

BENCHMARKING OF FUNCTIONAL AND STRUCTURAL ANALYTICS FOR NATIONAL PAVEMENT CONDITION CLASSIFICATION IN INDONESIA A CASE STUDY

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BENCHMARKING OF FUNCTIONAL AND STRUCTURAL ANALYTICS FOR NATIONAL PAVEMENT CONDITION CLASSIFICATION IN INDONESIA: A CASE STUDY

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INTRODUCTION

In recent years, the non-toll national road (nt-NR) management in Indonesia is indicated not optimal (Simamora and Hatmoko, 2014). The National Transportation Performance Evaluation and Assessment Team in 2009, a team in Indonesian Coordinating Ministry of Economic Affairs, mentioned that governance of road management has been suspected to be cause inefficiency and ineffectiveness of maintenance/rehabilitation of road infrastructure. In addition, when the post-construction and immediately after operated, several of road infrastructure newly constructed was severely damaged, and became a legal issue in Indonesia. Although the pavement was badly damaged category, it is very difficult to relate against the building failure in accordance with Indonesian Act, such as the Act No. 18/1999 concerning to Construction Service. Indeed, this situation had been suspected previously by Tumilar (2006), who mentioned that the Act No. 18/1999 is very difficult to implement due to its definition has multy interpretations. For instance, in the Indonesian Public Work Minister Regulation, No. 13 / PRT / 2011 is stated that

the worst conditions on the pavement is not passable. This classification indicates that the regulation has not been made clear to the pavement failure criteria.

Actually, when the badly damaged of pavement can be categorized into the building failure, the state (in Indonesia's context) would get any benefit financially, because the Act No. 18/1999 sets the penalties against the parties who caused the building failure. Therefore, it is important to develop an approach that can evaluate pavement objectively and comprehensively, thus the damage occurring can be justified according to the Act. There are several literatures that make failure category on pavement, including: PCI less than 10, (US Army, 1982, 2001; Park et al, 2007; Kodhuru et al, 2010), and rutt depth greater than 20 mm (Arampamoorthy and Patrick, 2010). Unfortunately, using PCI as single variable to classify pavement into failure category is considered to be less comprehensively, because PCI indicator is a representation of the functional service of pavement (Bennett et al., 2007; Sukirman, 1992). Bryce et al (2013) mentioned the assessment of road pavement will be more comprehensive if the functional and structural services are integrated.

Previously, Jimenez and Mrawira (2009) evaluated the pavement by integrating structural and functional services. The functional service used the IRI indicator, and the structural capacity used the deflection indicator obtained through FWD equipment. The problem in this method is the FWD is a representation of total strength of pavement structure (Chi et al., 2014). This makes it difficult to evaluate the pavement layer structure units. Evaluating each layer of the pavement structure is important, because the application of the management unit will provide a more objective assessment. Moreover, in that valuation models, IRI does not represent a pavement surface damage (US Army, 1982, 2001), so it is less appropriate to be used to measure pavement damage. However, the functional failure criteria (PCI <10) (US Army, 1982, 2001) and the method used by Jimenez and Mrawira (2009), is very important in the effort to integrate the functional and structural services on pavement.

The purpose of this study is to present an approach that will be able to classify the pavement into failed category, by integrating structural and functional services of pavement, and considering management unit, and using terminal services design as a benchmark. The specific objectives of this study were: 1) to assess the serviceability of pavement by integrating functional and structural services, and 2) to classify the pavement into the failing category with concerning the terminal serviceability designed, and pavement layer units. This valuation method expected can be used to measure whether the target is reached or not (Munehiro et al., 2011) based on each management unit of pavement. Beside that, this valuation method can also be used to detect the parties who are responsible for the outcome performance (Sydenham, 2004). Moreover, this method could potentially initiate to apply the Indonesian Act of Construction Service regarding to failure building clause, which has long been very difficult to be implemented. Thus, it is expected the NRnt management can be more optimized.

In this study, the primary limitation or axiom of the failure is a condition did not achieve purpose (Noon, 2009; Keminetzky, 1991 in Yates and Lockley, 2002, and Tumilar, 2006). According to Kocks Consult GmbH and Koblenz Universinj SRL (2009), "pavement design is a process of selection of appropriate pavement and surfacing materials to ensure that the pavement performs adequately and requires minimal maintenance under the anticipated traffic loading for the design period adopted. This selection process involves adoption of material types, thicknesses and configurations of the pavement layers to meet the design and performance objectives". Viewed from the aspect of pavement design, the purpose that must be

achieved on a pavement is the serviceability, which is called a terminal serviceability or terminal present serviceability index (PSI_T). While the failure of the pavement structure is indicated by the effectiveness of the capability under the minimum capability (Hudson et al., 1987; Faber et al., 2004). According to the Japan Society of Civil Engineering (JSCE, 2010), to achieve the level of the structure safety, the ratio (R) between capacity and workload must be greater than 1, meaning that $R = 1$ is a critical condition and $R < 1$ will result in failure.

This paper is organized into 5 sections: introduction, background review, methods of integrated assessment of road pavement, case study and the results discussion, and conclusions/ recommendations/future work.

BACKGROUND REVIEW

Pavement Management System(PMS)

According to Vitillo (2013), pavement management is a program to improve the quality and performance of the pavement and minimize costs through the implementation of good management consisting of: 1) the material management, 2) design, 3) construction, 4) management pavement, and 5) research and development. Meanwhile, a pavement management system is a set of procedures to collect, analyze, maintain, and report the pavement data to help decision makers in obtaining the optimal strategy to maintain pavement in order to provide its services during a specified period of time, and at a low cost.

Pavement management system (PMS) is designed to provide objective information and useful data, for analysis, so that the organizers can create a more cost effective and appropriate decisions related to road preservation. PMS can not make a final decision, but it can provide a basic understanding against the possible consequences on the alternative decisions (Vitillo, 2013; Townes et al., 2004). According to Townes et al. (2004), PMS helps provide answers to the following questions: 1) How is the general strategy of M & R, the most effective viewed from cost aspect ?, 2) Where (road segment) which requires M & R ?, and 3) When is the most appropriate time to perform road maintenance ?

In addition, Townes et al. (2004) said that, although different for each organizer, the basics of PMS is a database that includes a set of four common characteristics of data: 1) data inventory (including, pavement structure, geometry, environmental conditions, and others), 2) the use of the road (traffic volume and load, usually measured in equivalent single axel load-ESAL), 3) the condition of the pavement (driving quality, surface damage, friction, and / or capacity of the structure), and 4) pavement construction, maintenance history, and rehabilitation.

Road Management System in Indonesia

Indonesian Public Work Minister Regulation No. 11 / PRT / 2011, contains the procedures for road handling and classification of nt-NR conditions, as in Tab.1.(Appendix)

Assessment of Pavement

In Technical Manual No. 5-623 (US Army, 1982) and the UFC No. 3-270-06 (US Army, 2001), and Park et al. (2007), pavement conditions are classified as in Table 2. According to Park et al. (2007), the PCI is a function of the IRI as in Eq. 1, while the US Army (1982, 2001) gives a formula for PCI as in Eq. 2

$$PCI = f(IRI) \quad (1)$$

$$PCI = f(\text{distress; crack, pothole, rutt, etc.}) \quad (2)$$

Previously, Jimenez and Mrawira (2009) conducted an assessment of the pavement by integrating functional and structural variables using IRI and deflection (FWD) of pavement respectively as Eq. 3, where the PCI = Pavement condition index, IRI = international roughness index, FWD = falling weight deflection, α_1 and α_2 are the weight of functional IRI (0.40) and structural FWD (0.60). By considering the valuation method according to Jimenez and Mrawira (2009), variable FWD was to represent the condition of the structure totally, and the consequence was the condition of the structure for each layer of pavement would not be evaluated in detail. This condition will make difficult for decision-makers.

$$PCI = \alpha_1(IRI) + \alpha_2FWD \quad (3)$$

Research Findings and Gap

From the previous description it can be seen that the grouping system of road conditions is not clearly yet showing the role of pavement structure factor as in TM 5-623 (US Army, 1982) and UFC 3-270-06 (US Army, 2001). This can be seen from the explanatory variables of pavement conditions still tend using the surface damage factors, such as crack, pothole, rut, and others. Therefore, it is needed an evaluation that integrates both functional and structural factors of pavement. Indeed, integrated assessment of the functional and structural services has been done by Jimenez and Mrawira (2009), but that method needs to be improved with considering unit layer of pavement as shown in Fig.1.

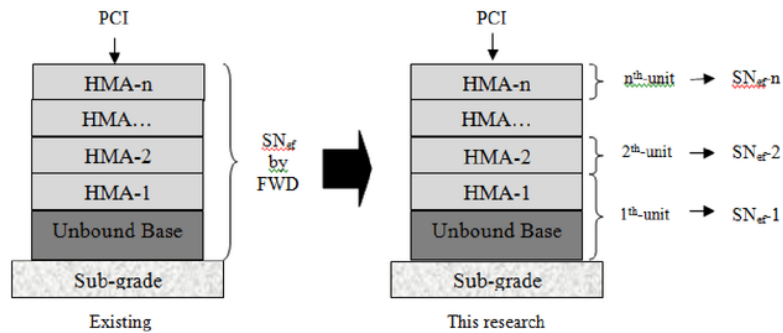


Figure 1. Existing conditions, gaps, and study results expected

Integrating functional and structural of pavement, considering management unit and using terminal serviceability as benchmark

Assessment that more objective and comprehensive related road pavement can be obtained by applying several concepts, including: 1) an integrated assessment of functional ability and structural (Bryce et al., 2013; Elseife et al., 2013; Mariani et al., 2012), 2) the assessment is based on the management unit (Lavinson, 1999), and 3) consider the achievements and targets (Munehiro et al., 2011). Mathematically, the assessment method that integrates functional and structural pavement can be made as Eq.4. The PCI is a function of the pavement surface condition obtained by Eq.2 (US Army, 1982, 2001), and the SCI is the ratio between the effective capacity of structure

(SN_{eff}) and the minimum/required capacity of structure ($SN_{min.}$), as Eq.5 (Bryce et al., 2013).

$$PSI = f(PCI) + f(SCI) \quad (4)$$

where,

$$SCI = \frac{SN_{eff}}{SN_{min.}} \quad (5)$$

The relationship between the PSI and the SCI can be seen from the relationship between ΔPSI ($PSI_o - PSI_T$) and the minimum SN on flexible pavement design in the AASHTO 1993 method (Garber and Hoel, 2002). Based on the achievement of target that may be obtained, given the qualification of the results, namely: 1) achievement above target, 2) achievement equal with target, and 3) achievement under target. Furthermore, by the semantic understanding by noted that failure, is a condition, that did not reach the goal (Indonesian Dictionary, Cambridge Dictionary), then, the result classification types are: 1) does not failed, 2) critical, and 3) failed. Thus, because the goal is the PSI, and the minimum requirement, is the PSI_T , then:

$$PSI; \begin{cases} > PSI_T & \text{not failed} \\ = PSI_T & \text{critical} \\ < PSI_T & \text{failed} \end{cases} \quad (6)$$

METHOD TO CLASSIFY PAVEMENT CONDITION: AN INTEGRATED ASSESSMENT, REFERENCE TERMINAL SERVICE, AND CONSIDER MANAGEMENT UNIT

In this study, data collection to decision-making stage of pavement comprises of: first, getting data which consists of primary and secondary data. Primary data consisted of the pavement surface condition obtained manually by using the TM 5-623 sheet (US Army, 1982), and the CBR data is obtained by using the DCP equipment. Secondary data consisted of the design data of pavement which is being evaluated ($SN_{minimum}$ or PSI_T), second, compiling the data into the PCI and SCI indicators, third, normalizing PCI and SCI value to PSI, fourth, determining PSI of the sample, and last, decision making against sample (not fail, critical, and fail). The stages 1-5 can be seen in the diagram as shown in Fig.2.

Pavement condition index PCI

PCI obtained manually by using the standard of TM 5-623 (US Army, 1982) as shown in Tab.3.

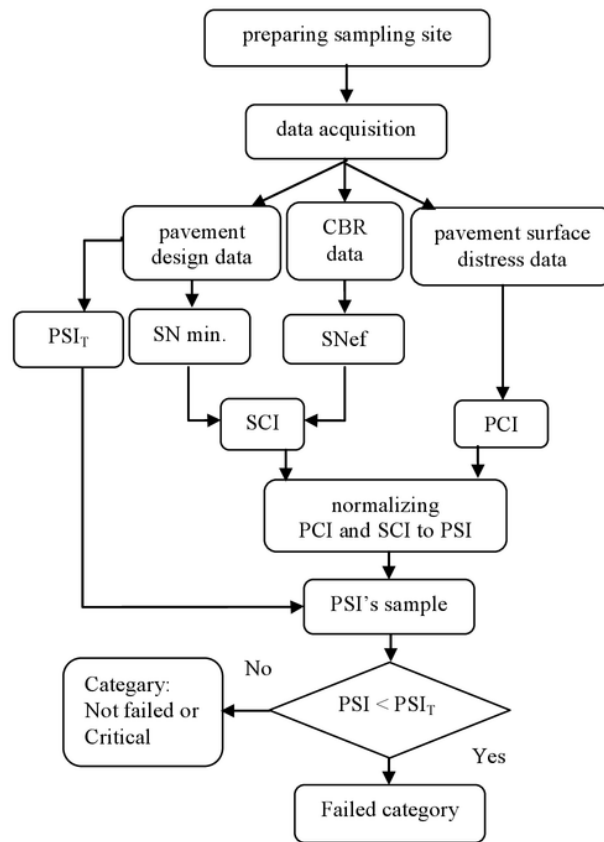


Figure 2. Flowchart of the decision making process to classify pavement condition into fail, critical, and not fail

Effective structural number (SN_{ef})

According to MassHighway (2006), the effectiveness of the SN (S_{nef}) can be determined using Eq.7, where: S_{nef}(i) is the effectiveness of SN of the pavement at the i-th layer, a_{ef}(i) is the effective relative strength of the pavement at the i-th layer, D(i) is the thickness of the pavement at the i-th layer.

$$SN_{eff} = \sum_{i=1}^n SN_{ef}(i) = \sum_{i=1}^n (a_{efi} \times D_i) \quad (7)$$

Meanwhile, MassHighway (2006) suggested using Eq. 8 to determine the coefficients of “a_{ef}”, where: “a_{design}” is the coefficient of the relative strength of the design of each layer of pavement, and RF is the reduction factor against “a_{design}” which depends on the pavement surface condition. Both of the “a_{design}” and “RF” coefficient in Eq.8 are referring to Table 2 and 3 respectively.

$$a_{eff} = a_{design} \times RF \quad (8)$$

In the other, the variable of “a₂ and a₃” were counted using Eq.9 and 10 (DPU, 2002), where E (elasticity) of granular material or aggregate is found refer to Eq. 11 (GmbH dan SRL, 2009). CBR is california bearing ratio of aggregate found by DCP test.

$$a_2 = 0.249 \times (\text{Log}_{10}E_{BS}) - 0.977 \quad (9)$$

$$a_3 = 0.227 \times (\text{Log}_{10}E_{SB}) - 0.839 \quad (10)$$

$$E = 5409\text{CBR}^{0.71} \quad (11)$$

Structure condition index (SCI)

As mentioned previously, SCI is a ratio between SNe_f and SN_{min}, as Eq.5. SNe_f illustrates the strength of existing structures, while SN_{min} illustrates the strength required which must be met during the design service life can be obtained on the pavement design documents being evaluated.

Normalizing of PCI and SCI to PSI

To determine the PSI, first perform the normalization process of size scale on PCI and SCI variables, as shown in Fig.3.

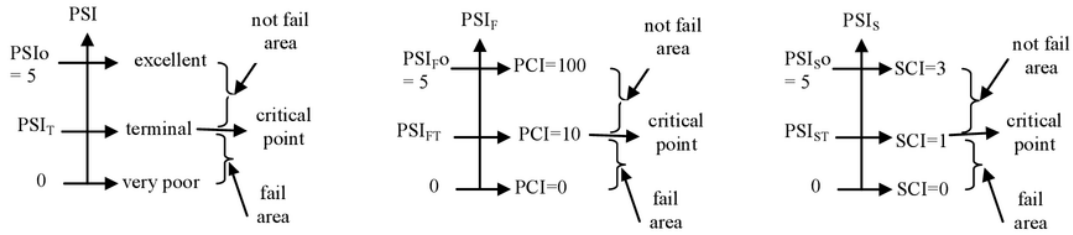


Figure 3. Normalizing concept of PCI to PSI_F and SCI to PSI_S

Present Serviceability index (PSI)

Based on the concept of normalization parameters, there are 9 conditions that may occur on the PCI and SCI together, which can produce PSI, involving:

PSI	Eq.
$PSI = \alpha 1x[2] + \alpha 2x[2]$: PCI = 10; SCI = 1	(12)
$SI = \alpha 1x[2] + \alpha 2x[SCIx2]$: PCI = 10; SCI < 1	(13)
$PSI = \alpha 1x\left[\frac{PCI}{10}x2\right] + \alpha 2x[2]$: PCI < 10; SCI = 1	(14)
$PSI = \alpha 1x[2] + \alpha 2x\left[2 + \frac{SCI - 1}{(SCImaks - 1)}x3\right]$: PCI = 10; SCI > 1	(15)
$PSI = \alpha 1x\left[2 + \frac{PCI - 10}{90}x3\right] + \alpha 2x[2]$: PCI > 10; SCI = 1	(16)
$PSI = \alpha 1x\left[\frac{PCI}{10}x2\right] + \alpha 2x[SCIx2]$: PCI < 10; SCI < 1	(17)
$PSI = \alpha 1x\left[2 + \frac{PCI - 10}{90}x3\right] + \alpha 2x[SCIx2]$: PCI > 10; SCI < 1	(18)
$PSI = \alpha 1x\left[\frac{PCI}{10}x2\right] + \alpha 2x\left[2 + \frac{SCI - 1}{(SCImaks - 1)}x3\right]$: PCI < 10; SCI > 1	(19)
$PSI = \alpha 1x\left[2 + \frac{PCI - 10}{90}x3\right] + \alpha 2x\left[2 + \frac{SCI - 1}{(SCImaks - 1)}x3\right]$: PCI > 10; SCI > 1	(20)

Classifying of pavement condition

Once obtained the PSI, then the last step is to classify the samples into categories: fail, critical, and not fail. In this study, the category of fail, critical, and not fail is the $PSI < PSI_T$, $PSI = PSI_T$, and $PSI > PSI_T$, respectively

CASE STUDY

Data Set Description

This study was conducted in 2013 at two locations were in Cianjur-Sukabumi and Kupang-Soe. In this study, there are 22 samples consisting of 19 samples obtained from Cianjur-Sukabumi (Tab.4) and 3 samples from Kupang-Soe (Tab. 5). Pavement surface condition was consisting of crack, pothole, rutt and other distress which were obtained using AASHTO 1993 method that was suggested by US Army (1982, 2001), while the capacity of pavement structure was obtained using the DCP equipment. The data of pavement structure, such as CBR and thickness of each layer was done by the staff of Cikampek Laboratory of Indonesian Public Work Depart for the Cianjur-Sukabumi location, and by the staff of Kupang State Polytechnic for the Kupang-Soe location.

In this study, the primary data consists of surface condition and structure of pavement. Pavement surface conditions consisting of surface distress such as cracks, holes, and others stated in the PCI. Other data of this study is secondary data, which consists of: 1) $PSI_T = 2$ (National road qualification in Indonesia), 2) $SCI_{max} = 3$ (effective strenght 3 x minimum strenght), 3) $\alpha_1 = 0.30$, $\alpha_2 = 0.70$ (Simamora and Hatmoko, 2013) and 3) SN minimum as shown in Tab.6.

Computing of PCI, SNeF, SCI, PSI

The PCI in this study are shown in Tab.7. In addition, the effective strength of the pavement structure (SNeF) can be determined using Eq.7. Meanwhile, the effective coefficient of the relative strength of pavement layers (a) can be calculated by Eq.8 for asphalt pavement (a1) as shown in Tab.8 and 9, and Eq.9 is used to find the coefficient a2 (Tab.10), and Eq.10 for the coefficients a3 (Tab.11). After the coefficients (a1, a2, and a3) are obtained, then SNeF can be determined as shown in Tab.12 and 13 for data captured from the field of Cianjur-Sukabumi, and Kupang-Soe, respectively.

Structural condition index on pavement is a variable that describes the ratio between the effective strength and minimum strength of pavement structure, which is expressed in the SCI. In this study, the SCI can be determined using Eq. 5 above, and its results can be seen in Tab.14. In Tab.14 can be seen that the SN-1 is the effective strength of the structure from the surface layer of asphalt, and SN-1 is the effective strength of the layer structure under the surface of the asphalt pavement structure. Thus, SCI-1 is a structural condition index for the asphalt surface layer structure, and SCI-2 is a structural condition index for the layer structure beneath the asphalt surface layer structure.

Once PCI and SCI are obtained, then the PSI for each sample was computed using Eq. 12 to 20, depending on the PCI and SCI value of sample. In this study, the discussion focused on the sample which could potentially be a problem, such as the sample that has the PCI and SCI was failing, or, failing PCI and SCI does not fail, or, PCI did not fail and the SCI was failing. For example, the sample No. 1 has a PCI =

12, and SCI-1 = 0.77: PCI is a category not fail, and SCI-1 is a category fail. Order to the sample No. 1 is used Eq. 18, thus, PSI is:

$$PSI = \alpha 1x \left[2 + \frac{PCI - 10}{90} x 3 \right] + \alpha 2x [SCIx2]$$

$$PSI = 0,30 x \left[2 + \frac{12-10}{90} x 3 \right] + 0,70 x [0,77 x 2] = 1,70$$

In the same way, the PSI for the other sample is computed, and the results are shown in Tab. 15.

Case Study Result: Sample Classification

Once the PSI of the sample is obtained, the next step is to classify the samples into three categories such as not failed, critical, and failed category. Sample which has: a $PSI > PSI_T$ is categorized into not failing, a $PSI = PSI_T$ is categorized into critical condition, and a $PSI < PSI_T$ is categorized into failing. Based on the PSI and PSI_T of sample, the classification of whole samples can be made as shown in Tab.16.

Discussion

From 20 samples that were evaluated in this study, 9 samples could potentially face a problem, such as: PCI is not failing and SCI is failing, PCI is critical and SCI is failing, PCI is failing and the SCI is not failing, PCI and SCI are failing. This situation makes the decision makers are in a difficult situation, and consequently, in the Indonesia context, Law relating to the building failure was very difficult to be implemented (Tumilar, 2006).

The result showed that integrated both of functional services and structural capacity of pavement, is very important in evaluating road pavement, especially in determining whether a pavement is failing or not. In addition, other factors play an important role are the unit management of pavement structure and minimum limit that must be achieved. All three of these factors can provide an objective and comprehensive assessment of pavement as shown in Tab.16. Sample No. 1 shows that the functional services of pavement does not fail, but the structure of the top layer of asphalt (SCI-1) is failing. Sample No. 1 has a $PSI = 1.70$ if the pavement was assessed by considering unit structure of pavement, and $PSI = 2.98$ if the assessment does not consider the unit structure factor and using total capacity of structure. These conditions make it clear that the sample No. 1 ($PCI > 10$) becomes failing category when the assessment considers unit structure, and becomes not failing when the assessment does not consider the unit structure of pavement. This assessment is very different from the opinion which states that the $PCI > 10$ is not failing (US Army, 1982, 2001). In addition, consideration of the unit management of pavement structure plays a very important role, and by doing so are expected to be obtained pavement assessment in more detail as suggested by Lavinson (1999).

Similarly, the sample failed functionally, and not failed structurally such as samples No.4,7,8, and 9, which have the PCI are failing category, but its SCI are not failing. PSI for these samples are greater than $PSI_T = 2$, both for the structure of the top layer of pavement (SCI-1), as well as for the total pavement structure (SCI_{tot}). These results show a clear difference to the existing failure criteria previously, which stated that the failing category is a $PCI < 10$ (US Army, 1982, 2001). Due to functional failure is not representing a pavement failure comprehensively, it is important to consider the other factor to be more comprehensive as well as pavement structure (Bryce et al., 2013; Elseife et al.,2013; Mariani et al., 2012).

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

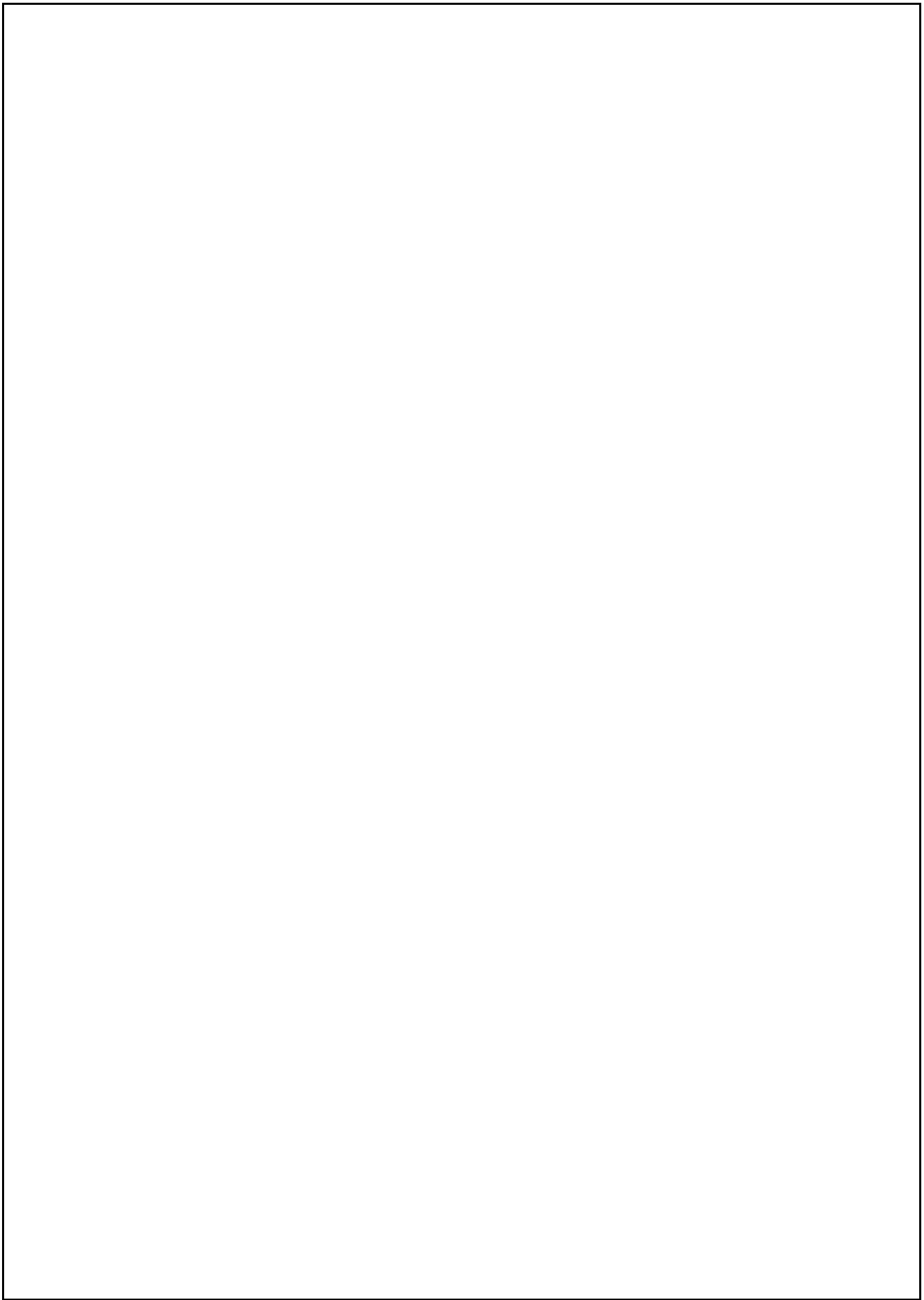
This study aims to present an integrated assessment by considering the unit Management and terminal services designed. In this study, the axiom of failure is a condition that is not reached terminal services are designed. Thus, in this study, the failure axiom on the pavement is the road that has a serviceability (PSI) under the design terminal serviceability (PSI_T). By using that axioms of the failure can be concluded: 1) pavement functionally, or structurally failed is not well-suited to classify the pavement into the failing category, 2) pavement functionally and structurally failed will be able to confirm pavement failure, and 3) pavement assessed by considering unit management has a greater chance against failure. This valuation method can be used to detect the parties, who are responsible for the outcome performance, and is potentially used to initiate the implementation of the Indonesian Act of Construction Service, which has been very difficult to implement. Thus, it is expected, the NRnt management can be more optimized.

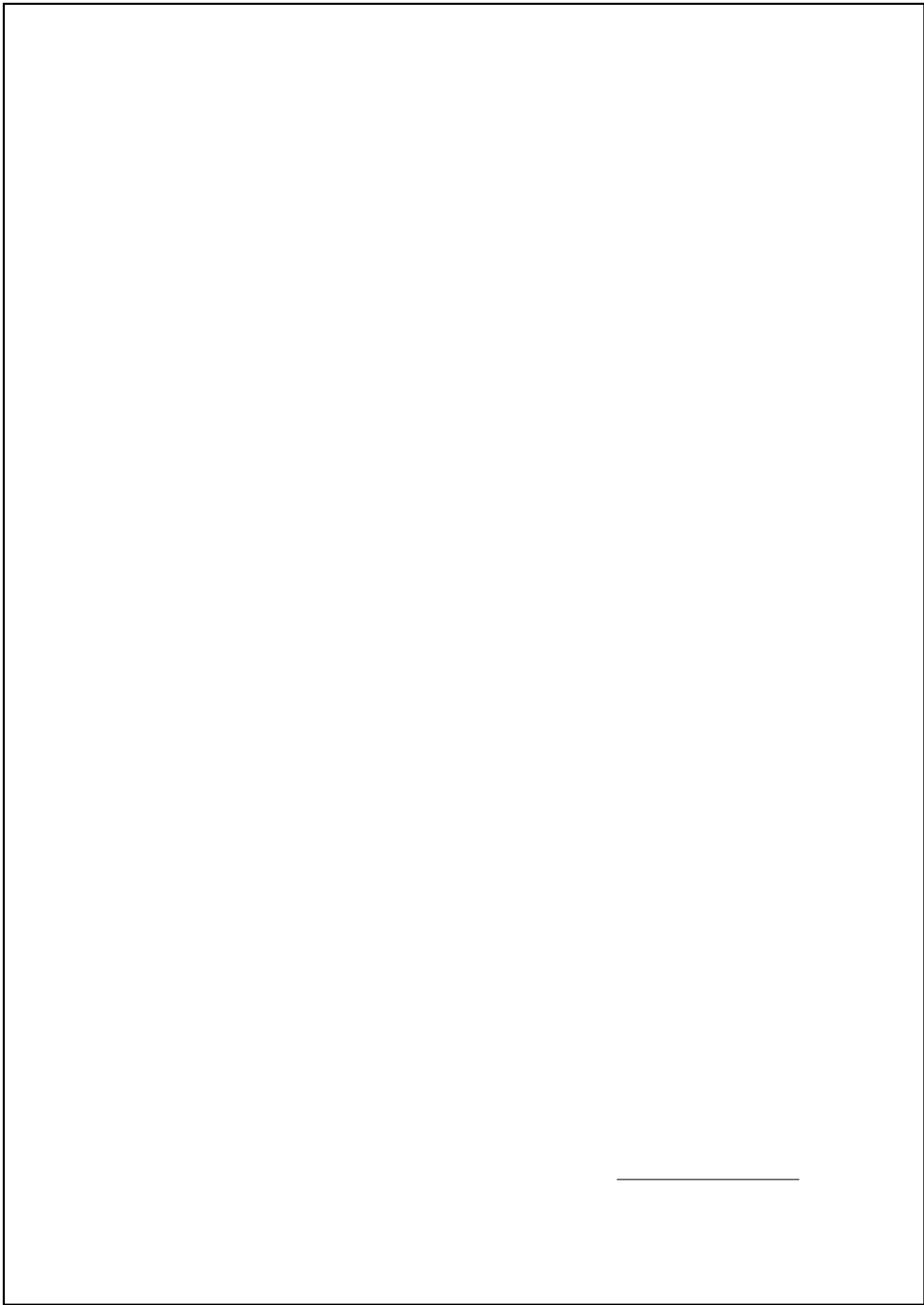
Therefore, to assess the pavement, whether failed or not recommended: first, is not enough to simply to consider condition of the road surface, but will have to consider the ability of the pavement structure, second, the assessment should have a clear reference, such as a minimum standard according to the design, last, an assessment is necessary to consider the unit management. In addition, due to this study is only limited to how to integrate between PCI and SCI, and utilize the design in the evaluation process at the pavement operation stage, and demonstrate the role of the unit management in road pavement evaluation system, then the failure cause needs to be studied further to ascertain whether due to natural or human actions. Failure due to nature is a disaster, and failure due to human is the building failure category which is needs to be accounted for.

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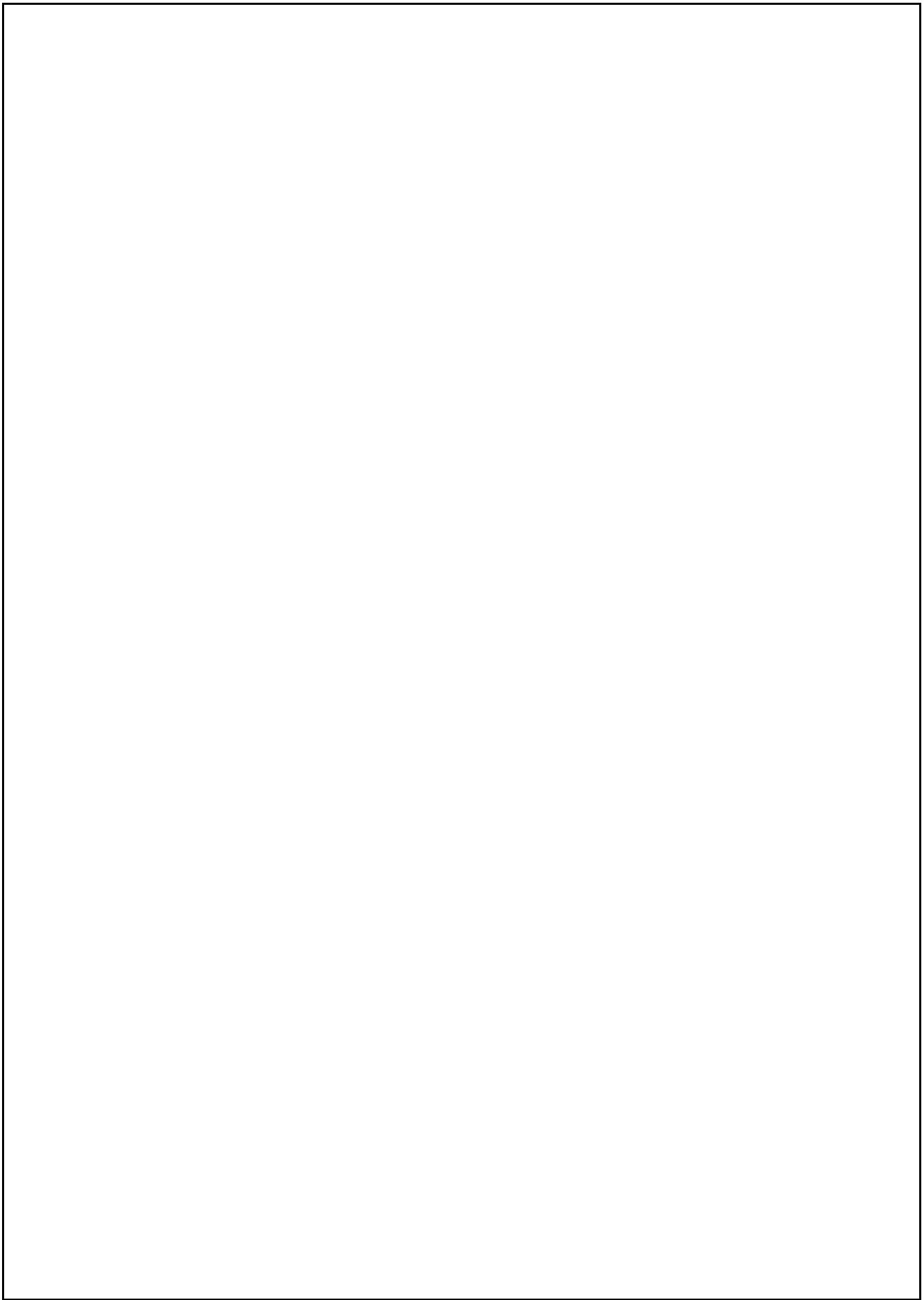












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GENERAL COMMENTS

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