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DEVELOPMENT OF FLEXIBLE PAVEMENT DESIGN TOOL BASED ON JABATAN KERJA RAYA (JKR)'S REVISED GUIDELINE

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ABSTRACT

Land and road transport system provides a vital artery of communication, commerce and trade that helps to propel Malaysia towards national rapid growth, modernization and prosperity. In order to ensure standardization and compliance to the sanctioned road construction practice in the country, the Arahan Teknik (Jalan) 5/85 had been introduced and used extensively by the engineering community since 1985 for most of the road pavement design needs. However, over the years the guideline was incompatible with the technological advancement in the area, and consequently it suffers from design inadequacy and inflexibility, and lack of functionality and safety. Since 2013 however, Jabatan Kerja Raya Malaysia (JKR) has introduced the new Arahan Teknik (Jalan) 5/85 (Pindaan 2013) that is technically con-current and relevant to prevailing circumstances through incorporation of state-of-the-art technological developments in road pavement construction from across the world while addressing many a shortcoming of the former guideline. As in many an application in the industry as well as academia, migration to a new thinking or work process would be greatly facilitated and expedited with the aid of ICT tools. Excel VBA (Visual Basic for Application) provides such a familiar, common and convenient platform to develop the occasionally intensive and quite engaging computational processes but with the look and feel of commercial software and at a fraction of the cost, and practically reutilizing existing resources. Such development was addressed in this paper and used to solve a real world project, the results of which were in agreement with manual computations. Furthermore, the functionality and flexibility of the program would allow for multiple scenario investigation and comparison that would facilitate optimized design solution.

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Keywords: Flexible road pavement; Mechanistic-Empirical method; Arahan Teknik (Jalan); Excel VBA, Software.

1. INTRODUCTION

Malaysia has an extensive road network covering over 18 904 km Federal roads, over 61 420 km State and Municipality roads, and 1820 km tolled Expressways which for the most parts comprise flexible or rigid pavement based on the 2010 statistics (Jabatan Kerja Raya Malaysia (JKR), 2015). Such massive public and private expenditures into the construction and maintenance of the road infrastructures could not easily be fathomed if not for the fact that they serve as a catalyst for economic and social growths of the nation by establishing line of communication and maintaining its competitive edge in this globalized market. To put this into perspective, about 96% of transported goods and passengers were carried by the road network (Mohd Jawi et al., 2012). As such, the need to ensure proper design, construction and continued operation of the road service is of vital national security interest that would ensure survival and success of the nation and its people in this globalized, open-market world order.

In Malaysian context, the design of the road pavement is regulated by respective authority namely the JKR and was initially based on Arahan Teknik (Jalan) ATJ 5/85. This guideline was invariably based on 1981 Asphalt Institute (MS-1) and AASHTO design procedures which have subsequently undergone several revisions while the guideline itself was slowed to follow suit and had remained unchanged since 1985; thus technically outmoded by several generations in technological advancement. As a result, the design procedures neither produce roads of sufficient durability for current and future traffics nor well optimized in terms of functionality and user safety.

In order to address these problems, in 2013 JKR released a revised version of the guideline called Arahan Teknik (Jalan) ATJ 5/85 (Pindaan 2013) which would eventually supersede the former guideline. The salient features of the current guideline include incorporation of technological advancement in road construction e.g. slope stabilization method and usage of polymer additive, cataloguing pavement structures for speedy design process, hierarchical design procedures based on the Equivalent Standard Axle Load (ESAL), and mechanistic design approach that takes into account construction material capacity (Jabatan Kerja Raya Malaysia (JKR), 2013).

The transition into a new thinking or work process would naturally be problematic or undesirable to those accustomed to the status quo both in the industry as well as academia. The challenges faced include realigning routine, relearning new processes, retraining manpower, retuning existing and acquiring new resources, and negotiating changing requirements over constricting timeframe. Peansupap et al. (2006) reported that even within largely ICT-literate Australian construction firms, at the personal level budgetary constraint for ICT investment, commitment from other project participants, ICT standardization issues and security concerns; and at the organizational level, basic computer experience, relearning time and unclear benefits of ICT use would still pose a barrier (Peansupap et al., 2006). Similar sentiments were shared by other researchers on the seemingly anachronistic tendency of the construction industry which is slow to adapt to new technologies (Ruddock, 2006; Chee, 2007; Brandon et al., 2008; Hosseini et al., 2012). Furthermore, more worrying would be the general trend that the state of ICTs utilization in the construction industry within the

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developing countries is not as mature as that of the developed countries (Sarshar et al., 2004; Ahuja et al., 2009). Current structural, social, cultural and economic framework may hinder or delay the progress in this direction but these excuses should not be given substance in this day and age of global enlightenment. Clearly a sound ICT strategy would be required if it were to succeed and key among this would involve humanizing the technology through accessibility, ease of use, right pricing and so forth.

Commercial software could greatly facilitate and expedite the required paradigm shifts among individuals and organizations and may provide ready solutions to some or all of the challenges posed above. However, as it was often the case no single tool could be envisioned to offer multitude of functionality and flexibility to meet ever changing circumstances and times but even for a more inclusive or generic system complexity would be inherent in multitude of technical nomenclature and choices. In such cases, a system that would address local requirements and fine tune to prevailing practices would be called for. Excel VBA programming provides such alternative avenue and may even be a more efficient and effective medium of implementation due to its pervasiveness and established familiarity among end users, and can be customized to conduct intensive and quite engaging computational processes while having the look and feel of commercial software but at a fraction of the cost and practically realigning existing resources.

2. THEORETICAL FRAMEWORK

The Mechanistic-Empirical (ME) design approach for new and rehabilitated pavement structures has been around since 2002 and has gathered momentum ever since. It involves a determination of pavement responses to traffic loads using mathematical models and relating them to observed performance of the pavement. The shift from the legacy empirical method or hypothetically mechanistic approach was driven by the needs to ensure higher pavement performance as well as its potency for rehabilitation upon distresses or other structural damages which are regular pitfalls often experienced by the road pavements in operation. As a result, the ME pavement design procedure was adopted by AASHTO in 2008 with the publication of a manual (with MEPDG acronym) and the companion software called DARWin ME in 2011 (American Association of State Highway and Transportation Officials, 2008). However, the computational process involved may be quiet complex, intensive and engaging, and may require specialists' competency in order to manage the required workloads.

There are several parallel works in the right direction in order to address this issue. Abdullah et al., (2014) published several simple and flexible design tables using ME pavement design guide software for the New York State Department of Transportation. The application of structured tables using the pavement design life, subgrade type and traffic volume as determinants (somewhat replicated in the new JKR guideline) should have facilitated many a manual design process, but may also have neglected the automation of still tedious initial and intermediate computation processes; thus prone to misinterpretations and inaccuracies. Khan emphasised on the need for proper design of the pavement thickness in determining the overall pavement performance and providing high serviceability level for the heavy traffic loads under the adverse climatic conditions. As such, an alternative software was developed called PAKPAVE based on AASHTO, Group Index and CBR to determine the thickness of each layer, design life evaluation and other common design parameter (Khan et al., 2012). In

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referencing AASHTO however, it might not be readily adaptable to local practice and the relatively unillustrated input-output interfaces would leave much to interpretative suggestion without accompanying instruction. This lapse may lead back to the improper pavement design concern suggested above. This developmental work is meant to address local practice requirements as well as render as much assistance as computationally practical. On the other hand, Srikanth attempted finite element modelling of flexible pavement in order to address the non-linear behaviour of materials (Srikanth, 2015). Similar work was also carried out by Gu using finite element modelling of flexible pavement but on geogrid-reinforced structure to account for lateral confinement effect of geogrid layer, interaction between geogrid and aggregate/soil, and non-linear cross-anisotropy of geogrid-reinforced unbound granular material (Gu et al., 2016). Although both works assume that the true inelastic material response could only be captured at a particle level to produce pavement design of long durability and high performance and there are evidences to support this view, such complex and rigorous analysis would rarely be needed and required under most circumstances, and may not be practical enough for the industrial applications.

In the context of Malaysia, there is the JKR's ATJ 5/85 (Pindaan 2013) which although conveniently prepared in a simple catalogue of pre-designed pavement structure form, still involves meticulous and repetitive computational process and can be made even simpler through automation; the details of which would be the gist of discussion for the rest in this paper. The catalogue is derived using improved design development data and employing mechanistic-empirical analytical methods. The pavement types covered by the guideline include new flexible and semi-flexible pavements consisting of one or two bound layers, new flexible pavements for low volume roads consisting of unbound or stabilized cement granular materials capped with a thin bituminous surface treatment, and new flexible and semi-flexible heavy duty pavements for severe loading conditions. The information usually needed as inputs for the pavement design includes types and volume of commercial vehicles, design life, sub-grade type and strength, type and properties of pavement materials, and environmental exposure. For the sake of convenience, the subsequent discussions on these varying items shall be broadly categorized into Design Traffic Estimation, Material Specifications, Environmental Effects and Pavement Design.

2.1 Design Traffic Estimation

Two elements of traffic data influence the performance of a pavement throughout its design life. Firstly, the Equivalent Standard Axle Load (ESAL) or wheel load which in Malaysia is set at 80 kN and also corresponds to that of AASHTO. Secondly, the traffic volume, which consists of the number of commercial vehicles during the base year, vehicle class and axle, load distribution, directional and lane distribution factors, and traffic growth factors. To facilitate pavement design particularly involving mixed traffic, the traffic information shall be converted into the number of ESAL repetitions using the load factors derived from axe loads studies and legal loads in Malaysia. (Federal Government Gazette, 2003)

The Number of ESAL for the base year (i.e. first year of the design period) and design lane can be estimated from the following equations for both single and multiple vehicle class conditions:

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$$ESAL_{Y1} = \begin{cases} \text{For single vehicle class:} \\ ADT \times 365 \times P_{CV} \times 3.7 \times L \times T \\ \text{For multiple vehicle classes:} \\ \left[ADT_{VC1} \times LEF_1 + ... + ADT_{VCn} \times LEF_n \right] \times 365 \times P_{CV} \times 3.7 \times L \times T \end{cases}$$

where:

$ESAL_{Y1}$ = Number of ESALs in one direction for the design lane in the base year

ADT = Average Daily Traffic in one direction (min.. 3 days)

$$= \begin{cases} \times 1.0 \text{ if traffic count covers a time period of 24 hours per day} \\ \times 1.2 \text{ if traffic count covers a time period of 06:00 to 22:00 hours per day} \end{cases}$$

ADT_{VCn}, etc. = Average Daily Traffic in each vehicle class; see also above

LEF_n = Load Equivalence Factor of applicable vehicle class (See Table 1)

P_{CV} = Percentage of commercial vehicles (CV) with unladen weight of more than 1.5 ton

L = Lane Distribution Factor (See Table 2)

T = Terrain Factor (See Table 3)

Table 1: Axle Configuration and Load Equivalence Factor, LEF based on Traffic Categories used by Highway Planning Unit (HPU) (Jabatan Kerja Raya Malaysia (JKR), 2013)

Vehicle		Load Equivalence Factor, LEF
HPU Designation	Class	
Cars and taxis	C	0
Small lorries and vans (2 axles)	CV1	0.1
Large lorries (2 to 4 axles)	CV2	4.0
Articulated lorries (3 or more axles)	CV3	4.4
Busses (2 or 3 axles)	CV4	1.8
Motorcycles	MC	0
Commercial traffic (Mixed)	CV%	3.7

Table 2: Lane Distribution Factor, L (Jabatan Kerja Raya Malaysia (JKR), 2013)

Number of Lanes (in ONE direction)	Lane Distribution Factor, L
One	1.0
Two	0.9
There or more	0.7

Note: Traffic in the primary design lane (one direction) decreases with increasing number of lanes.

Table 3: Terrain Factor, T (Jabatan Kerja Raya Malaysia (JKR), 2013)

Type of Terrain	Terrain Factor, T
Flat	1.0
Rolling	1.1
Mountainous/Steep	1.3

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Note: As terrain changes from flat to mountainous topography, the percentage of road sections with steep slopes and with curves increases, thus increasing stresses and strains in pavement structures due to breaking, acceleration and cornering of commercial vehicles.

The Design Traffic for the design lane in one direction can be estimated from the following equation:

$$ESAL_{DES} = ESAL_{Y1} \times \frac{(1+r)^n - 1}{r}$$

where :

$ESAL_{DES}$ = Design Traffic in one direction for the design lane

r = Average Annual Traffic Growth Factor during design period for CV

n = Number of years in design period (recommended 10 years and 20 years for low volume roads and medium to high volume roads respectively giving a probability of 85% against significnt distress throughout the intended design period with reasonable construction conformance to design and specifications)

Henceforth, the association between Traffic Category and Design Traffic values is established from Table 4. Whenever feasible, statistical analysis shall be carried to evaluate the design input values for material strength and stiffness.

Table 4: Traffic Categories based on ESAL of 80 kN (Jabatan Kerja Raya Malaysia (JKR), 2013)

Traffic Category	Design Traffic ($ESAL \times 10^6$)	Probability/Percentile applied to Properties of Sub-Grade Materials	Design Input Values for Material Strength and Stiffness (with Normal Distribution and Single-Tailed Analysis)
T1 (Low volume)	≤ 1.0	$\geq 60\%$	Mean-0.253×Standard Deviation
T2 (Low volume)	1.1 to 2.0	$\geq 70\%$	Mean-0.525×Standard Deviation
T3 (Medium volume)	2.1 to 10.0	$\geq 85\%$	Mean-1.000×Standard Deviation
T4 (High volume)	10.1 to 30.0	$\geq 85\%$	Mean-1.000×Standard Deviation
T5 (High volume)	> 30.0	$\geq 85\%$	Mean-1.000×Standard Deviation

2.2 Material Specifications

For the sub-grade classification, the guideline has retained the CBR value as determinant although direct measurement of its elastic stiffness property would likely be more valid for the said purpose as shown in Table 5. In establishing these correlations, two separate

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references are made to two flexible pavement design standards for primarily cohesive (Transport and Road Research Laboratory, 1984) and primarily granular (AASHTO, 2002) soils.

Table 5: Classes of Sub-Grade Strength (based on CBR) used as Input in the Catalogue of Pavement Structures (Jabatan Kerja Raya Malaysia (JKR), 2013)

Sub-Grade Category	CBR (%)	Elastic Modulus (MPa)	
		Range	Design Input Values
SG 1	5 to 12	50 to 120	60
SG 2	12.1 to 20	80 to 140	120
SG 3	20.1 to 30	100 to 160	140
SG 4	> 30	120 to 180	180

For both unmodified and polymer modified bituminous binder and wearing course specifications, the guideline outlines default elastic modulus (on average air voids and loading time of 5% and 0.1 s respectively corresponding to traffic speed of about 60 km/hr at a depth of 10 cm below pavement surface) and Poisson's ratio values at a temperature of 35°C as shown in Table 6 and Table 7. If PEN 60/70 were used instead for unmodified bituminous mixture, the elastic stiffness values shall be increased by 20%. The other mixture specifications shall be referenced to the appropriate JKR standard. (Jabatan Kerja Raya Malaysia (JKR), 2008)

Table 6: Elastic Properties of Unmodified Bituminous Mixture (Jabatan Kerja Raya Malaysia (JKR), 2013)

Bituminous Mixture based on PEN 80/100 Bitumen	Elastic Modulus (MPa)		Poisson's Ratio	
	25°C	35°C	25°C	35°C
Wearing Course AC 10 and AC 14	-	1200	0.35	0.40
Wearing Course SMA 14 and SMA 20	-	1200	0.35	0.40
Binder Course AC 28	2000	1600	0.35	0.40
Road Base AC 28	2000	-	0.35	-

Table 7: Elastic Properties of Polymer Modified Bituminous Mixture (Jabatan Kerja Raya Malaysia (JKR), 2013)

Bituminous Mixture based PMB	Elastic Modulus (MPa)		Poisson's Ratio	
	25°C	35°C	25°C	35°C
Wearing Course AC 10 and AC 14	-	1400	0.35	0.40
Wearing Course SMA 14 and SMA 20	-	1400	0.35	0.40
Binder Course AC 28	2500	2000	0.35	0.40
Road Base AC 28	2500	-	0.35	-

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For both unmodified and polymer modified bituminous road base specifications, the guideline outlines default elastic modulus and Poisson's ratio values at a temperature of 25°C as shown in Table 6 and Table 7. Other specifications shall be referenced to the appropriate JKR standard.
For unbound granular road base specifications of both crushed aggregate and wet-mix types, the guideline outlines minimum CBR value of 80% corresponding to an elastic modulus of about 350±100 MPa. Other specifications shall be referenced to the appropriate JKR standard.

For stabilized aggregate road base specifications using either primarily cement/lime or a combination of emulsion/foamed bitumen and cementitious materials, the guideline outlines default elastic modulus and Poisson's ratio values of 1800 MPa and 0.40, and 1200 MPa and 0.35 respectively. Other specifications shall be referenced to the appropriate JKR standard.

2.3 Environmental Effects

The guideline highlights two critical environmental factors to be considered in flexible pavement design namely:

- Temperature – Mean annual, maximum and maximum average (during the hottest 7-day period over pavement design life) air temperature values shall be 28°C, 45°C and 38°C respectively.

- Precipitation and other moisture – Preventive measures taken against moisture infiltration into pavement system, infiltrated moisture removal through incorporation of drainage layers and application of moisture-desensitized paving materials.

2.4 Pavement Design

The guideline recommended minimum thickness of pavement layers as a function of Traffic Category and Sub-Grade category as shown in Table 8.

Table 8: Conceptual Outline of Pavement Structures (Jabatan Kerja Raya Malaysia (JKR), 2013)

Pavement Structures	Traffic Category (based on millions ESAL @80 kN)				
	≤ 1.0	1.0 to 2.0	2.1 to 10.0	10.1 to 30.0	> 30.0
	T1	T2	T3	T4	T5
Combined Thickness of Bituminous Layers	5 cm	10 cm	18 cm	20 cm	24 cm
Crushed Aggregate Road Base + Sub-Base for Sub-Grade category of:					
SG 1	25+15 cm	20+15 cm	20+20 cm	NR	NR
SG 2	20+15 cm	20+15 cm	20+20 cm	20+20 cm	20+20 cm
SG 3	20+10 cm	20+10 cm	20+15 cm	20+15 cm	20+15 cm
SG 4	20 cm	20+10 cm	20+10 cm	20+10 cm	20+10 cm

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The flexible pavement design process can be categorized into three types based on the following loading conditions:

- Very low to low volume roads (ESAL< 1.0×10^6) – This category implies pavement category that would experience very low to low loading condition such as rural or other low volume roads. The guideline recommends the use of Figure 3.1 of the Catalogue of Pavement Structures of the guideline. Alternatively, Table 4.1 of the guideline may also be employed. This case is treated in the current development.

- Low to high volume roads (Typical application) – This category implies pavements that would experience typical loading condition in Malaysia such as urban roads and highways. The guideline recommends the use of Figure 3.1 to 3.6 of the Catalogue of Pavement Structures of the guideline. This case is treated in the current development.

- Heavy duty roads (Special application) – This category implies pavements that would experience sustained heavy loads or channelized repeated load applications that are well in excess of traditional traffic loading patterns. In such as case, the guideline recommends the use of a mechanistic design methodology in conjunction with special paving materials that offer high strength and stiffness under both dynamic and static loading conditions. This case is not treated in the current development but specialized commercial software is available in the market for this purpose.

3. SOFTWARE DEVELOPMENT

In general, the methodology adopted in the development of Excel VBA program flexible pavement evaluation based on JKR's revised guideline: Systematic compilation of related technical specifications, computational algorithm development, programmatic coding and trial run, and case study application and comparison with alternate process. The first step which has been divulged in length in the preceding sections and ordered in a logical sequence is based primarily on JKR's ATJ 5/85 (Pindaan 2013) guideline. Other associated materials for example JKR's ATJ 8/86 entitled "A Guide on Geometric Design of Roads" were also consulted to supplement the informational gaps, and provide a more generic and guided presence within the resulting development.

The second step deals with conceptualizing the programmatic procedures in ordered and sequential manners through logical flow chart illustration as shown in Figure 1 and implemented in Figure 2 below. It begins with specifying arbitrary but unique reference number for a particular road stretch under consideration. Then, in the absence of specific traffic study data a JKR road standard may be selected from the cell list or hyperlink-directed user form with associated sanctioned specifications to guide in the following entries of the program (see Figure 3 for alternate input process for this). Next come entries for number of lanes, terrain type, design period, average annual traffic growth for commercial vehicles, Average Daily Traffic in one direction and percentage of commercial vehicles which would establish parallel values for Load Equivalence Factor, Lane Distribution Factor and Terrain Factor from tabular extraction. Following this, the number of ESALs needs to be entered through manual or assisted computation via cell or hyperlink-directed user form entry (see Figure 4 for alternate input process for this) respectively which would produce the design

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traffic, traffic category and applicable probability for the materials. Next step involves specification of CBR or modulus values used in Sub-Grade categorization (see Figure 5 for alternate input process for this). Finally, selection of pavement standard and structure would lead to appropriate pavement material specification as contained in Catalogue of Pavement Structures (see Figure 6 for alternate output process for this). The same process may be repeated for other distinct road stretches through distinct worksheet columns.

The third step revolves around programmatic implementation through coding. The program was developed over a standard MS Excel worksheet and utilizing as much as the parent application platform and functionality for unassisted input-output processes and relatively simple computational tasks as shown in Figure 2. Furthermore, since the program is implemented in top-to-down column-wise manner, this allows for systematic expansion of the computational process for other distinct design processes through simple replication (i.e. standard copy-and-paste procedures) in the column direction of the worksheet without necessitating multiple data file processing and storage. For more assisted input-output processes and complex computational tasks, automation would be provided through VBA in the guises of user forms, Form/ActiveX controls, subroutines and user defined functions (as explained in Figure 3 to 6). In this case, care should be taken to place the cursor on desired singular column in order to apply the necessary changes to it. Association to multimedia materials referenced by the program would also be established through scripting rather than through object embedment in order to optimize the file size. This is implemented by storing the required materials into a separate subfolder called “SupportFiles” and locating it into a common parent folder as that of the program file. The program is saved into a single macro-enabled workbook file called RdDs1.0.xlsm. The final product has been tested in multiple occasions as necessary in order to ensure computational accuracy and efficacy during every step of the development process and later in its finished form.

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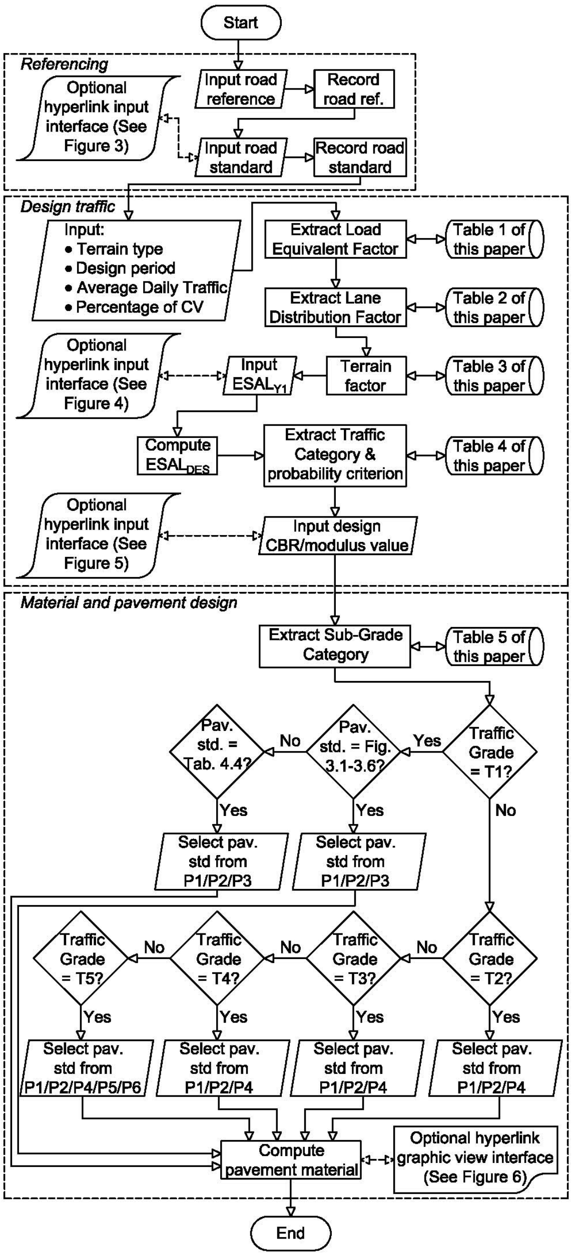

Figure 1: Flow chart of RdDs1.0 programming procedures

REFERENCES	ITEMS	SYMBOL/ FORMULA	UNIT	INPUT/ OUTPUT
	Element notation			
	Road standard			JKR U3
	Number of lanes in each direction			One
	Type of terrain			Rolling
	Design period	n	(yrs)	20
	Average annual traffic growth for design period for commercial vehicles	r	(%)	4
	Average Daily Traffic in one direction based on a minimum of 3 days, 24 hours per day	ADT		1350
	Percentage of commercial vehicles (Un-laden weight) > 1.5 ton	P_{CV}	(%)	16
Table 2.1	Load Equivalence Factor	LEF		3.5
Table 2.2	Lane distribution factor	L		1.0
Table 2.3	Terrain factor	T		1.1
Table 2.4	Total growth factor	TGF		29.78
	Number of ESALs for the base year (Design lane)	$ESAL_{Y1}$		303,534
	Number of ESALs for design lane in one direction	$ESAL_{DES}$		9,038,659
Table 2.5	Traffic category			T3
Table 2.5	Probability (Percentile) applied to properties of sub-grade materials		(%)	85
	Characteristic CBR/Modulus value used for design		(%)/(Mpa)	CBR 12.90
Table 2.6	Sub-grade category			SG2
Figure 3.1	Pavement standard			Fig. 3.1-3.6
Figure 3.2	Pavement structure			P1
Figure 3.3 Figure 3.4 Figure 3.5 Figure 3.6 Table 4.1	Pavement materials		(mm)	BSC:50 BC:130 CAB:200 GSB:200

Figure 2: Common RdDs1.0 worksheet opening template

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Figure 3: Road standard assisted-input interface

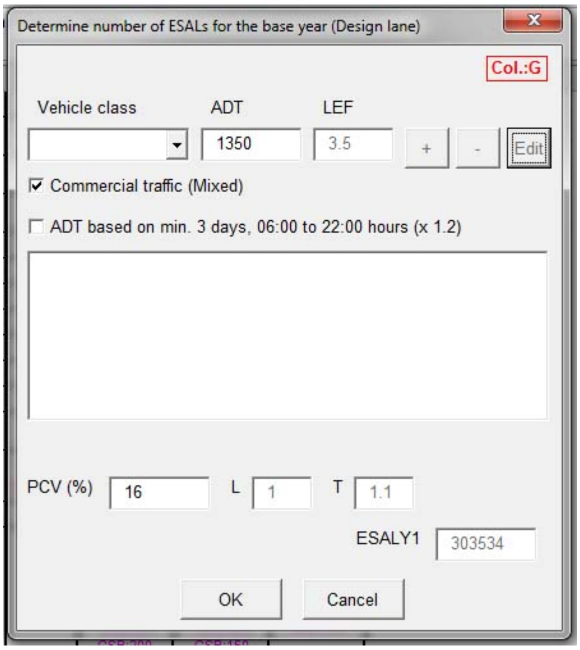

Figure 4: Number of ESALs assisted-input interface

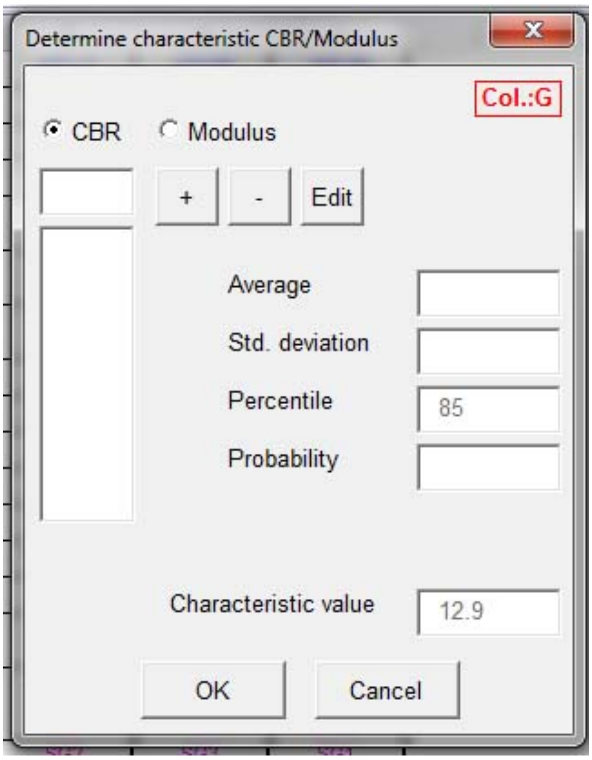

Figure 5: CBR/Modulus assisted-input interface

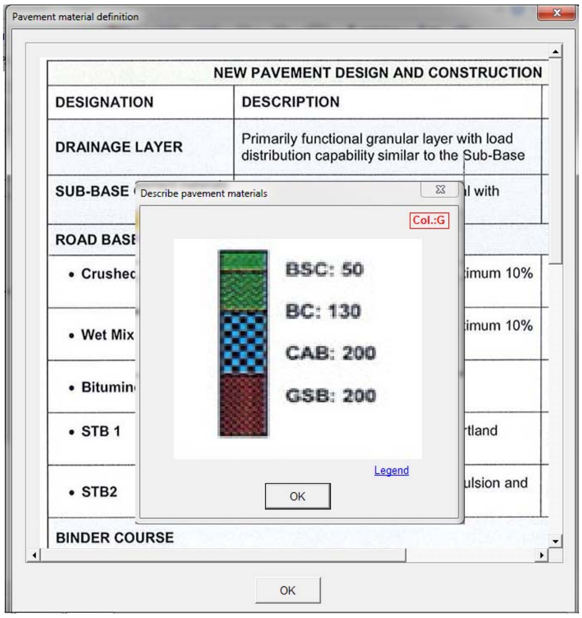

Figure 6: Pavement material assisted-graphic view interface

The final step which shall be treated in length in the succeeding section deals with putting the developed program through a more realistic test by applying a well-documented case study of an established project with observable physical performance and pre-existing design solution derived from an alternate process. As it happened, this process involves manual solution conducted by an experienced design engineer from the industry. The author wishes to set this criterion as a working benchmark rather than the commercial software results which are of

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foreign developments and may not be entirely customized to the local practices. However, a fair level of results agreement and trend can be construed under majority of cases where common or comparable design parameter can be set for the prescribed software.

4. CASE STUDY

What follows would describe the developmental circumstances of the selected case study which consists of an existing road stretches under operation. It was a Federal road project under the purview of JKR for the stretch of Jalan Kuala Krai towards Kota Bahru. This work had involved raising the underlying road platform and constructing the overlying pavement anew, and the authority had set the following design requirements:

Number of lanes	:	4
Terrain type	:	Flat
Design period	:	20 years
Average annual traffic growth for commercial vehicles	:	4.5 %
Average Daily Traffic based on min. 3 days @06:00 to 22:00 hours	:	1741 (686 of CV1, 586 of CV2, 331 of CV3 and 138 of CV4)
Percentage of commercial vehicles	:	10 %
Modulus of Elasticity of the Sub-Grade	:	Mean = 165 MPa Standard deviation = 28 MPa

From the information provided, the Lane Distribution Factor and Terrain Factor shall be 0.9 and 1.0 respectively. The Load Equivalence Factors applicable to CV1, CV2, CV3 and CV4 shall be 0.1, 4.0, 4.4 and 1.8 respectively giving ESALY1 of 1.353 millions and ESALDES of 31.37 millions (i.e. Traffic Category of T5) and applicable probability of the materials of more than 85 %. For the Sub-Grade, Characteristic Modulus of Elasticity shall be 119 MPa (i.e. Sub-Grade Category of SG 3). Hence, based on the prescribed non-technical constraints involving availability and cost the conventional flexible granular base type of pavement structure is deemed most appropriate for the project. Constituent layers include 50 mm Bituminous Surface Course (AC 10 or AC 14), 190 mm of Bituminous Binder Course or Road Base (AC 28), 200 mm of Crushed Aggregate Road Base and Granular Sub-Base. This selection is in fact identical to the one implemented on the ground.

Based on these results, it can be computationally deduced that the existing road pavement should suffice in catering for the projected traffics plying through the route under prescribed circumstances. This prediction is further backed up by direct observation of the road system in operation and performance on the ground which displays remarkable functionality and flexibility while exhibiting no structural distress over the years. In addition, a formal technical report containing adopted design parameter, manual computational descriptions and specific design details of the prescribed road pavement which was prepared by the original consultant of the project with recognized expertise, experience and professionalism has been used as the basis for comparison and found to be in adequate agreement with the program outcomes. This provides verification on the effectiveness of the software in conducting the road pavement design for the industrial problems.

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It is now beneficial to gauge to what extent that the prevalent manual design process would justify the software development particularly with respect to the intended road pavement design function. One way of appreciation would be to experience the former process first hand and document the challenges encountered along the way, and the author and its collaborators had signed on to this prospect. Firstly, in prescribing the ADT, LEF, L and T values external reference had to be made to distinct manuscripts. Secondly, in prescribing ESALY1 and ESALDES values separate computation had to be performed on specific formulas extracted from the relevant manuscript. Thirdly, in prescribing CBR or Modulus of Elasticity values a separate statistical process needed to be performed on a set of numerical data. Finally, in arriving at and visualizing the results external reference had to once again be made to the relevant manuscript. In general, time consumption and error potentials during multiple stages of the work process were inherent due to the multiplicity of tasks involved and human factors. In addition, the use of alternate software was also attempted but may also suffer from the incompatible guidelines built and high technicality apart from the usual problems associated with institutional or commercial software involving accessibility and cost.

5. CONSLUSION AND SUGGESTION FOR FUTURE RESEARCH

In conclusion, it can be deduced that many a drawback inherent in some of the available software as well as manual design project particularly relating to accuracy, functionality, flexibility, customization and acquisition cost can be addressed by the developed software. Furthermore, road pavement design cases as outlined in the new JKR guideline could be reasonably solved using the system and verified at various computational stages via a common interface. Lastly, complex project problem although technically soluble may require a degree of engineering judgment on the part of the users when it comes into actual implementation, but the same issues could also be said about other alternate systems. Examples of this scenario may revolve around selection of materials for a particular locality, sub-grade improvement, embankment construction, etc. This system allows for seemingly inexhaustible modelling try-outs and permits arrival at the most optimized solution.

It would be desirable to continue this work by incorporating more complex pavement design scenarios such as heavy duty flexible pavement and rigid pavements as well as technical correlations and models to make data entry and software usage as seamless a process and intuitive as possible. Only through such efforts would the level of conceptual abstraction be lowered and be made more comprehensible to wider users and practitioners of the trade.

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