

Proactive pavement asset management with climate change aspects

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Abstract. Pavement Asset Management System is a systematic and objective tool to manage pavement network based on the rational, engineering and economic principles. Once implemented and mature Pavement Asset Management System serves the entire range of users starting with the maintenance engineers and ending with the decision-makers. Such a system is necessary to coordinate agency management strategy including proactive maintenance. Basic inputs in the majority of existing Pavement Asset Management System approaches comprise the actual pavement inventory with associated construction history and condition, traffic information as well as various economical parameters. Some Pavement Management System approaches include also weather aspects which is of particular importance considering ongoing climate changes. This paper presents challenges in implementing the Pavement Asset Management System for those National Road Administrations that manage their pavement assets using more traditional strategies, e.g. worse-first approach. Special considerations are given to weather-related inputs and associated analysis to demonstrate the effects of climate change in a short- and long-term range. Based on the presented examples this paper concludes that National Road Administrations should account for the weather-related factors in their Pavement Management Systems as this has a significant impact on the system outcomes from the safety and economical perspective.

1. Introduction

Transport infrastructure, with pavements and bridges in particular, represents an enormous national asset that must be properly managed using modern economical and engineering principles. Traditional constraints in the efficient management of these assets have been associated with increasing traffic, annual weather variations, and material and construction variability. While these aspects are challenging, majority of the NRAs have accommodated and successfully developed management systems to support their decision-making processes. However, the last two decades brought an increasing concern about the effects of climate change and extreme events (such as flooding, land sliding, extreme raining) on the infrastructure assets [1] [2] [3]. While both aspects are valid and should be addressed, their implementation in the traditional management process can have significant consequences. Therefore implementation of both climate change and extreme events require a strategic planning and preparation of the appropriate adaptation measures. In other words, NRAs should be aware that climate change and extreme events will inevitably affect their assets and operations [4] [5]. Each NRA should decide what actions to undertake. Such a judgement should be based on the logical and comprehensive cost-benefit analysis that would accommodate stochastic



nature of climate-related events together with the probability of asset failure and its impact magnitude [4]. Such an approach allows the NRS to assess the risk as follows [1]:

$$\text{Risk} = P(\text{Climate Event Occurrence}) \times P(\text{Asset Failure}) \times \text{Consequence} \quad (\text{Eq. 1})$$

Risk analysis identifies and classifies potential vulnerabilities of the NRA transport assets to climate change. This issue has been presented in the number of recent reports and publications including [2] [6] [7] [8]. In addition to available reports, there is also a significant number of research projects that have been initiated to address climate-change and its implications on the transport assets. Some examples include projects sponsored by the European Commission under FP7 (WEATHER, STREST, RAIN, InfraRisk, EWENT) and projects sponsored by the Conference of European Directors of Roads, CEDR (ROADAPT, RIMAROCC, MIRAVEC, DETECTOR).

2. Proactive maintenance

Proactive maintenance is a management strategy to provide and maintain serviceable roads. It is a multi-year planned strategy to select most effective treatments to preserve pavement assets, to retard their future deterioration and to maintain or to improve their functional condition without increasing their structural capacity [9]. Proactive maintenance typically includes corrective and preventive maintenance as well as minor rehabilitation. The concept behind proactive maintenance is presented in Fig. 1. As compared to reactive approach, proactive approach promotes carefully selected maintenance activities applied at optimal timing that allow to keep pavements in very good condition. Such an approach is always more beneficial from the user, owner and environmental perspective that has been proven in numerous studies and put in practice [10]-[23]. In order to demonstrate the benefits of proactive maintenance, these studies utilize various economical tools to perform life-cycle planning (LCP) and they often incorporate not only technical aspects but also include social aspects (e.g. accidents, user delay, vehicle operation costs) as well as environmental aspects (e.g. air pollution, noise emission, energy consumption).

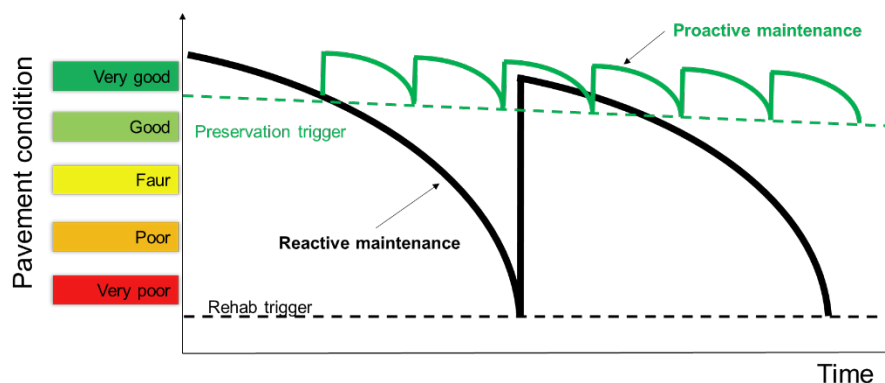


Figure 1. Concept of proactive and reactive maintenance approach (both condition-based).

It should be emphasized that optimized proactive strategy supports sustainable development and mitigates future maintenance burden. Among other advantages, it reduces carbon footprint, contributes to economy growth and improves road safety [24]. Proactive strategy is of paramount importance for the newer pavements before they reach significant deterioration. Proactive strategy should be defined and incorporated in the PMS tools as soon as the new roads are built to determine reasonable and objective funding allocation between newer and older network using life-cycle planning (LCP). Properly defined strategies in the PMS should allow to perform multi-aspect what/if scenarios to determined optimal timing for right proactive activities and to assess deferred maintenance and associated stop-gap needs.

3. Weather and climate changes vs. transport assets

Weather and climate refer to two distinct terms [25]. Weather is defined as conditions in the atmosphere and the space around us at a particular instance. Observed phenomena include temperature, rain, sun, snow, fog, clouds and wind. On the other hand, climate is the average weather collected over various time scales. Climate is simulated and predicted using global circulation models (GCM) [1]. These models operate at relatively low spatial resolution and very often do not provide sufficient information required for transport asset analysis. Therefore, regional climate models (RCMs) have been developed that cover only specific regions and operate at higher resolution. It should be noted that all climate models estimate average trends and thus contain natural variability. Their predictions are accompanied with the probability that contributes to the risk analysis presented in Equation 1.

Climate change can be also defined [25] as a change in the climate state that can be assessed using robust statistical tests. The change can be tested on average values or on the variability of properties and it should persist over significant time span (e.g. one decade). Climate changes may have a significant impact on transport infrastructure [1] [4] [6]. The impact magnitude depends on the specific asset and its vulnerability to a specific climatic phenomenon (temperature, rainfall, etc.) as well as other factors. Most common pairs of the climate phenomenon and infrastructure asset considered in the literature are as follows [1] [4] [6]:

- temperature – pavements,
- temperature – bridges,
- rainfall – pavements, drainage and integrity of the entire road structure,
- sea-level rise – drainage, integrity of coastal roads,
- hurricane intensity – bridges.

Next paragraph present several studies on the effect of the climate change on pavement performance. It is followed by more general considerations of the climate-related aspects in the PMS.

4. Climate-related aspects in PMS

Pavements, both asphalt and concrete, are susceptible to weather conditions. However, various conditions do not equally affect pavement performance. Therefore it is necessary to use realistic models that capture the dependence of material/structure behaviour in terms of climatic factors, such as temperature and rainfall. One such a study [2] demonstrates the impact of climate change on pavement performance using NOAA and MEPDG (Mechanistic-Empirical Pavement Design Guide). Analysis showed that climate changes contributed to the premature pavement rutting. Economic analysis showed that agency costs may increase but it can be offset in savings for the road users. Other study [26] was based on the LTPP (Long Term Pavement Performance) data and again the NOAA model. Presented examples showed that accounting for flooding and snowing in the pavement roughness model gives more accurate predictions which in turn can allow for more reliable assessment and timing of the Maintenance and Rehabilitation (M&R) activities. Two other studies [27] [5] investigated the rainfall and resulting moisture in pavement layers. Both studies concluded that increased moisture content will shorten pavement service life and that rainfall is one of the most important factors affecting the design and operation of the road network. Finally, recent study in Germany [28] focused on the importance of air temperature on the pavement life design. The analysis, using mechanistic pavement response model, showed that in some areas of Europe's pavement design (and associated PMS models) does not need to be changed because of current predictions in climate changes. Nonetheless presented methodology can be used to assess the need in other parts of the world.

These few studies confirmed that the effect of climate change on pavement performance varies depending on the climatic phenomenon and geographical region. However, if one wants to consider a broader view on pavements and consider their life-cycle PMS, there is a number of potential aspects that need to be considered. These aspects are presented in Fig. 2.

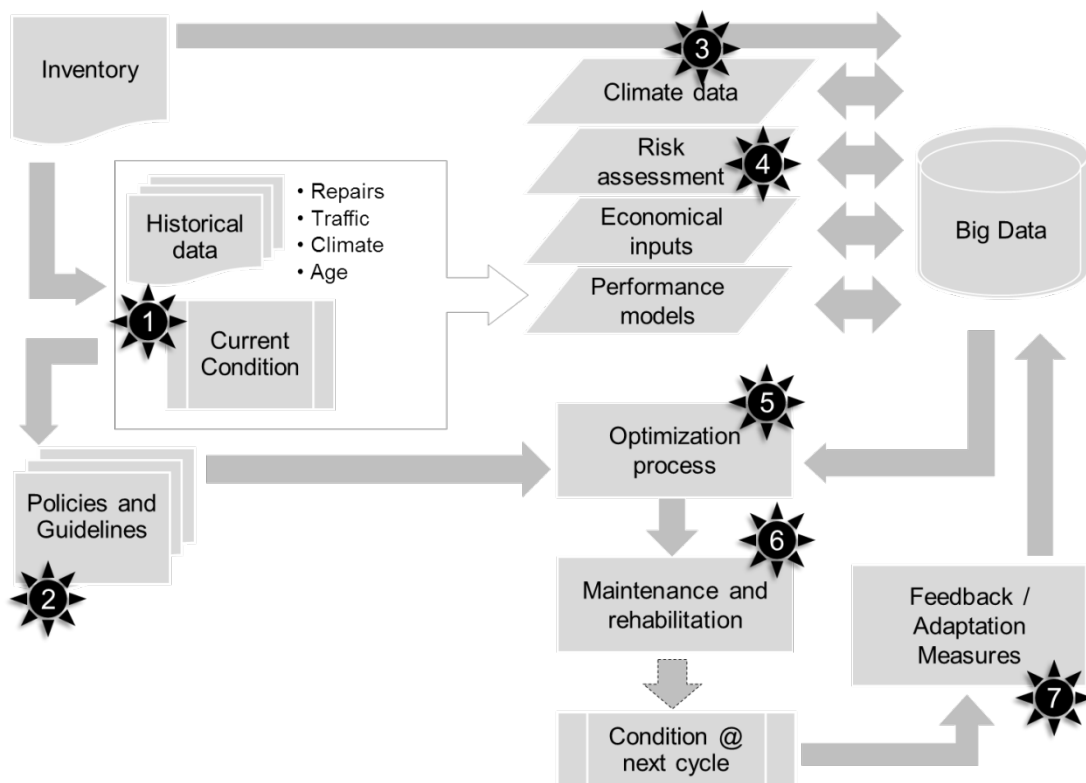


Figure 2. Potential climate aspects in the global PMS workflow.

Figure 2 presents climate-related aspects (depicted by the numbered stars) in the general PMS workflow. These aspects span across the entire PMS process and some of them are already present in the commercial PMS platforms and have been also identified in the aforementioned studies [1] [4] [29]. The following list presents in more details each of the seven aspects:

- (1) Historical weather data should be associated with pavement sections to link weather and performance; climate change and extreme events may affect operations of pavement conditions assessment and may require adaptation changes in measuring techniques.
- (2) Climate change and extreme events will demand new M&R techniques and alternative construction materials; decision tree and tables need to accommodate relevant climate information and criteria.
- (3) Extensive weather data should be collected together with other PMS data; predictive weather models should be developed and constantly validated.
- (4) Risk of extreme weather events should be incorporated into predictive weather, traffic, safety and performance models to assess the vulnerability potential and be used in the benefit/cost analysis.
- (5) Optimization process should combine previous aspects (risk, performance, M&R policies) and weather-related constrains should be incorporated into priority tables to rank recommended projects.
- (6) Climate change will affect not only M&R techniques (included in aspect #2) but it will also influence their timing, planning and operation to maintain construction safety and efficiency.
- (7) Relevant Key Performance Indicators (KPIs) should be introduced to assess and track adaption measures; KPIs should include safety and economical parameters; feedback loop should comprise all corresponding models including weather; monitor KPIs to update NRA policies and strategies.

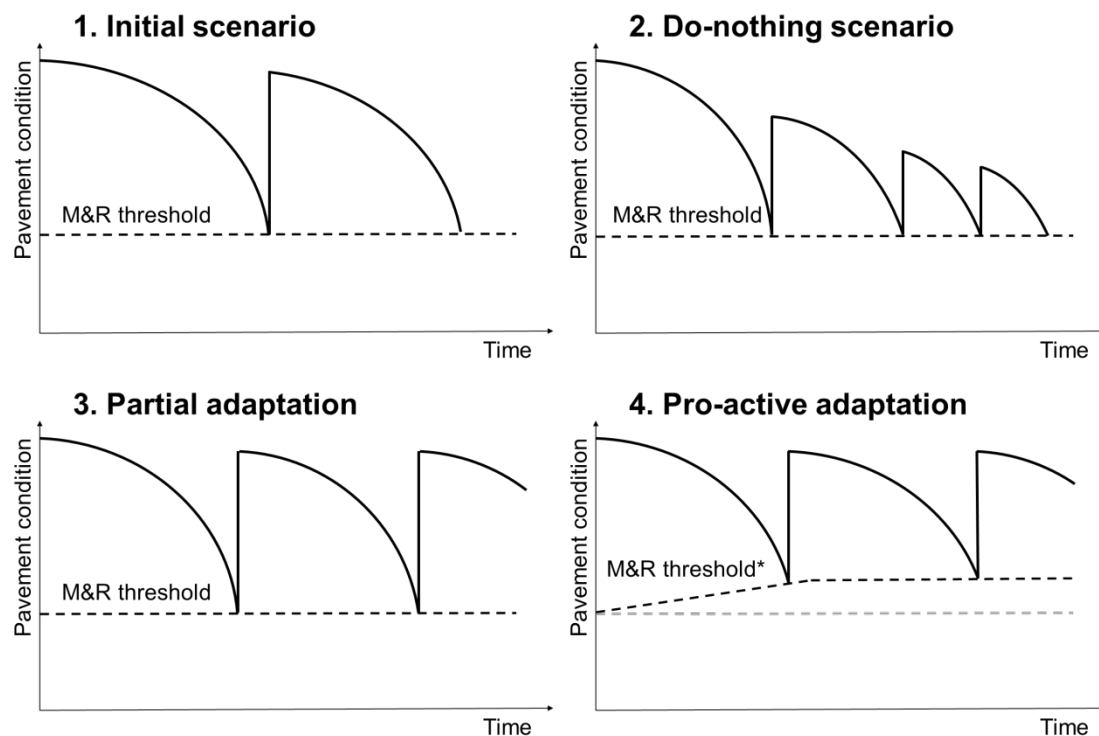


Figure 3. Mitigation of climate-related effects.

In order to complement the global effects presented in Fig. 2, Fig. 3 demonstrates the potential impact of climate change on the pavement performance. Different stages represent a potential progress of the NRA to mitigate the climate-related effects:

- (1) Initial scenario (no climate change): traditional PMS approach (no pavement preservation approach); performance-based trigger for the M&R activities.
- (2) Do-nothing (climate change): inadequate M&R activities; shorter initial performance gains and steeper deterioration curves; passive adaptation – no change in M&R threshold; results: poor pavement condition, high user and agency costs, safety concerns.
- (3) Partial adaptation (climate change): adaptation in M&R techniques; full performance recovery and much better resilient performance; still no change in M&R threshold.
- (4) Pro-active adaptation (climate change): adaptation in M&R techniques; full performance recovery and fully adapted resilient performance; adjusted condition threshold; inevitable higher agency costs as compared to scenario [1] but enhanced overall condition that leads to improved safety levels.

Figure 3 presents one potential sequence of different scenarios associated with climate adaptation in the PMS. It is certain that each NRA will try to embrace this challenge with different strategy that may produce different results across the transport network. Each strategy will depend on the NRA policy and available resources as well as the timing of adaptation measures. Several adaptation plans and strategies are presented in the next section.

5. Conclusions

- (1) Cost benefits and adaptation strategies are implemented by various NRAs: Number of NRA organizations have been examining and preparing various adaptation plans to face climate-change (FHWA, Highways Agency, Transport Scotland or Trefikverket). For example, the NCHRP study in the USA prepared the benefit/cost tool for climate adaptation strategies and also listed 8-step adaption diagnostic framework which is based on the risk analysis presented

earlier in Equation (1). A UK-based study focuses on pavements and proposed several recommendations to better handle climate change including:

- cost benefit of adaptation to hotter, drier summers,
 - need for wider analysis on climate change impacts,
 - need for improved data on impacts of weather conditions.
- (2) Development of adaptation action plans: Another report from the UK conducted by the Highways Agency discusses in more details the Agency's Adaptation Framework Model (HAAFM). It is a seven stage process that prepares adaptation action plans for all identified vulnerabilities.
 - (3) Need for measurable KPIs for asset management and climate change: Other strategy is presented in the report prepared by the FHWA explicitly on climate change adaptations for pavements. According to this study, climate changes will occur slowly and no immediate changes to current PMS practice is necessary. The key point is to identify when to modify the current practice and what KPIs should be used to monitor and trigger these modifications.
 - (4) Optimisation strategies for asset management: In another example provided by the Scottish NRA, the Agency reviewed their strategy developed in 2005 after 6 years of operations. All 28 recommendations that were prepared in the original study were found to be still valid. It should be mentioned that the Scottish strategy comprise a number of pro-active activities related to their road network addressing temperature, rainfall/flooding and wind aspects of the climate change.

In summary, given the ongoing drive for efficiency and resilience in transport infrastructure, the NRAs must acknowledge climate changes and implement appropriate adaptation plans in the foreseeable future. In particular, NRAs should account for the weather-related factors in their PMS as they have a significant impact on the PMS outcomes from the safety and economical perspective.

References

- [1] Meyer M., et al., Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report, NCHRP Report 750, 2014.
- [2] Flintsch G. W., Qiao Y., Impact of Climate Change on the Performance, Maintenance, and Life-Cycle Costs of Flexible Pavements, 11th National Conference on Transportation Asset Management July 10–12, 2016 Minneapolis Marriott City Center, Minneapolis, Minnesota.
- [3] Transport Scotland, Scottish Road Network Climate Change Study, Report, 2005.
- [4] Highways Agency by Atkins, Economics of Climate Change Adaptation and Risks, Final report, 2013.
- [5] Highways Agency, Climate Change Adaptation Strategy and Framework, 2009.
- [6] Willway T., et al., The effects of climate change on highway pavements and how to minimize them: Technical report. Project Report PPR 184, TRL Limited 2008.
- [7] FHWA, Climate change adaptation for pavements, FHWA-HIF-15-015, FHWA TechBrief, August 2015.
- [8] Crow R., et al., District 1 Climate Change Vulnerability Assessment and Pilot Studies: FHWA Climate Resilience Pilot Final Report, 2015.
- [9] G. R. Hicks, S. B. Seeds, and D. G. Peshkin, "Selecting a preventive maintenance treatment for flexible pavements," Washington, D.C, 2000.
- [10] S. Chan, B. Lane, T. Kazmierowski, and W. Lee, "Pavement preservation a solution for sustainability," *Transp. Res. Rec. J. Transp. Res. Board*, p. 7, 2011.
- [11] J. J. Hajek and W. A. Phang, "Prioritization and optimization of pavement preservation treatments," *Transp. Res. Rec.*, p. 11, 2017.
- [12] L. Cesar, "Pavement preservation theory and strategies," in *Northwest Pavement Management Association*, 2015, p. 56.
- [13] D. Peshkin, "Pavement preservation on highly trafficked roads: the new normal," in *National Pavement Preservation Conference 2016*, 2016, p. 26.

- [14] T. Scheinberg and P. C. Anastasopoulos, "Pavement preservation programming: a multi-year multi-constraint optimization methodology," in 89th TRB Annual Meeting, 2010, p. 16.
- [15] NAPA, "The pavement preservation tool of choice NAPA position on thin asphalt overlays for pavement preservation, Report number SR-210," Lanham, MD, 2014.
- [16] D. Pittenger, D. D. Gransberg, M. Zaman, and C. Riemer, "Stochastic life cycle cost analysis for pavement preservation treatments," in Transportation Research Board, 2012, p. 15.
- [17] K. L. Smith, L. Titus-Glover, M. I. Darter, H. Von Quintus, R. Stubstad, and L. Scofield, "Cost-benefit analysis of continuous pavement preservation design strategies versus reconstruction," Transp. Res. Rec. J. Transp. Res. Board, p. 11, 2005.
- [18] B. Visintine, G. R. Hicks, D. X. Cheng, G. Elkins, and J. Groeger, "Factors affecting the performance of pavement preservation treatments," in 9th International Conference on Managing Pavement Assets, 2015, p. 23.
- [19] B. Aktaş, D. Gransberg, C. Riemer, and D. Pittenger, "Comparative Analysis of Macrotexture Measurement Tests for Pavement Preservation Treatments," Transp. Res. Rec. J. Transp. Res. Board, p. 7, 2011.
- [20] D. F. Report, Performance-Related Specifications for Pavement Preservation Treatments, no. July 2016. National Academies Press.
- [21] J. Wiegmann and B. Yelchuru, "Resource allocation logic framework to meet highway asset preservation," National Academies Press, 2012.
- [22] Zimmerman K. A., Ram P. V., Pavement Management's Role in an Asset Management World, 9th International Conference on Managing Pavement Assets (ICMPA9), Washington, DC, May 18-21, 2015.
- [23] Zofka A., Josen R., Paliukaite M., Vaitkus A., Mechowski T., Maliszewski M., Elements of Pavement Management System: Case Study, Baltic Journal of Road and Bridge Engineering, Vol. 9, Issue 1, pp: 1-9, 2014.
- [24] World Road Association PIARC, "Preserve your country's roads to drive development, Report number 016R07EN," Paris, 2016.
- [25] FHWA, Climate Change & Extreme Weather Vulnerability Assessment Framework. FHWA-HEP-13-005. FHWA, 2012.
- [26] Shamsabadi S. S., Tari Y.S. H., Birken R., Wang M., Deterioration forecasting in flexible pavements due to floods and snow storms, 7th European Workshop on Structural Health Monitoring, July 8-11, 2014. La Cité, Nantes, France.
- [27] Bilodeau, J-P., Dore G., Thiam P. M., Drolet F. P., Long-Term Performance of Flexible Pavement Structures in a Changing Climate. Proceedings, Annual Conference of the Transportation Association of Canada: Better - Faster – Safer. September 22-25, 2013, Winnipeg, Manitoba, Canada.
- [28] Wistuba, M. P. and A. Walther. 2013. "Consideration of Climate Change in the Mechanistic Pavement Design." Road Materials and Pavement Design, Vol. 14, Sup. 1, Special Issue: EATA 2013.
- [29] Shahin, M.Y.; Walther, J.A. 1990. Pavement maintenance management for roads and streets using the PAVER system. USACERL Technical Report M-90-05.