varying severity (1st LEVEL and 2nd LEVEL).

Functional evaluation, as illustrated in Fig. 3, follows the pavement structural evaluation. If the structural evaluation indicated no need for intervention, then functional evaluation is performed immediately. In the circumstances where structural intervention is required, the roughness profile evaluation is to be performed after the implementation of the required intervention.

For sections under investigation that are both structurally adequate and fulfil the roughness evaluation, the PAME procedure is completed. For all other sections, maintenance treatments to improve the ride quality are suggested, with the roughness evaluation following the implementation of these interventions.

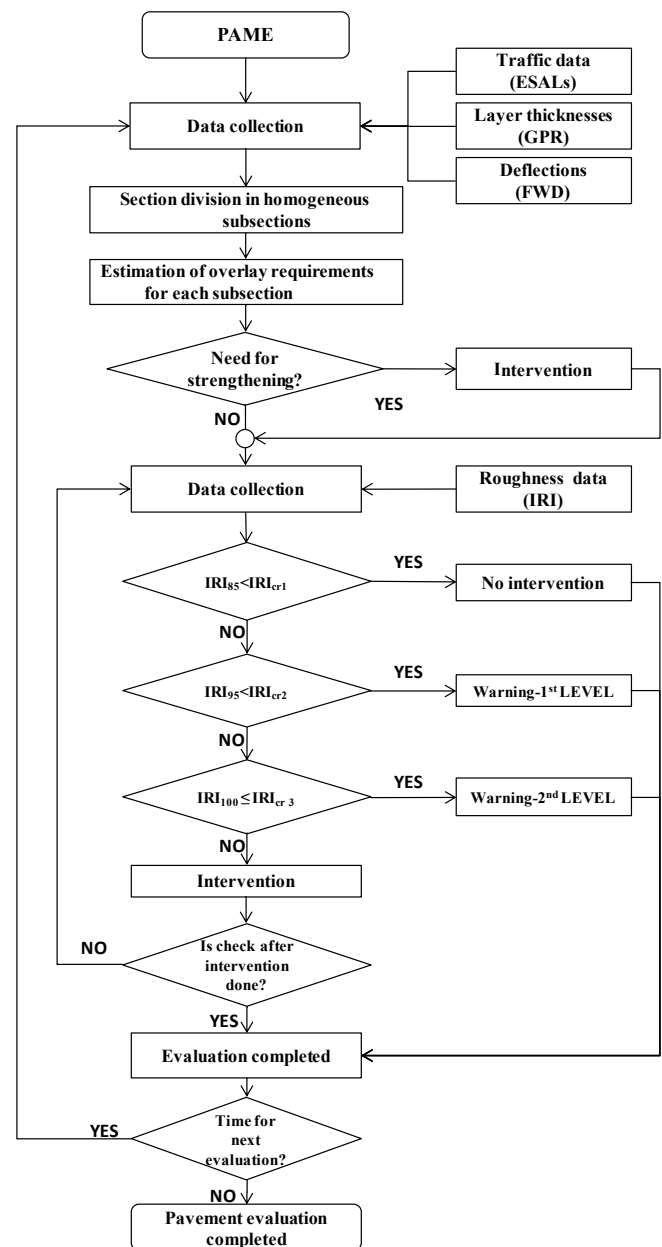


Fig.3. Flowchart of PAVement Monitoring and Evaluation (PAME) procedure.

The proposed procedure is to be periodically repeated for future pavement evaluation in order to support pavement management activities.

III. IMPLEMENTATION

a) Test site

A pilot implementation of the PAME procedure was performed on a highway road section, in order to verify the applicability of the proposed methodology. Both NDT data (i.e. deflection, layer thicknesses and roughness) and traffic information along the heavily trafficked flexible pavement were collected and further analyzed for this purpose. NDT testing using the Laboratory of Highway Engineering of National

Technical University (NTUA) equipment (Fig. 4) was undertaken along the outer traffic lane, as this lane is subjected to the majority of truck traffic and thus exhibits more load-associated distress in comparison with other traffic lanes.

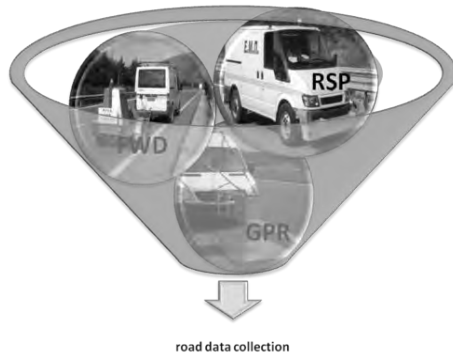


Fig.4. NDT systems used for data collection.

FWD (Dynatest, 2001) measurements were performed at a 200m spacing in the right wheel path of the lane, while the GPR (RoadScanners, 2001) records were continuous along the entire length of the lane. During the FWD testing, the in-situ pavement temperatures and air temperatures were recorded for analysis purposes. Finally, roughness data was recorded using a Road Surface Profiler (RSP) (Dynatest, 2007).

IV. DATA ANALYSIS AND RESULTS

Structural evaluation of the highway pavements condition followed the segmentation of the road section into homogeneous subsections, based on approximately uniform pavement structure and bearing capacity. The final segmentation is based on the division of the main section into subsections according to the normalized deflection values (D_0 index), asphalt layer thickness and traffic using a suitable statistical technique (i.e. Cum Sum method).

Fig. 5 illustrates the division of the road section based on the asphalt concrete layer thicknesses into (eight) subsections, based on the statistical values (si) derived from the implementation of the Cum Sum method.

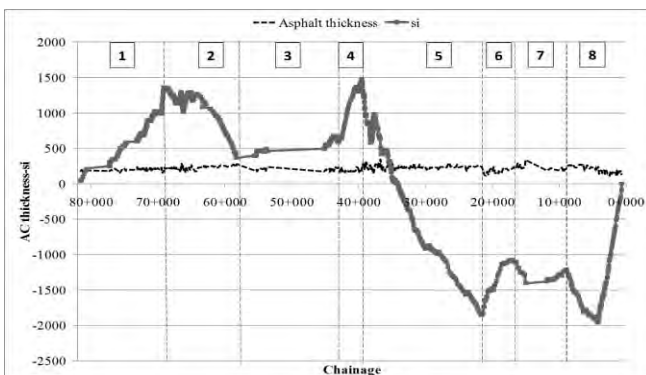


Fig.5. Segmentation of road section based on AC layer thickness.

The implementation of the Cum Sum method according to the D_0 index and the traffic leads to the final segmentation of the road section into nine uniform subsections (SS_1-SS_9), illustrated in Fig. 6.

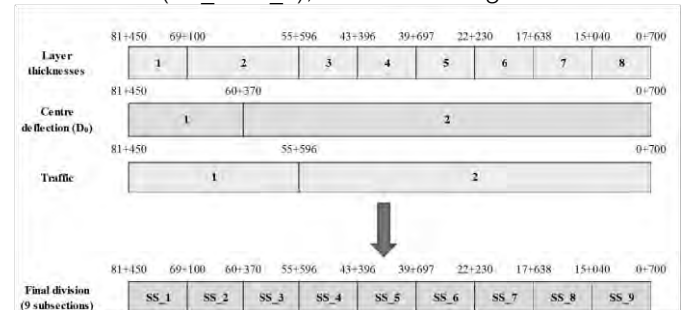


Fig.6. Final road segmentation based on AC layer thicknesses, D_0 index and traffic.

After defining the homogeneous subsections, a structural evaluation analysis is conducted, in order to assess the in situ pavement layer properties (i.e. backcalculated moduli). This information is subsequently utilized to determine the bearing capacity and calculate the overlay requirements for a 20-year design period.

Structural analysis results (Fig. 7) indicate that seven out of nine subsections appear to be structurally adequate, with the two remaining (SS_2 and SS_8) sections in need of structurally reinforcement.

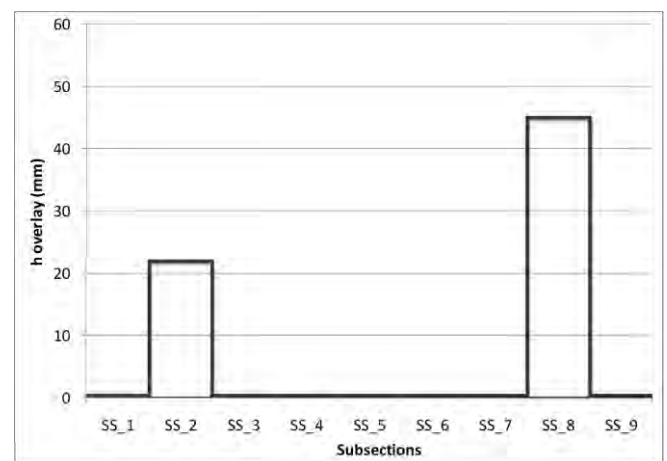


Fig.7. Overlay requirements per subsection (SS).

After the structural evaluation, a longitudinal profile evaluation of the pavement surface along each subsection is conducted, only after the required, if necessary, intervention measures are implemented. The functional evaluation is based on statistical analysis of the measured IRI. Within the scope of the current application, for single IRI index values, a 10 meter long representative longitudinal road segment was adopted. By analyzing the distribution of the relative frequencies of the measured IRI values for the subsections SS_1-

SS_9, the probability density function type log-normal distribution showed the best approximation, according to Kolmogorov-Smirnov test results (Fig. 8). The theoretical distribution function that best fits the distribution of the obtained IRI data is then used to calculate the characteristic variable values at the recommended confidence levels in order to evaluate the recommended criteria (Table 3).

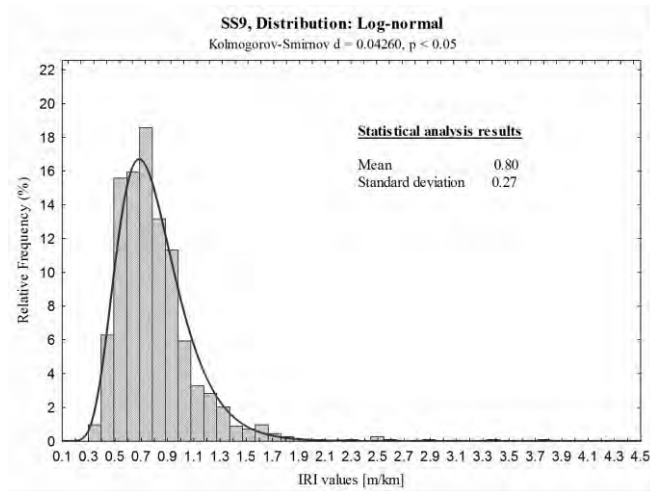


Fig.8. Best fit probability distribution function.

Motorway Subsection	Confidence levels and characteristic variable values					
	85%			95%		
	IRI ₈₅	IRI _{cr1}	Eval.	IRI ₉₅	IRI _{cr2}	Eval.
SS1	1.0	1.1	✓	1.1	1.8	✓
SS2	0.8	1.1	✓	0.9	1.8	✓
SS3	0.7	1.1	✓	0.7	1.8	✓
SS4	1.0	1.1	✓	1.2	1.8	✓
SS5	0.9	1.1	✓	1.0	1.8	✓
SS6	0.9	1.1	✓	1.0	1.8	✓
SS7	0.9	1.1	✓	1.1	1.8	✓
SS8	0.9	1.1	✓	1.0	1.8	✓
SS9	1.1	1.1	✓	1.2	1.8	✓

Table 3. Longitudinal roughness evaluation results

The results of the subsection's functional evaluation indicate that the pavement condition is adequate and pavement intervention is not required. Based on the above, the proposed PAME procedure is concluded.

V. CONCLUSIONS

The PAME procedure developed in the present work is a useful procedure to assist in pavement management activities on a project level basis, through the determination of optimum section strategies and priority interventions, especially in incidences where data availability/requirements are limited. The main requirement for the PAME method is the collection of NDT thickness, deflection and roughness data, which is to be properly analyzed and evaluated based on weighted criteria, following a strict pavement monitoring program.

Apart from rural roads or highways such as the one considered in the present work, the PAME

procedure could be used for urban roadways or other road classifications. The criteria, particularly the functional criteria, will change depending on the road type, as the desired IRI performance level would be different dependent on road classification. In any case the proposed procedure is fairly straightforward in its implementation and the data feeding the evaluation is objective, in contrast with many pavement condition collection methods, that can be very subjective, and dependent on personnel collecting or analyzing the data.

The PAME procedure can provide the road owners/operators with a simple and practical tool to support pavement management activities. The procedure ensures pavement agencies a cost effective use of their constrained resources. Moreover, the proposed methodology has the ability to be customized according to the road owners' requirements and the corresponding intervention strategies.

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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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