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Assessment of Traffic Inputs to Pavement Design and Rehabilitation

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ABSTRACT

Traffic and the consequent loads that vehicles transfer to the roads are major factors considered in pavement design. Heavy vehicles, particularly trucks that carry the largest loads cause the most damage to pavements. In the design process, axle loads attributed to heavy vehicles are derived and the total equivalent standard loads are estimated over a design period. The total loads are then utilized in coming up with the appropriate design that takes into account pavement type and thickness, among others. This paper analyzes the traffic inputs to pavement design through assessment of actual highway sections along the Pan-Philippine Highway also known as the Doa Remedios Trinidad Highway. Original design loads due to previous projections of traffic is compared to present loads and new projections of future traffic loads. As such, pavement performance level could be gauged and the adequacy of current pavement types and thickness can be determined. Recommendations are formulated and proposed in relation to the importance of accurate traffic inputs in pavement design, especially the development of heavy vehicle factors that allow for a more accurate estimation of equivalent axle loads as well as implications to economic design of pavements.
Key Words: traffic inputs, axle loads, pavement design

1. INTRODUCTION

1.1. Background of the Study

The two basic functions of roads are to guide the driver and to support the load that passes through it. These roads have their own service lives, which is the span of time that the particular road section will render its service based on the two main functions as defined from the engineering point of view. It is a common situation in the Philippines that by ocular inspection alone, certain roads may be judged as non-serviceable even before the expiration of service lives. The load directly affects the condition of the road and is the primary reason for its deterioration; therefore an analysis of the present load that passes a road is almost always necessary at any point in its service life. In consequence, a basic pavement management system requires proper identification and measurement of the signs of road deterioration. Having a

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pavement management system (PMS) is good practice, which includes techniques that may provide guidance for the prioritization and extent of maintenance that may be employed for the road under study.

1.2. Statement of the Problem

Highway pavement design requires traffic inputs, particularly loads derived from the volume and mixture of heavy vehicles that would be using the road [14]. In the design of Philippine roads, these traffic inputs are not given much importance, with highway engineers often using unsuitable data for heavy vehicle counts and load factors. Such has resulted in poor pavement design or, in the other extreme, over-designed highways.

1.3. Objectives

The primary aim of the study is to evaluate traffic inputs to pavement design and rehabilitation. Secondary is the assessment of the performance of the given road section within its service life. In the process of realizing these objectives, the following tasks are to be undertaken:

a. Obtain the traffic and load characteristics of typical national highway sections;
b. Evaluate the design and current loads applied on the road based on traffic parameters;
c. Recommend directions for road pavement design, maintenance or rehabilitation.

1.4. Significance of the Study

The need to identify defects and deterioration in highway structures ranges from safety reasons to the calculation of load capacity to the establishment of pavement management systems. In the Philippines and other developing countries, an analysis of critical road networks, links that are candidates for rehabilitation, is necessary primarily due to the lack of funds. Prioritization and timing of maintenance are the main ideas of this management system. However, it deals with the different weights assigned for different types of road distress, and it is in part subjective, depending on the judgment of officials in charge of the inspection of a particular road segment [11].

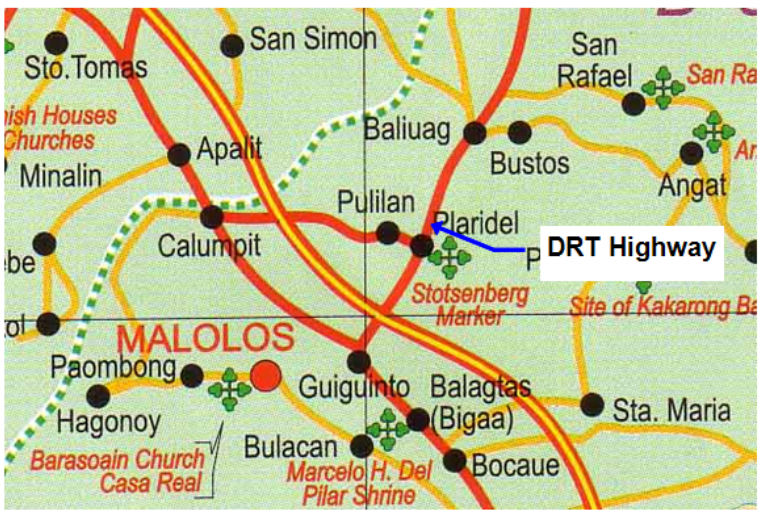
In this study, the effect of traffic inputs leading to pavement distress is of main concern. Also, from the study conducted, an analysis on the viability of the proposed maintenance/rehabilitation of the road will be initialized. The road's future performance will also be obtainable using methods that are employed in similar studies and that are generally accepted in the traffic-engineering field. If reconstruction is necessary in the future, the data will be of help in planning and most especially in the design of the road.

In relation to pavement management systems, the study gives the current load carried by the pavement which may be correlated to the type of distress and presents material such as growth rates, that may be necessary in the prediction of the future loads and hence, future distress.

1.5. Scope and Limitations

According to a JICA Feasibility Study [8], the two most considered gauges of pavement condition are roughness and pavement distress. Pavement distress in this context refers to the defects on the road, which may be brought about by several factors. There are several factors that contribute to road distress. Some of the major elements contributing to highway wear and tear include climate, economic development plans, and for the most part, the type and amount of load that pass through it. For the purposes of the study, the effect of traffic inputs (i.e., translated to dynamic loads) to pavement distress is of main concern.

The study area includes two sections of the Pan-Philippine Highway in Luzon. The first section is located in Pulilan, Bulacan near its border with the town of Baliuag. Note that at this portion of the Pan-Philippine Highway, it is also known as the Doa Remedios Trinidad Highway or DRT Highway. Figure 1 shows a map of Bulacan where Pulilan is located. The general design of the road section, the volume counts, and the traffic growth rates used for traffic projection were obtained from the JICA Publication of 1987 [8]. Recent data on traffic volumes were taken from the DOTC Inter-Regional Passenger and Freight Flow Surveys [9] conducted in 2004.



(Source: E-Z Map, 2003)

Figure 1. Map of Bulacan

The second road section is located in San Jose City, Nueva Ecija. Figure 2 shows a map of the province and the location of San Jose City. Primary data for the San Jose segment and the DRT, particularly classified volume counts were obtained from the survey reports of the Inter-Regional Passenger and Freight Flow Surveys in the Republic of the Philippines [9]. The design specifications from which the actual primary data was compared were obtained from the JICA Feasibility Study [8].

It should be noted also that this paper would focus on the pavement, including its design and maintenance. It does not take into account other related structures such as drainage, pavement shoulder, signage, etc.

The sections considered for this study all have Portland cement concrete (PCC) pavements. Note also, that in the interest of the estimation of traffic loads, established heavy vehicle factors were used. Determination of local factors was limited to available data.

Figure 2. Map of Nueva Ecija

2. CONCEPTUAL FRAMEWORK

The main intent of the analysis is to assess traffic inputs in determining the need for road maintenance or rehabilitation. The study attempts to relate the results to the type and level of rehabilitation or maintenance is recommended, based on the concepts of the idealized pavement management systems.

The conceptual framework illustrated in Figure 3 shows the comparison of road pavement design (projected) loads with estimated loads determined from actual traffic inputs. Whether rehabilitation is necessary or not can be decided from the assessment of road performance based on the differences between projected and actual loads.

A better measure to determine road serviceability is based on distress or the physical analysis of the road's overall state. Distress would be a function of parameters including traffic characteristics along the highway. Traffic using or that is projected to pass through a particular road comprise the load used in the design of pavements. Heavy vehicle factors (i.e., truck factors) are utilized to convert the volumes under different heavy vehicle classes into equivalent standard axle loads of 8.2 metric tons.

3. METHODOLOGY

3.1. Characterization of Road Sections

Two road sections were considered in the study. These are the Doa Remedios Trinidad (DRT) Highway segment in Pulilan, Bulacan, and the Pan-Philippine Highway segment at San Jose City, Nueva Ecija. For the DRT road segment, previous data on classified volume counts were

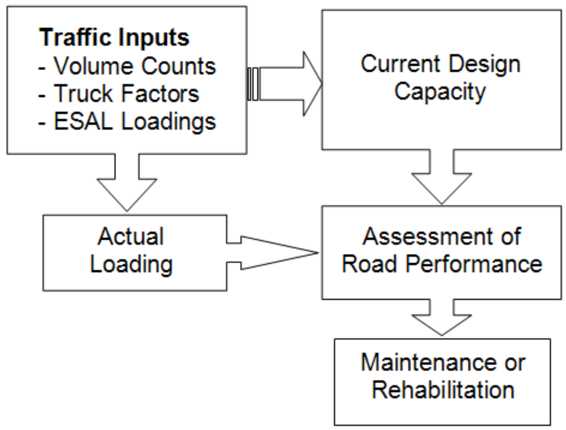


Figure 3. Conceptual Framework

obtained from the DPWH Compilation of Average Annual Daily Traffic (AADT) of 1998 [3]. These were the last counts made by the DPWH in Pulilan and are shown in Table I.

Type of Vehicle	**1998 volume**
Mini bus	65
Big bus	1,226
Rigid truck	2,621
Articulated truck	108

(Source: DPWH [3])

Table I. Previous 24-hr Volume Counts for Pulilan

For the section at San Jose City, Nueva Ecija, data came from the Feasibility Study conducted by JICA [8]. There were no available counts from the DPWH AADT compilation. Traffic growth rates that were used for the projection of previous data to 2004 came from the same publication. Table II shows vehicle count data for San Jose while Table III contains traffic growth rates established in the JICA study.

Type of Vehicle	**1987 Volume**
Bus	233
Truck	1,055

(Source: JICA [8])

Table II. Previous 24-hr Volume Counts for San Jose

Recent vehicle counts were sourced from the JICA passenger and freight flow study [9] conducted in 2004. 24-hour counts utilizing an expanded vehicle classification allowed for a more detailed treatment of heavy vehicles. These counts are shown in the Table IV.

	1986 - 1990	1990 - 2000	2000 - 2010
North Study Section (San Jose)	5.2 (4.7-5.8)	5.6 (5.1-5.9)	5.6 (5.1-5.9)
South Study Section (Pulilan)	4.3 (2.8-5.0)	5.3 (4.0-5.9)	5.4 (4.8-5.9)

(Source: JICA [8])

Table III. Traffic growth rate (%)

Vehicle Type	**Pulilan**	**San Jose**
Small buses	8	3
Large buses	1,054	2,038
Rigid truck 2 -axle	2,013	4,132
Rigid truck 3 -axle	700	1,122
Trailer 3 & 4 -axle	224	473
Trailer 5 & more-axle	76	284
Tank lorry	144	443
Mixer	2	1
Prime mover	0	2
Dump truck	143	1,272

(Source: JICA [9])

Table IV. Recent 24-hr Volume Counts (Year 2004)

Both sections were in good condition and pavements were concrete. Other sections along the Pan-Philippine/DRT Highway are concrete with asphalt overlays. However, pavement deterioration was evident at urbanized areas including stretches within Baliuag, Bulacan and Cabanatuan City, Nueva Ecija.

3.2. Truck Factors

In the determination of pavement design loads, it is important to estimate the equivalent standard axle loads (ESAL) attributed to the projected traffic that will use the road throughout its service life. The ESAL values would be dependent primarily on truck factors derived from the weights of heavy vehicles plying along existing roads that would have similar characteristics as the highway to be designed. In the case of high rehabilitation, truck factors are estimated from weights of actual heavy vehicle traffic using the road.

The DPWH commonly uses truck factors that are derived from studies (e.g., Feasibility Studies) conducted for particular highway projects throughout the country. Oftentimes, these factors do not reflect an accurate estimation of the loads that pavements would have to bear due to the use of simplified classification of heavy vehicles. The Metro Iligan Regional Industrial Development Project (1993), for example, came up with truck factors for three types of heavy vehicles: bus (1.35), 2-axle truck (1.85), and 3-axle truck (10.30). Meanwhile, the Metro Manila Road Pavement Rehabilitation Project (1994) estimated truck factors of 0.70 for buses and 1.6 for all types of trucks.

The use of such truck (or heavy vehicle) factors would tend to provide flawed inputs to pavement design. Such may be evident from the deteriorated pavement that can be observed in many Philippine highways that are used as main corridors for passenger and freight flow.

Measurements of heavy vehicle weights are not within the scope of the study due to its being a major undertaking. An example of a robust set of truck factors may be obtained from the journal issued by the Asphalt Institute [12]. The truck factors, which are tabulated in Table V, were established for use in the United States but which include road classification to differentiate among different types of traffic conditions with respect to the area of application.

Type of Vehicle	Highway System Type		
	Interstate Rural	**Other Rural**	**Urban**
Single-unit trucks			
two-axle, four-tire	0.02	0.02	0.03
two-axle, six-tire	0.19	0.21	0.26
three-axle or more	0.56	0.73	1.03
Tractor-Semitrailers			
three-axle	0.51	0.47	0.47
four-axle	0.62	0.83	0.89
five-axle	0.94	0.98	1.02

(Source: The Asphalt Institute [12])

Table V. Distribution of Truck Factors for Different Classes of Highways and Vehicles in the United States

The closest that one could come to the values in Table V would be the truck factors shown in Table VI. The DPWH truck factors were culled from the Feasibility Study for the Improvement of the Pan-Philippine Highway [8]. These truck factors represent a relatively wider area and more extensive road length as compared with the Metro Iligan and Metro Manila truck factors. Also, it is presumed that the truck factors incorporated a more diverse sample of trucks utilizing the Pan-Philippine Highway.

Vehicle Type	**Truck Factor**
Bus	2.08
2-Axle Truck	3.20
3-Axle Truck	2.57
Trailer	8.00

(Source: DPWH [8])

Table VI. Local Truck Factors

3.3. Estimation of Volumes

In this study, The equation used for the projection of the previous data for the two road sections is:

$$T_n = \left[(1+r)^n - 1\right]/r \times T_i$$

Where: T_i = initial traffic volume
T_n = total volume for the service life (cumulative)

r = the traffic growth rate
n = service life of the structure

The projected volume could then be obtained from the equation:

$$\textbf{Projected volume in year n} = \textbf{Cumulative volume in year n} - \textbf{Cumulative volume in year (n-1)}$$

4. RESULTS AND DISCUSSION

4.1. Traffic Assessment

The assessment of traffic anytime within the service life of a road section is necessary primarily because road safety and capacity is always desired to be at a high level, and because certain assumptions used to design the road must be confirmed and corrected if possible. The two methods used (truck factor method and load equivalency factor method), yield different results but are both conservatively done. Traffic growth rates are assumed to follow the estimates in Table III. The projected volumes of heavy vehicles for 2004 were derived using the formulas in the preceding section. That is, (Cumulative Volume) 2004 minus (Cumulative Volume) 2003 yields the volume for 2004.

The projected traffic volumes for the year 2004 based on 1987 and 1998 count data for San Jose City and Pulilan, respectively, is shown in Tables VII and VIII. These values are used in estimating the traffic loads for pavement design along with the most recent actual counts mentioned in Table IV.

Type of Vehicle	1987 Volume	2004 Projection
Bus	233	557
Truck	1,055	2,522

Table VII. Projected Traffic Volumes for San Jose

Type of Vehicle	1987 Volume	2004 Projection
Mini bus	65	85
Big bus	1,226	1,595
Rigid truck	2,621	3,410
Articulated truck	108	141

Table VIII. Projected Traffic Volumes for Pulilan

Table VII consists only of 2 vehicle classifications since the total number of the other types of vehicles necessary for load computations is negligible. In addition to this, public utility vehicles (which comprise a great number of small and large buses) traversing the particular road section today may not be present at the time the survey was conducted.

The 2004 projected volume of buses in San Jose is 557 and the DPWH truck factor from Table VI is 1.48.

$$\begin{aligned} \textbf{ESAL} &= \textbf{Number of vehicles} \times \textbf{truck factor} \\ &= 5572.08 = 1,158.56 \cong 1,159 \end{aligned}$$

The daily ESAL is computed as the summation of all ESAL values from the different heavy vehicle classifications. Thus, for the case of San Jose, the daily ESAL is computed below.

$$\begin{aligned} \textbf{Daily ESAL} &= \sum(\textbf{ESAL per type of vehicle}) \\ &= 1,159 + 6,482 = \underline{7,641} \end{aligned}$$

Also, the yearly ESAL is computed as follows.

$$\begin{aligned} \textbf{Yearly ESAL} &= \textbf{365} \times \textbf{daily ESAL} \\ &= 365 \times 7,641 = \underline{2,788,965} \end{aligned}$$

A summary of projected and actual ESALs using the DPWH truck factors for both Pulilan and San Jose road sections are presented in Tables IX and X.

Type of Vehicle	**2004 Projection**	**2004 Actual**	**Truck Factor**	**ESAL (Projected)**	**ESAL (Actual)**
Buses	1,680	1,062	2.08	3,495	2,209
2-Axle Truck	-	2,013	3.20	-	6,441
3-Axle Truck	3,410	989	2.57	8,764	2,542
Trailer (4-Axle or more)	141	300	8.00	1,128	2,400
			Daily	**13,387**	**13,593**
			Yearly	**4,886,255**	**4,961,445**

Table IX. Estimated ESAL for Pulilan using projected volumes for 2004 (Truck Factors from DPWH)

Type of Vehicle	**2004 Projection**	**2004 Actual**	**Truck Factor**	**ESAL (Projected)**	**ESAL (Actual)**
Buses	557	2,041	2.08	1,159	4,246
2-Axle Truck	-	4,132	3.20	-	13,223
3-Axle Truck	2,522	2,840	2.57	6,482	7,299
Trailer (4-Axle or more)	-	757	8.00	-	6,056
			Daily	**7,641**	**30,824**
			Yearly	**2,788,965**	**11,250,760**

Table X. Estimated ESAL for San Jose using projected volumes for 2004 (Truck Factors from DPWH)

For the Pulilan road section, a yearly ESAL of 4,961,445 was estimated corresponding to the actual volume. This was obtained using the truck factors and the average number of vehicles per classification, for the duration of the study. This was compared with the ESAL of the projected volume count obtained from the JICA publication [8]. A value of 4,886,255 ESAL's was calculated, which is almost the same as the actual (a difference of 1.53%).

As for the San Jose study section, a yearly ESAL of 11,250,760 was obtained corresponding to the actual volume. This is about 4 times that of the ESAL corresponding to the projected volume (i.e., 2,788,965). The computation was done, in a similar fashion as that of the Pulilan road section. The same truck factors were used for the two segments. Also, the same growth rates were employed in the projection of the number of vehicles to the base year 2004.

4.2. Implications on Maintenance and Rehabilitation

The vehicle classification for the San Jose road section considers only two types of vehicles, buses and trucks, regardless of the number of axles. In the case of Pulilan, there were only three classifications considered, omitting 2-axle trucks. Such are perceived to be too simplistic when compared with the number of classifications used for the present DWPH volume count format, where there is an expanded classification for freight vehicles. Hence, the difference in the design and actual ESAL values is associated with a considerable degree of uncertainty.

The uncertainty is derived from the significant differences in the ESAL values calculated using the appropriate and corresponding truck factors as well as the distribution and volume of trucks (i.e., according to the number of axles). Such is shown in the calculations in the preceding section 4.1, where the number of ESAL's for both the San Jose and Pulilan sections vary according to available information on truck factors as well as heavy vehicle distribution.

The high variability of ESAL values would have serious implications on maintenance and rehabilitation of roads since these are basic inputs to the design of pavements. This is because pavement loads are indicated by ESAL values. From Tables IX and X it is easy to see the impacts of the interaction of volume data and truck factor information on estimated ESAL values. A difference of about 9 million axles for the San Jose section and about 7 million axles for the Pulilan would usually lead to changes in road design that would have implications on the required quantity and quality of materials.

5. CONCLUSIONS

This paper examined the typical traffic and load characteristics of national roads in the Philippines. Segments along the Pan-Philippine Highway/Doa Remedios Trinidad Highway at Pulilan, Bulacan and San Jose, Nueva Ecija represented typical sections. Pavement loads were estimated and compared based on both projected and actual data including derived truck factors and those used by DPWH. The results point to significant discrepancies between ESAL values as influenced by differences in traffic volume, heavy vehicle composition and distribution, and truck factors used in deriving loads.

Truck factors are sensitive to the number of samples (i.e., heavy vehicles) and the weights of these samples. Also, important would be the mixture of loaded and empty vehicles. Less samples combined with weights of predominantly fully or overloaded trucks will result in high truck factor values. These may explain, in part, the truck factors derived for certain road feasibility studies in the Philippines. More information on heavy vehicle volume and composition (according to the DPWH classification) would allow for the derivation of more accurate as well as more sensible truck factors for each heavy vehicle classification. Practical truck factors would ensure optimal and economical design of pavements.

6. RECOMMENDATIONS

If a Pavement Management System (PMS) is desired particularly for local government units, a history of traffic must be documented, as well as the current state or physical condition of the pavement in concern. This will be very useful in planning for future procedures related to pavement maintenance. Schedules of rehabilitation must be recorded as these may be used in refining the timing of these periodic preservation works.

Data collection may involve advanced tools and made more accurate if actual 24-hour traffic counts are done, instead of projecting the available 10-hr data for the computation of the daily (24 hrs) load. Also, pavement sections along critical routes such as truck routes must be given particular attention. Estimates or past computations of axle loadings may be revisited given the regular traffic counting program of the DPWH. Truck factors need to be updated regularly and according to the heavy vehicle categories of DPWH's expanded classification. As such, significant changes in freight traffic may be monitored and appropriate pavement maintenance may be applied on affected road sections.

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