OCENA STANJA I PERSPEKTIVE ODRŽAVANJA MOSTOVSKIH KONSTRUKCIJA U GRADU NIŠU

CONDITION ASSESSMENT AND MAINTENANCE PERSPECTIVES OF BRIDGE STRUCTURES IN THE CITY OF NIS

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1 UVOD

Potrebu za mostovima čovek je osećao od svog postanka. Mostovi su građevinski objekti koji saobraćajnicu prevode preko neke prepreke, što je utilitarna definicija mosta. Pri tome se podrazumeva zadovoljenje određenih ljudskih potreba, stvaranje novih oblika na zemljinoj površini, kao i objektivna težnja ka funkcionalnosti, stabilnosti, racionalnosti, unutrašnjem skladu i skladu sa okolinom. Takođe, mostovske konstrukcije istovremeno moraju biti sigurne i trajne, ali – neretko – most može biti i svojevrsno umetničko delo. Tehnički besprekorno rešen zadatak, a što podrazumeva optimalnu funkcionalnost i pouzdanost uz najmanje moguće troškove, neće biti potpun ako rezultat nije ujedno i lep most.

Mostovi su građevinski objekti koji svojom veličinom, izgledom, pojavom u prostoru, pa čak i simbolikom, vrlo često dominiraju ambijentom ili krajolikom u kojem se nalaze. Stoga, uz osnovne principe veštine projektovanja i građenja mostova (objektivnost, funkcionalnost, stabilnost, racionalnost i originalnost) – koje mora zadovoljiti svaki most, dolazi i estetika.

Može se reći da mostovi nisu konstrukcije, jer mostovi sadrže konstrukcije.

Vekovna tradicija mostogradnje i njen razvoj putem svojevrsnih oblika građenja različitih mostovskih konstrukcija, predstavlja težnju ka zadovoljenju mnogih čovekovih potreba i zahteva. U tom procesu, čovek je koristio razne materijale i sredstva koja su mu u pojedinim periodima stajala na raspolaganju, a najstariji primitivni mostovi su raznovrsne forme od srušenih

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1 INTRODUCTION

People always need bridges. A utilitarian definition of bridges is that they are structures intended to carry a road across some obstacle. This entails meeting of certain human needs, creation of new forms on the face of the earth and an objective aspiration to functionality, stability, rationality, interior harmony and harmony with the environment. In addition, bridge structures should be safe and durable, but often, it is a work of art. A technically impeccably performed design, which means optimum functionality and reliability with the least possible cost, is unlikely to be complete if it has not resulted in a beautiful bridge as well.

Bridges are civil engineering structures which very often dominate the environment or landscape where they are situated by their size, appearance in space and even by symbolism. Therefore, fundamental principles of designing and constructing bridges (objectivity, functionality, stability, rationality and originality), which should be met by any bridge, are accompanied by esthetics.

It can be said that bridges are not structures, since bridges contain structures.

Centuries long tradition of bridge-building and its development through various forms of construction of different bridge structures, represents an aspiration to satisfy various human needs and demands. In this process, man used materials and resources at his disposal in specific periods, and the oldest primitive bridges are certainly various forms ranging from felled trees to stone slabs, plant fibers and timber beams. Bridge-building history is a sound basis and instruction

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stabala ili od kamenih ploča, te od biljnih vlakana i drvenih greda. Graditeljska istorija mostogradnje dobra je pouka i podloga za stvaranje novih savremenih dela. Industrijska revolucija i njene posledice pred mostogradnju su postavljali nove zadatke, stvarajući preduslove za razvijanje novih konstrukcija i ostvarivanje još većih raspona.

Uspeh u projektovanju i građenju mostova zasniva se na dobrom poznavanju teorije konstrukcija i materijala, mašti i hrabrosti konstruktera u razvijanju novih ideja, kao i volji da se uči na tuđim greškama i sopstvenim iskustvima. Savremene metode analize sve više se primenjuju pri proučavanju i konstruisanju mostovskih konstrukcija, što daje ne samo lakše i ekonomičnije mostove, već se adekvatnim oblikovanjem konstrukcijskih detalja omogućuje mostovskim konstrukcijama pravilniji rad, a samim tim i postizanje većih raspona, te dalje domete savremenih mostova. Nova saznanja doprinose tome da – uz novu tehnologiju i tehniku – čovekova mašta postaje stvarnost.

Mostovske konstrukcije – zbog svoje individualnosti, složenosti i funkcionalnosti – imaju značajan uticaj na društvo, ukupnu razvijenost neke zemlje i sveukupni napredak čovečanstva. Mostovi imaju izuzetno veliki značaj – kako u funkcionalnom, tako i u ekonomskom pogledu. Kao specifični objekti u prostoru, koji pre svega „spajaju ljude”, u sastavu su saobraćajnog sistema i planiraju se, projektuju, grade i održavaju radi obezbeđenja društvene i ekonomske dobiti, te predstavljaju objekte izuzetno velike kapitalne vrednosti. Potpuni ili privremeni prekid saobraćaja usled oštećenosti mostovskih konstrukcija, može da izazove poremećaj sa ozbiljnim posledicama za normalno funkcionisanje privrednih i drugih tokova. Generalno, mostovi su suštinski važni i za obezbeđenje i očuvanje kvaliteta života uopšte. Dakle, održivo funkcionisanje ove infrastrukturne imovine od ključne je važnosti za celokupnu državu i samu društvenu zajednicu.

2 EKSPLOATACIONI VEK MOSTOVA

Mostovske konstrukcije predstavljaju i najosetljiviji deo saobraćajne mreže. Kao objekti u spoljnoj sredini, direktno i u potpunosti su izloženi agresivnom dejstvu neposredne okoline (npr. uticaj temperature, soli, razna aero zagađenja), kao i sve oštrijim uslovima eksploatacije stalnim povećanjem osovinskog opterećenja, intenziteta i frekvencije saobraćaja. U toku eksploatacije, usled permanentnog starenja materijala i uticaja drugih raznovrsnih parametara i procesa, neminovne posledice jesu oštećenja i progresivno pogoršanje stanja, što povećava stepen dotrajalosti[1] mostovskih konstrukcija. Sve ove pojave negativno utiču na nosivost, upotrebljivost, trajnost, kao i na stepen pouzdanosti mostovskih konstrukcija, a samim tim – i na njihovu sigurnost.

[1] *Dotrajalost*: prirodan i neizbežan proces gubljenja početnih karakteristika prilikom razvoja oštećenja i pogoršanja stanja mostova, promenom svojstava konstitutivnih materijala usled starenja i uticaja svih delovanja tokom eksploatacije. *Stepen dotrajalosti* (*EC1 – Degree of deterioration*): mera napredovanja procesa koji ugrožavaju konstrukcije mostova tokom eksploatacionog veka.

for making new, contemporary structures. The Industrial revolution and its consequences, set new tasks for bridge-building engineering, creating preconditions for development of new structures and bridging larger spans.

Success in designing and building bridges is based on the theory of structures and materials, imagination and courage of designers in developing new ideas, and in the will to learn from numerous mistakes and their own experiences. Contemporary analysis methods are being increasingly used in studying and designing bridge structures, which results not only in more lightweight and more cost-effective bridges, but also in adequate formation of structural details which enables bridge structures to perform better, and thus enables achieving larger spans of contemporary bridges, which so reach further. New findings with new technology help human imagination become reality.

Bridge structures, because of their individuality, complexity and functionality have a significant impact on the society, total level of development of a country and overall progress of humanity. Bridges have an extremely high importance both in functional and economic terms. As specific structures in space which primarily “connect people” they are integral part of transportation systems and they are planed, designed, built and maintained in order to provide social and economic benefit, and represent structures with a huge capital value. Full or temporary interruption of traffic due to the damage of bridge structures can cause a disruption with severe consequences for normal functioning of economic and other activities. In general, bridges are essentially important for provision and preservation of the quality of life. Therefore, sustainable functioning of this infrastructural property is of key importance for the entire country and social community.

2 SERVICE LIFE OF BRIDGES

Bridge structures represent the most sensitive part of transportation network. As outdoor structures, they are directly and entirely exposed to the aggressive effects of the environment (temperature, salts, air pollution etc.), as well as to the increasingly severe service conditions, such as increasing axle loads, intensity and frequency of traffic. During service, due to the permanent ageing of material and impact of various parameters and processes, there is an inexorable accumulation of damage and progressive deterioration of the structural condition, which increases the dilapidation degree[1] of bridge structures. All these phenomena have a negative impact on bearing capacity, serviceability, durability and safety degree of bridge structures, and therefore on their overall safety.

[1] *Deterioration*: a natural and unavoidable process of losing the initial characteristics in the process of damage development and deterioration of bridge condition, meaning the change of the properties of constitutive materials due to aging, and effects of all impacts during service. D*egree of deterioration* (EC1 - Degree of deterioration): is the measure of the progress of processes endangering bridge structures during service life.

Predviđeni period u kome treba da budu obezbeđena navedena potrebna svojstva naziva se projektovani eksploatacioni vek objekta, a u praksi to predstavlja period od puštanja objekta u saobraćaj do njegovog zatvaranja. Osnovni razlozi koji dovode do zatvaranja mosta za saobraćaj [OECD 1992] jesu:

− Konstrukcijska (strukturalna) neadekvatnost – uzrokovana nedostacima koji dovode do opadanja stabilnosti mostovskih konstrukcija, kao i smanjenja sigurnosti objekta – najčešći je razlog zatvaranja starijih mostova. Konstrukcijski vek mosta u ovom slučaju odgovara „životnom” veku objekta koji može biti veoma dug (duži od 100 godina).

− Funkcionalna neadekvatnost – kada njegova geometrija ili nosivost ne zadovoljavaju aktuelne zahteve, te se most zatvara za saobraćaj, iako su njegove konstrukcije u dobrom stanju.

Funkcionalni vek mosta manji je od konstrukcijskog (25-50 godina), naročito u zemljama sa znatnim porastom saobraćajnog opterećenja.

Adekvatnom primenom odgovarajućih mera održavanja, popravki, sanacija i rekonstrukcija, mostovske konstrukcije mogu se održavati u dobrom stanju, sve dok ne dostignu neki optimalni vek, tzv. ekonomski vek, posle koga se stavljaju van upotrebe. Ekonomski vek definiše se kao period posle koga intervencije na održavanju, popravkama ili rekonstrukciji nisu isplative u poređenju s cenom novog mosta. Ekonomski vek jeste i cilj kome se teži u toku eksploatacionog veka nekog objekta.

Na slici 1 predstavljene su dužine trajanja pojedinih ciklusa u životu nekog mosta [OECD 1992], gde je:

The anticipated time period within the mentioned properties that should be provided is called design service life of the structure, and in practice it is the time span since commissioning of a structure (opening it for traffic) to closing down. The most common reasons necessitating closing down of a bridge for traffic [OECD 1992] are:

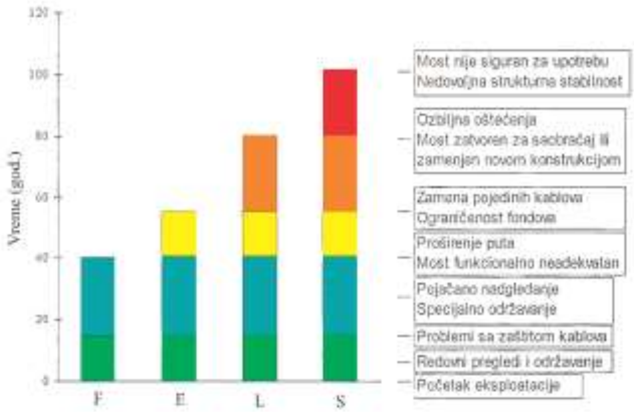
− Structural inadequacy of old bridges, caused by the deficiencies which lead to the decline of bridge structure stability, and reduced safety. The structural life of a bridge, which corresponds with the service life of the structure, can be very long (over 100 years).

− Functional inadequacy, when the bridge geometry or bearing capacity fails to meet current requirements, so it is closed down even though its structure is in good condition.

Functional life of bridge is shorter than the structural life (25 - 50 years), especially in the countries with a significant increase of traffic load.

Adequate implementation of appropriate maintenance, repairs, restoration and reconstruction, may keep the bridge structures in good conditions, until they reach an optimum life, the so called, economic life, after which they are decommissioned. The economic life is defined as a period after which the maintenance, repair and reconstruction interventions cease to be cost-effective in comparison with the cost of a new bridge. The economic life is also a goal to be reached during service life of a structure.

In figure 1, durations of certain cycles in the life of the bridge [OECD 1992] are represented, where:



F – funkcionalni vek mosta
functional life of bridge

E – ekonomski (optimalan)
economical life (optimal)

L – eksploatacioni vek
service life

S – konstrukcijski vek
structural life

Slika 1. Dužine trajanja pojedinih ciklusa eksploatacije mosta
Figure 1. Durations of individual cycles of bridge service

Eksploatacioni vek zavisi od konstrukcijske adekvatnosti (50-100 godina) i funkcionalne adekvatnosti (25-50 godina). To znači da optimalni vek zavisi i od konstrukcijskog i od funkcionalnog veka i najčešće je kraći od prvog a duži od drugog.

Konstrukcijski i funkcionalni vek nisu direktno međusobno zavisni, jer vitkije mostovske konstrukcije imaju brže pogoršanje stanja od masivnih konstrukcija. S druge strane, konstrukcijski vek može se produžiti blagovremenim i kvalitetnim održavanjem i popravkama, a takođe se može privremeno prihvatiti funkcionalna neadekvatnost u određenim situacijama. Isto tako, za

Service life depends on the structural adequacy (50 - 100 years) and functional adequacy (25 - 50 years). This means that optimum life depends both on structural and functional lives and most often it is shorter than the former and longer than the latter.

Structural and functional lives are not directly mutually dependent, because slender bridge structures deteriorate faster than massive structures. On the other hand, structural life can be prolonged with timely and quality maintenance and repairs, and also, functional inadequacy can be temporarily acceptable in certain situations. Also, for the proposes of normal traffic and normalno odvijanje saobraćaja i potrebnu sigurnost korisnika, podjednako je značajna adekvatnost – kako u konstrukcijskom, tako i u funkcionalnom pogledu. U tom smislu, treba naglasiti njihovu međusobnu povezanost i uslovljenost, te odrediti neophodno potrebne mere za istovremeno obezbeđenje i konstrukcijske i funkcionalne adekvatnosti.

Sigurnost i upotrebljivost jesu osnovna svojstva mostovskih konstrukcija da neprekidno očuvaju upotrebnu vrednost, odnosno radnu sposobnost, u toku nekog perioda (eksploatacionog veka). Uz obezbeđenje potrebne trajnosti za odgovarajući nivo pouzdanosti, ona daju osnovni imperativ korektnog oblikovanja i konstruisanja savremene populacije mostova u svetu. Međutim, nemoguće je postići apsolutnu sigurnost, večitu trajnost ili savršenu upotrebljivost, ali zato moramo težiti stanju optimuma.

Izuzetno je značajno da se uvede efikasnije održavanje postojećih mostova – kako bi se izašlo u susret javnom interesu, te je zbog toga razvijen sistem upravljanja mostovima.

3 SISTEM UPRAVLJANJA MOSTOVIMA

Danas širom sveta postoje mnogobrojne mostovske konstrukcije, različitih namena, koje su izgrađene u raznim sredinama, različitim vremenima, od raznorodnih materijala, raznovrsnih oblika, sistema, raspona i dimenzija. S druge strane, preventivnom održavanju ovih objekata – kao optimalnom rešenju iz tehničkog, organizacionog i ekonomskog aspekta – nije se posvećivala neophodna pažnja onoliko koliko je to potrebno, naročito kada je reč o našem području. Uočen je permanentni porast oštećenja na mostovima, uz enormni pad nosivosti i bezbednosti mostova, pa su čak zabeležena i rušenja nekih vrlo značajnih mostova u svetu [Pakvor, Bajić et al, 2000].

Mostovske konstrukcije dostižu svoj eksploatacioni vek kada troškovi njihovog daljeg održavanja u stanju potrebne sigurnosti, upotrebljivosti i trajnosti postanu veći od troškova održavanja koji su smatrani prihvatljivim u toku tog eksploatacionog veka.

Sadašnje okolnosti ne omogućavaju neograničena ulaganja s bilo koje tačke gledišta, pa je zajednički problem svih zemalja taj da u svoj saobraćajni sistem ulažu na najkorisniji i najefikasniji način. To je bio povod da se preduzme niz koraka radi definisanja problema, utvrđivanja postojećeg stanja, postavljanja cilja i iznalaženja načina za postizanje optimalnih rezultata putem odgovarajućih istraživanja i tehno- ekonomskih analiza. Ispravnim ulaganjem, smanjuju se ukupni troškovi i omogućuje se očuvanje investicija za duži period. Stoga, veoma je značajna potreba da se uvede efikasnije održavanje postojećih mostova, kako bi se izašlo u susret javnom interesu.

S jedne strane, mostovi su podložni pogoršanju stanja usled starenja konstrukcijskih elemenata i konstitutivnih materijala; s druge strane, njihovo duže isključivanje iz funkcije, radi sanacije, rekonstrukcije ili zamene, može da izazove veoma neprijatne poremećaje saobraćaja na putevima i prugama. Lošem stanju mostova znatno doprinose i veoma loša organizacija i iskorišćenost postojećih kapaciteta, kao i nedovoljno iskustvo u upravljanju.

U skladu s tim, potrebno je raspolagati efikasnim

necessary safety of users, structural and functional adequacies are equally important. In this sense, one must emphasize their mutual interdependencies and specify necessary measures for simultaneous insurance of both structural and functional adequacies.

Safety and serviceability are fundamental properties of bridge structures to be preserved, so that the bridges would be serviceable, that is, operable within a certain time period (service life). They provide the necessary durability at a corresponding level of safety and they are the goal of proper designing of contemporary bridges in the world. However, it is impossible to achieve absolute safety, eternal durability or perfect serviceability, so an optimum solution must be sought.

It is vitally important to introduce a more efficient maintenance of the existing bridges in order to satisfy the public interest, and for this reason, the bridge management system was developed.

3 BRIDGE MANAGEMENT SYSTEM

There is a large number of bridge structures worldwide, having various uses, built in most diverse environments, times, materials, forms, systems, spans and dimensions. On the other hand, preventative maintenance of these structures, as an optimum solution from the technical, organizational and economical aspects, was not paid due attention, especially in our parts. A permanent increase of damage on the bridges was detected, followed by the enormous decrease of bearing capacity and safety, and there were even collapses of some very important bridges in the world [Pakvor, Bajić et al, 2000].

Bridge structures reach their service life when the cost of their further maintenance in the condition of required safety, serviceability and durability exceed the maintenance cost considered acceptable in the course of the service life.

Present day circumstances hinder unlimited investments of any kind, so the common problem off all the countries is how to invest in their transportation system in the most useful and efficient way. It was a motivation to take a number of steps in the direction of defining the problem, determining the current condition, setting a goal and finding ways to obtain optimum results using appropriate research and techno-economical analyses. Correct investment results in reduction of total costs and provides preservation of investments for a long period of time. For this reason, it is crucial to introduce a more efficient maintenance of existing bridges, in order to satisfy the public interest.

On one hand, bridges are susceptible to deterioration due to aging of structural elements and constitutive materials, and on the other hand, their long decommission for the purposes of restoration, reconstruction or replacement can cause very adverse disturbances of traffic on the roads and railways. Poor condition of bridges is considerably contributed by very poor organization and efficiency of the existing capacity, as well as the inexperience in management.

Accordingly, it is necessary to possess an efficient bridge management system, and to use it to reach sistemom upravljanja mostovima i na osnovu njega doneti razumne i utemeljene odluke o raspodeli sredstava, s tačke gledišta očuvanja saobraćajnih pravaca i okoline, uz poštovanje postojećih okolnosti. Na značaj primene sistema upravljanja mostovima direktno ukazuju nedostaci i oštećenja mostovskih konstrukcija, što u prvom redu jesu posledice neblagovremenog i neadekvatnog održavanja. Nedostaci nastaju prilikom planiranja, projektovanja i građenja, a oštećenja nastaju tokom upotrebe mostovskih konstrukcija. Ovakav problem zahtevao je efikasan sistem upravljanja mostovima koji će dati razumne i utemeljene odluke o raspodeli sredstava u uslovima veoma ograničenih fondova i budžeta.

Savremeni procesi planiranja, projektovanja, izgradnje i eksploatacije mostova danas se ne mogu zamisliti bez adekvatnog sistema upravljanja mostovima.

U takvoj situaciji neophodno je primeniti globalni pristup upravljanja mostovima, te planiranjem i koordinacijom relevantnih aktivnosti povećati efikasnost upravljanja tokom celokupnog eksploatacionog veka.

Upravljanje mostovima jeste proces kojim se nadgledaju, prate, održavaju i popravljaju uočena pogoršanja stanja mostovskih konstrukcija, s raspoloživim sredstvima u toku proračunskog upotrebnog veka. Proračunski upotrebni vek je pretpostavljeno razdoblje korišćenja mostovskih konstrukcija, uz redovno održavanje, ali bez velikih popravki.

Problematika upravljanja mostovima uključuje celokupni eksploatacioni (životni) vek mostovskih konstrukcija, počev od koncepta i osnovnih prethodnih studija, preko procesa projektovanja, građenja, eksploatacije i gazdovanja, tj. održavanja, tokom adaptacije, sanacije, rekonstrukcije i na kraju njihove zamene ili uklanjanja. Stoga, upravljanje kao poslovni proces zahteva multidisciplinarni pristup i poznavanje svih tehničkih i drugih netehničkih disciplina. Krajnji cilj jeste optimalno zadovoljenje filozofije trajnosti, tj. postići maksimum učinka s minimumom uloženih sredstava. Upravo zato, upravljanje mostovima i njihovo adekvatno održavanje jeste perspektivan posao u savremenom građevinarstvu.

Strategija razvoja sistema upravljanja mostovima u svetu bazirana je na metodologiji za razvoj sistema optimizacije i korišćenja resursa u procesu upravljanja i održavanja mostova. To uključuje stanje mostovskih konstrukcija, njihov kapacitet nosivosti, stepen oštećenja odnosno dotrajalost konstitutivnih elemenata mostovskih konstrukcija, saobraćajne efekte, kao i popravke, sanacije i rekonstrukcije.

Koncept upravljanja mostovima počeo je da se razvija u svetu ne tako davno, da bi se izašlo u susret svim tim rastućim potrebama. Prvi sistemi upravljanja mostovima u svetu počeli su da se razvijaju od 1970. godine [Gligorijević, 2016].

Jedna od prvih zemalja koja je uvela sistematsko, dobro isplanirano i organizovano istraživanje u sferi upravljanja mostovima jeste Amerika. U SAD, od početka izgradnje sistema mreže međudržavnih autoputeva, sredinom pedesetih godina prošlog veka, federalna sredstva izdvajana su samo za novogradnju, proširenje i jačanje infrastrukture. Shodno tome, aktivnosti na održavanju, revitalizaciji i obnavljanju postojeće infrastrukture bile su prilično ograničene ili odlagane od strane državnih organa. Ovakve zaostale potrebe ulaganja u postojeću infrastrukturu SAD, a koje

sensible and well-grounded decisions of allocation of resources, from the standpoint of preservation of traffic communications and the environment, with consideration of the existing circumstances. The importance of implementation of bridge management system is directly reflected through the deficiencies and damage of bridge structures, primarily due to untimely and inadequate maintenance. Deficiencies are created during planning, designing and construction, and damage occurs during the usage of bridge structures. Such problem requires an efficient bridge management system which assists in making sensible and well-grounded decisions about resources allocation in the conditions of very limited funds and budgets.

Contemporary processes of planning, designing, construction and service of bridges cannot be conceived nowadays without an adequate bridge management system. Proper investment, leads to reduction of total cost and ensures preservation of investments for a longer time period.

In such situation, it is necessary to implement a global approach to bridge management, and by planning and coordinating relevant activities, to increase management efficiency during entire service life.

Bridge management is a process, used to supervise, monitor, maintain and repair detected deterioration of bridge structures, using available resources during design service life. Design service life is a predicted period of usage of bridge structures, with regular maintenance but without any considerable repair.

The subject of bridge management includes entire service life of bridge structures, starting from the concept and basic preliminary studies, through designing, construction, service and maintenance processes (adaptation, restoration, reconstruction) to the final replacement or removal of bridge structures. For these reasons, management as a business process requires a multidisciplinary approach and knowledge of all technical and other non-technical disciplines. The ultimate goal is optimum satisfaction of durability philosophy, i.e. achieving maximum effects with a minimum of invested resources. For this reason, bridge management and adequate maintenance is a perspective business in contemporary civil engineering.

Strategy of development of bridge management system in the world is based on methodology for development of optimization system and usage of resources in the process of management and maintenance of bridges. This includes condition of bridge structures, their bearing capacity, damage degree, that is, deterioration of constitutive elements of bridge structures, traffic effects, as well as repairs, restoration and reconstructions.

The bridge management concept started to develop recently in the world, in order to meet the growing demand. The first bridge management systems in the world started to develop since 1970 [Gligorijević, 2016].

One of the first countries to introduce a systemic, well-planned and organized research in bridge management domain is the USA. In the USA, since the beginning of construction of interstate highway network by the middle of 1950s, the Federal budget was allocated only for new construction, expansion and strengthening of infrastructure. Accordingly, the activities on maintenance, revitalization and renewal of the nisu dobile dovoljnu pažnju, doprinele su permanentnom pogoršanju stanja svih konstrukcijskih elemenata objekata postojeće infrastrukture SAD.

Prvi programi za upravljanje mostovima u SAD datiraju još iz ranih sedamdesetih godina XX veka. Posledice rušenja više mostova u SAD, prvo *Silver* mosta 1967. godine [15], a potom i drugih kapitalnih mostova, kao i sve veći jaz između raspoloživih sredstava i potreba nacionalne mreže mostova Amerike, uticali su na stimulisanje povećanog obima istraživanja ove problematike i na razvoj sistema upravljanja mostovima sredinom osamdesetih godina. Ubrzo nakon toga, 1991. godine, intermodalni zakon o efikasnosti transporta u SAD nalaže državama potrebu da razvijaju i implementiraju sisteme upravljanja mostovima. Sistemi upravljanja mostovima u većini država SAD razvijeni su sredinom devedesetih godina XX veka [Small,1999].

Danas, američke državne transportne agencije uspostavile su programe inspekcija mostova i većina njih je implementirana u savremen sistem upravljanja mostovima *AASHTOWare Bridge Management* (ranije *Pontis*). U svetu, poslednjih godina znatno se povećava broj država koje su razvile i koje koriste sistem upravljanja mostovima.

Savremen sistem upravljanja mostovima sadrži procenu stanja mostova, modeliranje budućeg pogoršanja stanja i ponašanja, kao i module za donošenje odluka u pogledu toga kako najekonomičnije održavati, popravljati i obnavljati mostovske konstrukcije.

Očuvanje bitnih svojstava mostovskih konstrukcija u toku njihovog životnog veka predstavlja permanentan zadatak sistema upravljanja mostovima. Prema podacima iz bogate prakse upravljanja razvijenih zemalja, plansko održavanje kroz eksploatacioni (životni) vek konstrukcija mosta zahteva ulaganja približno 2% do 3% investicione vrednosti godišnje.

U Srbiji, generalno posmatrano, usled dugogodišnjeg nedovoljnog ulaganja u održavanje i rekonstrukciju mostova, stanje mostova može se oceniti kao neprihvatljivo, naročito kada je u pitanju njihova starost. Redovno održavanje uglavnom je primitivno, tako da se ubrzava starenje konstrukcijskih elemenata i pogoršava stanje mostova, a veće popravke i sanacije gotovo su jedini vid aktivnosti i obavljaju se u bezizlaznim situacijama.

Osnovni savremeni Sistem upravljanja mostovima u Srbiji uveden je 1986. godine, kao originalan i za to vreme izuzetno moderan sistem [Bebić, 1986]. Za potrebe kvalitetnog upravljanja mostovima i primene ovog sistema na teritoriji Republike Srbije formirana je elektronska baza podataka o mostovima (BPM), koja u svakom trenutku pruža sve potrebne informacije o traženim mostovskim konstrukcijama, na osnovu urađenih inspekcijskih pregleda. Cilj formiranja baze podataka o mostovima bio je da se prikupe raspoložive informacije o mostovskim konstrukcijama radi ustanovljavanja prioriteta u održavanju mostova i razvoja sistema upravljanja mostovima u Srbiji.

Uspostavljanje prioriteta u aktivnostima održavanja mostovskih konstrukcija treba shvatiti kao odgovor na neadekvatna finansijska sredstva koja su izdvajana za održavanje mostova u uslovima opšte političke i ekonomske situacije u Srbiji poslednjih decenija. Od 1991. godine, primenjivana je verzija SR - 02, koja sadrži inventarske podatke i podatke o stanju mostova u trenutku pregleda. Da bi se olakšao rad na unošenju

existing infrastructure were quite limited or postponed by the state authorities. Such absence of investment into the existing infrastructure of the USA, lacking adequate attention, led to permanent deterioration of all the structural elements of the existing infrastructure in the USA.

The fist bridge management programs in the USA date back to the early 1970's. Collapse of several bridges in the USA, first the "*Silver*" bridge in 1967 [15], and then of other capital bridges, and the growing gap between the available resources and needs of national network of the USA bridges stimulated increased research of this issue and gave rise to the development of bridge management system by the mid 1980's. Soon after that, in 1991, the intermodal law on efficiency of transport in the USA obliges the states to develop and implement the bridge management systems. Bridge management systems in the majority of the USA states were developed in the mid 1990's [Small,1999].

Nowadays, state transport agencies in the USA, established bridge inspection programs, and most of them are implemented into the contemporary bridge management system *AASHTOWare Bridge Management* (earlier *Pontis*). In the world, recently, the number of states which developed or are developing bridge management system is increasing considerably.

Contemporary bridge management system contains bridge condition assessment, modelling of the future deterioration and behaviour and modules for decision making about most cost-efficient ways of maintenance, repair and renewal of bridge structures.

Preservation of the important properties of bridge structures during their service life represents a permanent task of bridge management systems. According to the data from the extensive experience of management in the developed countries, planned maintenance during the service life of bridge structures requires investments of approximately 2% to 3% of the investment value annually.

In Serbia, generally speaking, due to the long lasting lack of investment into maintenance and reconstruction of bridges, the bridge condition can be evaluated as unacceptable, especially in terms of their age. Regular maintenance is mostly primitive, which accelerates ageing of structural elements and deteriorates the bridge condition, and large repairs and restorations are almost the only form of activities, and they are performed in the situations when they remain the only alternative to closing down the bridge.

The basic contemporary Bridge management system in Serbia was introduced in 1986 as original, and it was a modern system for the time [Bebić, 1986]. For the needs of quality management of bridges and implementation of this system in the territory of the Republic of Serbia, an electronic database of bridges was formed (BPM), which at any moment provided all necessary information about the researched bridge structures on the basis of performed inspections. Formation of the data base had a goal to collect the available information about bridge structures in order to establish a priority in bridge maintenance and development of bridge management system in Serbia.

Establishing priorities in the bridge structure maintenance activities should be understood as a response to inadequate finances which were allocated for bridge maintenance in the general political and podataka, urađena su detaljna korisnička uputstva.

Prateći dalji razvoj računarske tehnike, baza podataka o mostovima prošla je više faza razvoja i od 1999. godine u upotrebi je verzija SR - 03, a od 2003. godine koristi se verzija koja radi pod MS ACCESS-om.

Međutim, praktična primena Sistema upravljanja mostovima u Srbiji, tokom niza godina, pokazala je određene nelogičnosti u dobijenim listama prioriteta.

U svojoj doktorskoj disertaciji [Gligorijević, 2016], autor ovoga rada dao je novi predlog, na osnovu optimizovanog kriterijuma vrednovanja prioriteta. Time su otklonjene uočene nelogičnosti našeg aktuelnog sistema upravljanja mostovima i ostvareno je značajno poboljšanje efikasnosti određivanja liste prioriteta.

Predloženom metodologijom, a na osnovu rezultata sopstvenog višedecenijskog monitoringa mostova, ocenjeno je trenutno stanje i data je prognoza budućeg stanja mostovskih konstrukcija na gradskim saobraćajnicama Niša, prezentovana u ovom radu.

4 OCENA STANJA MOSTOVA U GRADU NIŠU

Za potrebe istraživanja u doktorskoj disertaciji, autor ovoga rada 1997. godine, nakon izrade Elaborata o stanju mostova [Gligorijević et al, 1997], formirao je bazu podataka za mostovske konstrukcije na gradskim saobraćajnicama Niša. Od 1998. godine prati pogoršanje stanja ovih mostova na osnovu izvršenih periodičnih kontrolnih, redovnih i glavnih inspekcijskih pregleda mostovskih konstrukcija u gradu Nišu. Značaj ovih mostova zahtevao je takav pristup koji podjednako obezbeđuje i blagovremeno, ali i racionalno održavanje i popravke, odnosno ojačanje i/ili zamenu ovih objekata.

Posle svakog inspekcijskog pregleda, metodologijom predloženom u doktorskoj disertaciji [Gligorijević, 2016], sračunata je ocena stanja svih elemenata mostova iz baze podataka, tj. njihov „rejting", na osnovu kojeg su formirane rang-liste prioritetnih aktivnosti neophodnih intervencija. Analizom dobijenih rang-lista prioriteta, uočeno je da u njima nema bitnijih promena između dva redovna inspekcijska pregleda (interval od dve godine), ako u tom periodu nije bilo aktivnosti održavanja. Kako su sanacije i popravke nekih ugroženih mostova na gradskim saobraćajnicama Niša izvršene u periodu od 1999. godine do 2002. godine, odnosno pre drugog glavnog pregleda mostova iz 2003. godine, a kasnije nisu urađene, u ovom radu je prikazan rejting mostova nakon glavnih inspekcijskih pregleda (interval od šest godina).

Globalno stanje mostovkih konstrukcija, nakon inspekcijskog pregleda 1997. godine, prikazano je na slici 2.

Prvi na rang-listi, most „Mramor", imao je izuzetno visok rejting i zahtevao je hitnu sanaciju, jer je bila ugrožena njegova stabilnost usled erozije rečnog korita u zoni srednjeg stuba S2, na šta je već ukazano u elaboratu iz 1997. godine. Takođe, elementi gornjeg

economic conditions in Serbia in the last several decades. Since 1991, the version SR - 02, was used, which contains inventory data and data on the condition of bridges at the moment of inspection. In order to make the work on data input easier, detailed user instructions were made.

Following the further development of computer technology, the database on bridges passed through several development phases, and since 1999, the version SR – 03 was used, and since 2003, there has been a version working under MS ACCESS.

However, practical application of the Bridge management system in Serbia during a long time exhibited certain illogical issues in the obtained lists of priority activities.

In his doctoral dissertation [Gligorijević, 2016], the author of this paper provided a new proposal based on the optimized criterion of priority evaluation. This removed the detected illogical issues of our current bridge management system and provided a considerable improvement of efficiency in determining the priority list.

The proposed methodology, based on the results of his own bridge monitoring lasting for several decades, is used to provide bridge condition assessment and maintenance perspectives of bridges in the city of Nis, that are presented in this paper.

4 ASSESSMENT OF BRIDGE CONDITION IN THE CITY OF NIŠ

For the needs of research in the doctoral dissertation, the author of this paper formed a database for bridge structures in the city transport of Niš in 1997, after producing the Analysis of bridge condition [Gligorijević et al, 1997]. Since 1998, he has been monitoring deterioration of the condition of those bridges on the basis of performed periodical control, as well as regular and main inspections of bridge structures in the city of Niš. Importance of these bridges demanded an approach which provided an equally timely and cost-effective maintenance and repair, that was strengthening and/or replacing these structures.

After every inspection, using methodology proposed in the doctoral dissertation [Gligorijević, 2016], condition of all the bridge elements in the data base was assessed, i.e. their rating was made, which was used for making rank-lists of priority activities and necessary interventions. The analysis of the obtained rank-lists of priorities showed that there were no considerable changes between two regular inspections (2 year interval), if there were no maintenance activities in that period. Since restorations and repairs of some affected bridges on the main traffic routes of Niš were performed in the 1999-2002 period, that is, before the second main inspection of 2003 and they were not performed later; this paper shows the rating of the bridges after the main inspections. (6 years interval).

Global condition of bridge structures after inspection of 1997 is presented in figure 2.

The first on the rank list, the "Mramor", bridge had an extremely high rating, and demanded urgent restoration, because its stability was at risk due to the erosion of the riverbed in the zone of the medium pier S2, which was indicated in the Analysis of 1997. Also, the superstructure elements were badly damaged [Gligorijević et stroja mosta bili su jako oštećeni [Gligorijević i dr, 2002], te je most hitno saniran 2002. godine.

al, 2002], so the bridge underwent emergency restoration in 2002.

Slika 2. Broj i procenat mostova za svaki tip održavanja nakon pregleda 1997. godine
Figure 2. Number and percentage of bridges for each type of maintenance after 1997 inspection

Most „Mladosti", nakon NATO agresije 1999. godine i rušenja mostova na autoputu u okolini Niša, primio je celokupni saobraćaj koridora X, što je dodatno pogoršalo stanje mosta [Gligorijević, 2002], pa je zbog ugrožene stabilnosti urgentno rekonstruisan i ojačan prethodno napregnutim karbonskim trakama 2001. godine [Gligorijević, 2007]. Most u ulici „12. Februar", bombardovan je 1999. godine i obnovljen iste godine [Gligorijević, 2002].

Na taj način, najugroženiji mostovi s vrha ove rang-liste bili su popravljeni do sledećeg glavnog pregleda mostova na gradskim saobraćajnicama Niša. Može se reći da je splet okolnosti značajno uticao na to da se najviše oštećeni mostovi poprave i da se ispoštuje data rang-lista prioriteta.

Most kod Vrežinskog bazena, koji se nalazi na perifernoj gradskoj saobraćajnici s manjim intenzitetom saobraćaja, ostavljen je da čeka svoju popravku u narednom periodu, dok Tvrđavski most – kao četvrti na ovoj rang-listi – svojim rejtingom skreće na sebe pažnju, jer je u samom centru grada, neposredno ispred ulaza u Nišku tvrđavu.

Globalno stanje mostovkih konstrukcija, nakon inspekcijskog pregleda 2003. godine, s novoizgrađenim mostovima iz 2005. godine, prikazano je na slici 3.

After NATO aggression of 1999 and destruction of bridges on the highway near Niš, the "Mladosti" bridge received the entire corridor X traffic, which additionally aggravated the its condition [Gligorijević, 2002]. Therefore, due to the endangered stability it was urgently reconstructed and strengthened using pre-stressed carbon strips in 2001 [Gligorijević, 2007]. The bridge in "12. Februar" street was bombed in 1999 and renewed in the same year [Gligorijević, 2002].

In this way, the most critical bridges from the top of this rank-list were repaired until the next main inspection of bridges on the main transport routes of Niš. It can be said that owing to a turn in events the bridges that were most damaged were repaired, and the rank-list of priorities was observed.

The bridge next to the Vrežina swimming pool, which is on the peripheral city route with a low intensity of traffic, was left to wait for its repair in the next period, while the Fort bridge, as the fourth on this rank-list draws attention to itself by its rating, since it is located in the centre of the city, immediately in front of the gate of the Fort.

Global condition of bridge structures after inspection of 2003 with newly constructed bridges of 2005 is presented in figure 3.

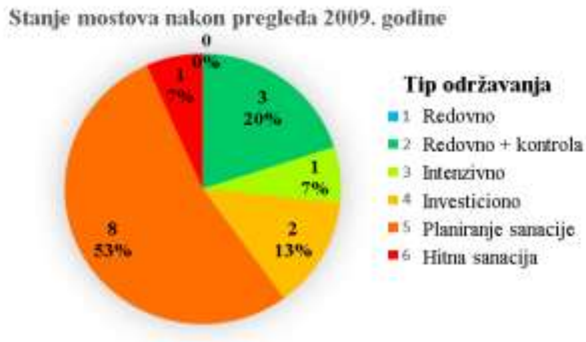
Slika 3. Broj i procenat mostova za svaki tip održavanja nakon pregleda 2003. godine
Figure 3. Number and percentage of bridges for each type of maintenance after 2003 inspection

Na vrhu rang-liste iz 2003. godine nalaze se dva izuzetno značajna mosta – već spomenuti Tvrđavski most u centru grada i most kod Ćele-kule. Međutim, u narednom periodu nisu preduzete nikakve aktivnosti radi popravke i održavanja mostova u Nišu.

Globalno stanje mostovskih konstrukcija nakon inspekcijskog pregleda 2009. godine, prikazano je na slici 4.

On top of the rank-list of 2003, there are two extremely important bridges, the already mentioned Fort bridge in the centre of the city and the bridge near the “Skull tower“. However, in the following period, no activities including repair and maintenance of bridges in Niš were undertaken.

Global condition of bridge structures after inspection in 2009 is presented in figure 4.



Slika 4. Broj i procenat mostova za svaki tip održavanja nakon pregleda 2009. godine
Figure 4. Number and percentage of bridges for each type of maintenance after 2009 inspection

Napredovanje procesa pogoršanja stanja Tvrđavskog mosta, naročito montažnih adheziono prethodno napregnutih betonskih talpi pešačkih staza, umnogome je povećalo rejting čeličnog mosta ispred Tvrđave u Nišu, tako da ovaj most ostaje na prvom mestu rang liste prioriteta 2009. godine. Prvo incidentno urušavanje dela pešačke staze desilo se juna 2008. godine [Gligorijević, 2009], a koje je „sanirano” zamenom oštećene adheziono prethodno napregnute talpe armiranobetonskom.

I pored ove iznuđene intervencije, čelični most u centru Niša svojim izuzetno visokim rejtingom i prvim mestom na rang-listi prioriteta, nakon izvršenog glavnog pregleda mostova 2009. godine, zahtevao je hitnu i ozbiljnu popravku. Nažalost, to se nije desilo, te 2014. godine dolazi do novog, znatno većeg urušavanja uzvodne pešačke staze. Krajem 2014. godine i početkom 2015. godine montažne talpe zamenjene su livenim betonom armiranim čeličnim vlaknima. Već u proleće 2015. godine, novoizgrađena pešačka staza pokazala je brojne prsline. Iako su uočena oštećenja, glavnim inspekcijskim pregledom 2015. godine nove pešačke staze ocenjene su najboljom ocenom („dobro”), ali je pogoršanje stanja ostalih nosećih elemenata ovog mosta uticalo da njegov rejting 2015. godine bude izuzetno visok i da most ostane na prvom mestu rang-liste prioriteta.

U periodu od 2009. godine do 2015. godine, nije bilo nikakvih drugih intervencija koje bi popravile stanje na ostalim mostovskim konstrukcijama iz baze podataka mostova u gradu Nišu.

Globalno stanje mostovkih konstrukcija, nakon inspekcijskog pregleda 2015. godine, prikazano je na slici 5.

I pored izvršenih radova na zameni betonskih ploča pešačkih staza na mostu ispred ulaza u Nišku tvrđavu, on ostaje na prvom mestu rang-liste prioriteta nakon pregleda 2015. godine, jer ima izuzetno veliki rejting (u klasi rejtinga stanja mosta 6), što zahteva hitnu sanaciju nosećih konstrukcijskih elemenata, odnosno tip održavanja 6.

Advance of deterioration of the Fort bridge, and especially of pre-fabricated pre-stressed concrete structures of pedestrian sidewalks, significantly increased the rating of the steel bridge in front of the Fort in Niš, so this bridge remained on the top of the rank-list of priorities of 2009. The first incidental collapse of a part of pedestrian sidewalk occurred in June 2008. [Gligorijević, 2009], which was “repaired” by replacing the adhesion prestressed element with an reinforced-concrete one.

Notwithstanding this forced intervention, the steel bridge in the centre of Niš, with its extremely high rating and the first place on the rank-list of priorities after the main inspection of bridges of 2009 required an urgent and serious repair. Unfortunately this did not happen, and in 2014 there was a new, considerably larger destruction of the upstream pedestrian sidewalk. By the end of 2014 and beginning of 2015, prefabricated elements were replaced with steel fibber reinforced cast concrete. As early as in spring 2015, newly built sidewalk exhibited numerous cracks. Even though the damage was detected, the main inspection of 2015 evaluated the new sidewalks with the best mark – “good”, but the deterioration of other bearing elements of this bridge made its rating of 2015 extremely high, and the bridge remained at the first place of the rank-list of priorities.

In the from 2009 to 2015 there were no other interventions which would improve the condition of the remaining bridge structures listed in the database of bridges in the city of Niš.

Global condition of bridge structures after inspection of 2015 is presented in figure 5.

Notwithstanding the performed works on replacement of concrete slabs of pedestrian sidewalks on the bridge opposite the entrance to the Niš fortress, it remains on the first place of the rank-list of priorities after the inspection of 2015 because it has an extremely high rating (in the class of bridge condition rating 6), which calls for an urgent repair of bearing structural elements, i.e. maintenance type 6.

Slika 5. Broj i procenat mostova za svaki tip održavanja nakon pregleda 2015. godine
Figure 5. Number and percentage of bridges for each type of maintenance after 2015 inspection

Drugo mesto na rang-listi prioriteta u 2015. godini zadržao je most kod Ćele-kule, ali sa znatno većim rejtingom, čime ulazi u klasu rejtinga stanja mosta 6 i takođe zahteva „hitnu sanaciju" nosećih konstrukcijskih elemenata, odnosno tip održavanja 6. Treba naglasiti i to da je ovaj most na rang-listama prioriteta bio na drugom mestu još nakon pregleda 2009. godine, ali od tada nisu preduzete nikakve aktivnosti da se most popravi.

Na trećem mestu, na rang-listama prioriteta 1997. godine, 2009. godine i 2015. godine, nalazi se most kod Vrežinskog bazena, koji je sagrađen u „Karpoš" sistemu i ima ugroženu stabilnost zbog velikog oštećenja donjeg stroja mosta.

Često se govori da je upravljanje mostovima veština iznalaženja najboljeg odgovora na pitanja: šta? (*what*?), gde? (*where*?), kada? (*when*?) i pošto? (*how much*?). Odgovore na prva dva pitanja daje baza podataka inventara mostova i zapisnik o pregledu mosta, ako je registrovao štete. Odgovor na druga dva pitanja daje sistem upravljanja, primenom inženjerskog prosuđivanja (*engineering judgment*) i ekonomske analize (*economic considerations*).

Formirane rang-liste prioriteta daju najbolje odgovore na prva tri osnovna pitanja sistema upravljanja mostovima: šta? (*what*?), gde? (*where*?) i kada? (*when*?), jer su pregledi svih mostovskih konstrukcija sa ovih rang-lista vršeni redovno, na osnovu kojih su određene klase rejtinga stanja za iste vremenske preseke.

The second place on the rank-list of priorities in 2015 was kept by the bridge near the "Skull tower" but with a considerably higher rating which was also bridge condition class 6 and also required "urgent restoration" of bearing structural elements, maintenance type 6. It should be pointed out that this bridge was on the second place after inspection of 2009, but no activities were undertaken since then with the purpose of repairing the bridge.

In the third position, on the rank-lists of priorities of 1997, 2009 and 2015 was the bridge near the Vrežina swimming pool, which was built in "Karpoš" system and whose stability is endangered because of the extensive damage of the bridge substructure.

It is often said that the bridge management is a skill of finding the best answers to the following questions: *what*, *where*, *when*? and *how much*? The answers to the first two questions are provided by the database of bridge inventory and the bridge inspection report, if damage was detected. The answer to other two questions is provided by the management system, by implementing *engineering judgment* and *economic considerations*.

The formed rank-lists of priorities provide the best answers to three basic questions of the bridge management system: *what*? *where*? and *when*?, because inspections of all bridge structures from these rank-lists were performed regularly, on which basis the condition rating classes for the same time points were determined.

5 MODELI POGORŠANJA STANJA MOSTOVSKIH KONSTRUKCIJA

Pogoršanje stanja elemenata mostovskih konstrukcija jeste proces smanjenja njihovih svojstava pri normalnim uslovima rada. Pogoršanje stanja pokazuje složene fenomene fizičkih i hemijskih promena koje se dešavaju u različitim komponentama mostovskih konstrukcija. Svaki element mosta ima svoju jedinstvenu stopu pogoršanja, što čini problem komplikovanijim. Pouzdano i precizno prognoziranje brzine napredovanja procesa pogoršanja stanja, za svaki element mostovskih konstrukcija, od presudnog je značaja za uspeh bilo kog sistema upravljanja mostovima.

Za prognoziranje i predviđanje stanja konstitutivnih elemenata mostova u nekom budućem trenutku, neophodan je teorijski model procesa pogoršanja stanja

5 MODELS OF BRIDGE STRUCTURE CONDITION DETERIORATION

Deterioration of bridge structure element condition is a process of decline of their properties under normal operational conditions. The condition deterioration process shows complex phenomena of physical and chemical changes which occur in various components of bridge structures. Every bridge element has its characteristic deterioration rate which makes the problem even more complicated. Reliable and precise forecast of the deterioration process progress, for each element of bridge structures shows critical importance for success of any bridge management system.

Forecast and prediction of condition of constitutive elements of bridges in some future moment requires a theoretical model of deterioration process – aging of the

- starenja mosta. Modeli pogoršanja stanja elemenata mostovskih konstrukcija uvedeni su krajem osamdesetih godina XX veka, kako bi se predvidelo buduće stanje infrastrukturne imovine u funkciji očekivanog nivoa usluge. U studiji sprovedenoj u centru transportnih sistema (*Transportation Systems Center - TSC*) [Busa et al, 1985] u Kembridžu, ispitivani su faktori koji utiču na pogoršanje stanja elemenata jednog mosta. Studija je zaključila da najuticajniji faktori koji utiču na pogoršanje stanja mostovskih konstrukcija jesu starost, intenzitet saobraćajnog opterećenja, uslovi okolne sredine, parametri korišćeni pri projektovanju i proračunu konstrukcijskih elemenata mosta, kao i kvalitet korišćenih materijala i kvalitet same izgradnje. Prema izveštaju FHWA [USDOT/FHWA, 1989], većina istraživanja ukazala je na to da indeksi pogoršanja stanja pokazuju značajne promene u prvih nekoliko godina eksploatacije, a da kasnije imaju tendenciju da predvide sporiji pad rejtinga stanja mostovskih konstrukcija.

Mogućnost prognoziranja procesa pogoršanja stanja osnovnih tehničkih i funkcionalnih karakteristika mostova, kao i procena preostalog servisnog veka, izuzetno su važni ulazni podaci za sistem upravljanja mostovima. Modeli kojima se prognozira pogoršanje stanja mostovskih konstrukcija tokom vremena od ključnog su značaja za efikasno planiranje održavanja. To naročito dolazi do izražaja u procesu optimizacije i planiranja potrebnih aktivnosti i odgovarajućih finansijskih sredstava.

Modeliranje procesa pogoršanja stanja veoma je kompleksno i složeno, jer je mnogo faktora koji utiču na ovu pojavu, zbog čega se u mnogim zemljama posvećuje velika pažnja tom problemu. Različite tehnike primenjuju se za prognoziranje pogoršanja stanja mostovskih konstrukcija. U principu, modeli za predviđanje pogoršanja stanja mostova mogu se svrstati u četiri kategorije: modeli fizičko- hemijskih procesa pogoršanja stanja, deterministički modeli, stohastički modeli i modeli veštačke inteligencije.

6 PROGNOZA BUDUĆEG STANJA

Kada postoji ažurna baza podataka sa inspekcijskih pregleda mostovskih konstrukcija, može se definisati vreme zadržavanja mostova u pojedinom stanju. Determinističkim modelom, na osnovu vremena zadržavanja mostova u određenoj klasi rejtinga stanja, može se odrediti trajektorija pogoršanja stanja mostovskih konstrukcija i ustanoviti klasa rejtinga stanja mostova u budućnosti. Nove mostovske konstrukcije polaze od klase rejtinga stanja „1” i sukcesivno prolaze kroz svaku narednu klasu rejtinga stanja, dok ne dostignu najgore stanje „6”. Na osnovu redovnih inspekcijskih pregleda promene stanja mostova u Nišu tokom vremena, ustanovljeno je vreme zadržavanja mostova u pojedinoj klasi rejtinga i dobijeno najkraće vreme potrebno da nov most stigne do nedopustivog rejtinga stanja „6”, koje iznosi 42 godine, ukoliko se nikakva intervencija ne preduzima i ne ulaže u održavanje i popravke. Podrazumeva se da mostovske konstrukcije ne smeju da borave u klasi rejtinga stanja „6”.

Postavlja se ključno pitanje: koja društvena zajednica može sebi da dopusti da „zamenjuje” mostove svakih četrdesetak godina?

Pogoršanje stanja mostovskih konstrukcija na gradskim saobraćajnicama Niša analizirano je i prime-

bridge. The models of deterioration of condition of bridge structures were introduced by the end of 1980’s in order to predict the future condition of infrastructural property in the function of the expected level of service. In the study conducted in the *Transportation Systems Centre - TSC* [Busa et al., 1985] in Cambridge, the factors aggravating the condition of the elements of a bridge were examined. The study concluded that the most influential factors of bridge structure deterioration condition are age, intensity of traffic load, environmental conditions, parameters used in design of structural elements of the bridge, and quality of the used material and quality of construction process itself. According to the report of FHWA [USDOT/FHWA, 1989], most of the research indicated that the indices of condition deterioration showed considerable changes in the first several years of service, while later on they tend to predict a decelerated decline of rating of bridge structures condition.

The potential for forecast of the condition deterioration process of basic technical and functional characteristics of bridges, as well as the evaluation of the remaining service life are invaluable input data for the bridge management system. The models which forecast deterioration of bride structures condition in time are crucial for efficient planning of maintenance. This is particularly prominent in the process of optimization and planning of necessary activities and corresponding finances.

Modelling of the condition deterioration process is very complex and intricate, since there are multiple factors affecting this phenomenon, because of which due attention is paid to that in many countries. Various techniques are implemented for the forecast of bridge structure condition deterioration. In principle, the models for forecast of bridge condition deterioration can be classified in four categories: models of physical - chemical processes, deterministic models, stochastic models and artificial intelligence models.

6 FUTURE CONDITION FORECAST

The length of time that bridges spend in certain condition can be defined according to the updated database of the bridge structure inspection. In addition, trajectory of bridge structure deterioration can be determined along with the future rating class of bridge condition by using deterministic model based on the length of time the bridge spends in certain class of condition rating. New bridge structures start from the condition rating class "1" and they successively pass through every following class of condition rating, until the worst condition "6" is reached. On the basis of regular inspections of bridge condition change in time in Niš, the length of time bridges spend in certain rating classes was established, and the shortest time required for a new bridge to reach impermissible condition rating "6" was obtained; it amounts to 42 years, if no interventions are undertaken and no investments are made in maintenance and repair. It is stated that bridge structure should not dwell in the condition rating class "6".

The key question is: what social community can afford to “replace” the bridges every 40 years?

Bridge structure condition deterioration on the traffic routes of Niš was also analyzed using stochastic models. Usage of stochastic models considerably contrinom stohastičkih modela. Upotreba stohastičkih modela značajno doprinosi na polju modeliranja pogoršanja stanja infrastrukture, zbog izuzetno visoke neizvesnosti i slučajnosti koje karakterišu proces pogoršanja stanja konstrukcija. Najčešće korišćena tehnika za prognoziranje pogoršanja stanja infrastrukture je model Markovljevih[2] lanaca. Markovljevi modeli pogoršanja stanja mostovskih konstrukcija zasnivaju se na konceptu definisanja stanja u smislu ocene stanja konstitutivnih elemenata mosta i dobijanja verovatnoće prelaza iz jednog stanja u drugo stanje. Pomoću Markovljevog lanca računa se verovatnoća da se element mosta ili mostovska konstrukcija u određenom trenutku vremena nađe u određenom stanju. Stanja su diskretne kategorije. Broj stanja (stepena dotrajalosti) u kojima se Markovljev proces može naći je konačan (u ovom slučaju 6). Između dva sukcesivna inspekcijska pregleda moguć je prelazak iz boljeg stanja u gore stanje najviše za jedan nivo ocene stanja. Markovljevi procesi bi trebalo da ispunjavaju sledeće uslove [Collines, 1972]:

– sistem je definisan nizom konačnih stanja i može biti u jednom jedinom stanju u datom trenutku;

– poznato je početno stanje sistema i raspodela verovatnoće početnog stanja;

– pretpostavlja se da su verovatnoće prelaza stacionarne tokom vremena i nezavisne od načina kako je samo stanje bilo postignuto.

Verovatnoća prelaza

butes to the modelling of infrastructure condition deterioration, because of extremely high uncertainty and randomness which characterize the process of structure condition deterioration. Most frequently used technique for forecasting the infrastructure condition deterioration is the Markov[2] chains model. Markov's models of bridge structure condition deterioration are based on the concept of definition of the condition in terms of assessing the condition of constitutive elements and obtaining the probability of transition from one condition to another. By using the Markov's chain, one calculates the probability of a bridge element or bridge structure being in a certain condition in a certain moment in time. Conditions are discrete categories. The number of conditions (deterioration degrees) in which the Markov process can be found is finite (in this case it is 6). Between two successive inspections, a transition from a better to a worse condition is possible, but not for more than one degree of condition assessment. The Markov's processes should satisfy the following conditions [Collines, 1972]:

– a system is defined by a series of finite states and it can be only in one state in a given time,

– the initial condition of the system and distribution of initial condition probability are known,

– it is assumed that the probabilities of transitions are stationary in time, an independent of the way how the state was achieved.

Transition probability

$$P_{ij} = P[X_t = i, X_{t+1} = j] \tag{1}$$

iz jednog stanja u drugo stanje, predstavljena je matricom (n x n) koja se naziva matrica verovatnoća prelaza **P**, gde je n broj stanja. Oblik matrice verovatnoća prelaza jeste:

from one state into another is represented by the matrix (n x n) which is called the matrix of transition probability **P**, where n is the number of the condition. The form of the transition probability matrix is:

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & 0 & 0 & \cdot & 0 \\ 0 & p_{22} & p_{23} & 0 & \cdot & 0 \\ 0 & 0 & p_{33} & p_{34} & \cdot & 0 \\ 0 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & 0 & \cdot & \cdot & p_{n-1\,n-1} & p_{n-1\,n} \\ 0 & 0 & \cdot & \cdot & 0 & 1 \end{bmatrix} \tag{2}$$

U ovom slučaju, matrica verovatnoća prelaza **P** jeste kvadratna matrica 6. reda sa elementima p_{ij}, gde je:

In this case transition probability matrix **P** is a square matrix of 6[th] order with the elements p_{ij}, where:

$$0 \le p_{ij} \le 1 \tag{3}$$

Svaki element u ovoj matrici p_{ij} predstavlja verovatnoću da će komponenta sistema napraviti prelazak iz stanja „i" u trenutku t_n u stanje „j" u trenutku t_{n+1}> t_n (tokom određenog prelaznog perioda).

Pretpostavka da tokom jednog diskretnog vremenskog razdoblja (od t_n do t_{n+1}), proces može ili ostati u istom stanju ili preći u prvo naredno više stanje, daje konačan oblik matrice verovatnoća prelaza.

Ako je sadašnje ili početno stanje poznato, tj. **p(0)** = [$p_1(0)$ $p_2(0)$ $p_3(0)$ … $p_n(0)$], onda se buduće stanje može predvideti u svakom trenutku t.

Each element in this matrix p_{ij}, represents a probability that a system component will transit from state "i" at the moment t_n into state "j" at the moment t_{n+1}> t_n (in the course of certain transition time period).

The assumption that during one discrete time period (from t_n to t_{n+1}), the process can either remain in the same state or transit into the first successive higher state provides the final form of the transition probability matrix.

If the present or initial state is known, i.e. **p(0)** = [$p_1(0)$ $p_2(0)$ $p_3(0)$ … $p_n(0)$], then the future state can be forecast at any given moment t.

[2] Андрей Андреевич Марков (14. 06. 1856-20. 07. 1922) bio je ruski matematičar i član Ruske akademije nauka. Najpoznatiji je po svojim istraživanjima u teoriji stohastičkih procesa, koja su posle postala poznata kao Markovljevi procesi.

[2] Андрей Андреевич Марков (June 14th 1856 - July 20th 1922) was a Russian mathematician and a member of the Russian academy of sciences. He was the most famous for his research of the theory of stochastic processes, which later became known under the name of Markov's processes.

Vektor verovatnoća početnog stanja formira se tokom prvog niza pregleda mostovskih konstrukcija. Vektor verovatnoća budućeg stanja dobija se množenjem vektora verovatnoća početnog stanja **p(0)** s matricom verovatnoća prelaza **P** na *m*-ti stepen, kao što je dato matričnom jednačinom (4).

Initial state probability vector is formed during the first series of bridge structures inspections. Future state probability vector is obtained by multiplying the vector of initial state probability **p(0)** with the transition probability matrix **P** to *m*-th power, as provided by the matrix equation (4).

$$\boldsymbol{p}(t_n) = \mathbf{p}(0) \times \boldsymbol{P}^m \tag{4}$$

gde je:

Where is:

$$\boldsymbol{p}(t_n) = [\ p_1(t_n)\ \ p_2(t_n)\ \ p_3(t_n)\ \ldots\ p_n(t_n)] \tag{5}$$

vektor verovatnoća budućeg stanja nakon *m* vremenskih intervala (godina).

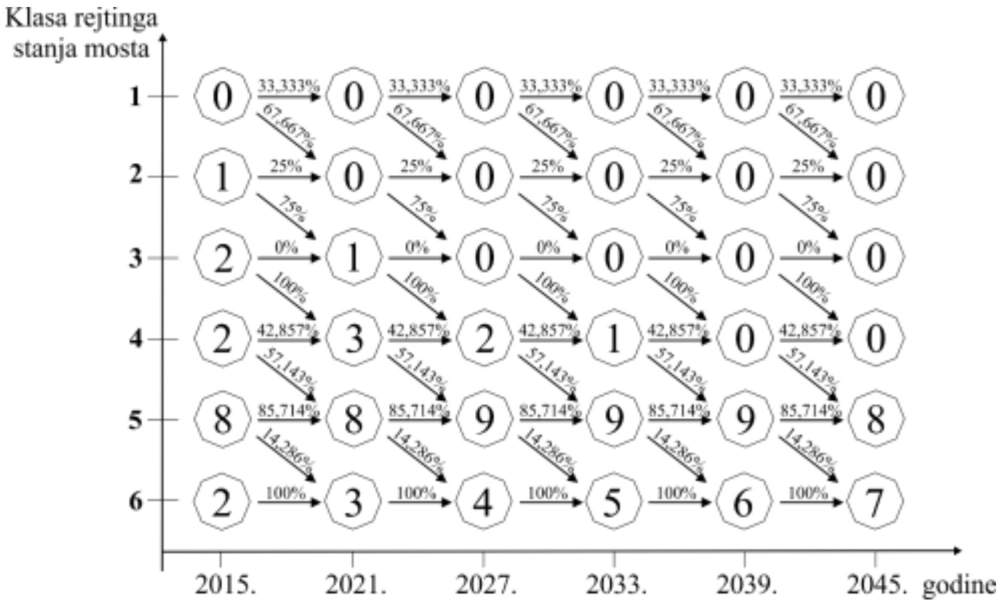
Na osnovu jednačine (4), sračunate su verovatnoće da određeni broj mostova boravi u svakoj klasi rejtinga stanja za period do 2045. godine, ako bi se nastavila primenjivana „jeftina” strategija „ne preduzimati ništa” (*do nothing*), odnosno „čekati”.

Pogoršanje stanja mostovskih konstrukcija na gradskim saobraćajnicama Niša, dobijeno stohastičkim modelom Markovljevog lanca za prognozirani period, predstavljeno je na slici 6.

the future state probability vector after *m* time intervals (years).

On the basis of the equation (4), are calculated probabilities that certain number of bridges is dwelling in each condition rating class for the period until 2045 if the implemented “cheap” *do nothing or wait* strategies persist.

Bridge structure condition deterioration on the city traffic routes of Niš, obtained using the stochastic model of the Markov’s chain for the forecast time period, is displayed in figure 6.



Slika 6. Grafički prikaz Markovljevog lanca pogoršanja stanja mostova u Nišu
Figure 6. Graphic preview of the Markov chain bridges deterioration in Nis

Dobijeni broj mostova u klasi rejtinga stanja 6 treba uzeti uslovno (podrazumeva se da mostovske konstrukcije ne mogu da borave u klasi rejtinga stanja „6”), jer dosledna primena ovakve „jeftine” strategije „ne preduzimati ništa”, odnosno „čekati” neminovno dovodi do njihovog urušavanja. Dakle, vođenjem ovakve „jeftine” strategije održavanja „ne radi ništa” (*do nothing*), koja ne proizvodi nikakve direktne troškove, dobija se najkraći eksploatacioni vek mosta. Stoga, nameće se potreba za planiranjem aktivnosti održavanja mostovskih konstrukcija, čime bi se produžio eksploatacioni vek postojećih mostova uz razumne troškove. Zbog toga, dalja istraživanja i aktivnosti autora ovoga rada usmerena su na program preventivnog održavanja – kako na individualnom, tako i na mrežnom nivou,

The obtained number of bridges in the condition rating class 6 is only provisional (it is comprised that bridge structures cannot dwell in the condition rating class "6", because “consistent implementation” of such “cheap” strategy – “do nothing” or “wait”, will lead to their certain collapse. Therefore, using such “cheap” maintenance strategy “do nothing” which fails to incur any direct costs, will result in the shortest service life of the bridge. For these reasons, it is imperative to plan the bridge structure maintenance activities, which would extend the service life of the existing bridges with the reasonable costs. For this reason, further research and the activities of the author of this paper are directed towards the program of preventative maintenance, both at the individual and network level, selection and choice selekciju i izbor strategija i programa za održavanje i rekonstrukciju, odnosno zamenu objekta na osnovu metode analize koštanja životnog ciklusa (*life-cycle cost*) i optimizacije radova, kao i na selekciju i manipulaciju ogromnog broja neophodnih podataka za sve mostove u mreži. Fokus ovih istraživanja je da se nađe odgovor na osnovno pitanje „kako se može uraditi bolje?", a u skladu s raspoloživim sredstvima, umesto dosadašnjeg menadžment pristupa „prvi najgori", s obzirom na to što je nivo finansiranja daleko ispod potreba za rekonstrukcijom i revitalizacijom svih neadekvatnih mostovskih konstrukcija u zemlji, kod kojih su utvrđeni određeni konstrukcijski i funkcionalni nedostaci.

7 ZAVRŠNE NAPOMENE

Sistem upravljanja mostovima obezbeđuje racionalan i sistematičan pristup svim aktivnostima koje se odnose na upravljanje mostovima kako na individualnom, tako i na mrežnom nivou. Najekonomičnije obezbeđenje nosivosti, upotrebljivosti i trajnosti, uz zahtevani nivo pouzdanosti i sigurnosti postojećih mostova, veoma je značajna tema savremene projektantske prakse i naučnih istraživanja. Ovaj problem znatno se uvećava kada je reč o celovitom saobraćajnom sistemu - mreži. Za razliku od tradicionalnog pristupa da se mostovi tretiraju ponaosob, a problemi rešavaju u trenutku kada već nastanu, sistemi za upravljanje mostovima baziraju se na bankama podataka i imaju planski i organizovan pristup rešavanju problema na nivou mreže objekata.

Za obezbeđenje planskog i kvalitetnog optimalnog upravljanja mostovima, izuzetno je važno da odgovorna ličnost koja upravlja bazom podataka i rezultatima pregleda mostova, mora biti sertifikovani inženjer sa znanjem i iskustvom u projektovanju i građenju mostovskih konstrukcija.

Upravljanje mostovima i drugim objektima u sklopu saobraćajne mreže, veoma je kompleksan sistem s velikim brojem izuzetno raznovrsnih, ali međusobno usko povezanih i zavisnih aktivnosti.

Problematika se povećava shodno veličini mreže, rastu obima saobraćaja, promeni transportnih sredstava, zatim različitoj osetljivosti konstrukcija i okoline, kao i istorijskom nasleđu koje se prvenstveno ogleda u prevaziđenim metodama projektovanja i građenja, sanacije, rekonstrukcije i održavanja. Na primer, korišćenje dilatacionih sprava za sprečavanje prekomernih podužnih pomeranja i sila na dugačkim železničkim mostovima skupo je i loše rešenje u pogledu bezbednosti saobraćaja, udobnosti, kao i troškova održavanja [16]. Zbog toga se primenjuju druga moguća rešenja – u skladu s projektom konstrukcije. U ovakvim slučajevima, upravljačke odluke ne mogu biti zasnovane na intuitivnom procenjivanju i prosuđivanju. One nužno moraju biti zasnovane na rezultatima ključnih elemenata celovitog upravljačkog sistema, sposobnog da iz aspekta široke društvene zajednice dugoročno proceni sve posledice odlaganja ili nepreduzimanja potrebnih mera održavanja mostovskih konstrukcija. Dosadašnji rezultati ukazuju na potrebu novih istraživanja i usvajanja adekvatne strategije održavanja, odnosno planskog i sistematskog pristupa u oblasti upravljanja mostovima. Način na koji se taj pristup ostvaruje određen je

of strategies and programmes for maintenance and reconstruction, i.e. replacement of structures based on the life-cycle cost analysis method and on the optimization of works and on selection and manipulation of immense number of necessary data for all the bridges in the network. The focus of these research has a goal of finding an answer to the fundamental question "how to work better?", according to the available resources, instead of the management approach of tackling the "first and worst", regarding that the level of finances is far below the requirements for reconstruction and revitalization of all inadequate bridge structures in the country where certain structural and functional deficiencies are detected.

7 CLOSING REMARKS

Bridge management system provides a rational and systematic approach to all activities which relate to bridge management, both on an individual and the network level. The most cost-effective provision of bearing capacity, serviceability and durability, with the required level of reliability and safety of the existing bridges is a very important topic of contemporary designer practice and scientific research. This problem considerably rises the question about the integral transportation system network. As opposed to the traditional approach that bridges are treated individually, and problems are solved when they occur, the bridge management systems are based on databases and have a well planned and organized approach to problem solving at the level of structure network.

For provision of the planned and good quality optimum bridge management, it is very important to have a certified engineer with knowledge and experience in designing and building bridge structures as a responsible person who manages the database and bridge inspection results.

Management of bridges and other structures within a transportation network is very complex system with a high number of extremely diverse but mutually closely connected and dependent activities.

The complexity of the problem increases according to the size of network, rise of traffic frequency, change of transport vehicles, different sensibility of structures and environment and to the historical legacy which primarily means obsolete methods of designing and building, restoration, reconstruction and maintenance. For instance, usage of expansion devices prevention of excessive longitudinal displacements and forces on the long railway bridges is a costly and poor solution in terms of traffic safety, comfort and maintenance cost [16]. For this reason, alternative solutions in accordance with the structural design are implemented. In such cases, the management decisions cannot be based on the intuitive assessment and judgment. They should be necessarily based on the results of the key elements of comprehensive management system able to provide a forecast to the wide social community of all the consequences of delaying and doing nothing regarding the bridge structure maintenance. Current results indicate the need for a new research and adoption of adequate maintenance strategy, that is, a planned and systematic approach in the field of bridge management. The way in which this approach is realized is determined razvojem sistema upravljanja mostovima, a uspešnost upravljanja bitno zavisi od izbora i doslednog sprovođenja svih relevantnih aktivnosti koje čine taj sistem.

by the development of the bridge management system, and the success of management greatly depends on the choice and consistent performance of all the relevant activities comprising this system.

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REZIME

OCENA STANJA I PERSPEKTIVE ODRŽAVANJA MOSTOVSKIH KONSTRUKCIJA U GRADU NIŠU

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Mostovi su građevinski objekti koji svojom veličinom, izgledom, pojavom u prostoru, pa čak i simbolikom, vrlo često dominiraju ambijentom ili krajolikom u kojem se nalaze. S druge strane, preventivnom održavanju ovih objekata – kao optimalnom rešenju – nije se posvećivala neophodna pažnja koliko je to bilo potrebno, naročito kada je reč o našem području. Uočen je permanentni porast oštećenja na mostovima, uz enormni pad nosivosti i bezbednosti mostova, te su od ogromnog značaja razvoj i uvođenje adekvatnog sistema upravljanja mostovima s ciljem efikasnijeg održavanja i očuvanja postojećih mostovskih konstrukcija.

Sistem upravljanja mostovima u Srbiji uveden je 1986. godine, kao originalan i za to vreme izuzetno moderan. Međutim, njegova praktična primena pokazala je određene nelogičnosti u dobijenim listama prioritetnih aktivnosti.

U svojoj doktorskoj disertaciji, autor ovoga rada dao je novi predlog – na osnovu optimizovanog kriterijuma vrednovanja prioriteta. Time su otklonjene uočene nelogičnosti našeg aktuelnog sistema upravljanja mostovima i ostvareno je značajno poboljšanje efikasnosti određivanja liste prioriteta.

Predloženom metodologijom, a na osnovu rezultata sopstvenog višedecenijskog monitoringa mostova, urađena je ocena stanja i perspektiva održavanja mostova u gradu Nišu, koja je prezentovana u ovom radu.

Ključne reči: Upravljanje mostovima, vrednovanje prioriteta, analiza, ocena stanja, prognoza.

SUMMARY

CONDITION ASSESSMENT AND MAINTENANCE PERSPECTIVES OF BRIDGE STRUCTURES IN THE CITY OF NIS

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Bridges are civil engineering structures which very often dominate the environment or landscape where they are situated by their size, appearance in space and even by symbolism. On the other hand, preventive maintenance of these structures, as an optimum solution, is paid insufficient deal of attention, especially in our country. A permanent increase of damage on the bridges is observed, followed by an enormous decrease of bearing capacity and safety, which means that it is critical to develop and introduce an adequate system of bridge management with an aim of maintenance and preservation of existing bridge structures.

Bridge management system in Serbia was introduced in 1986, as an original, and extremely contemporary system for the time. However, its practical application exhibited certain illogical issues in the obtained lists of priority activities.

The author of this paper, in his doctoral dissertation, offered a new proposition based on the optimized criterion of priority evaluation. This removed certain illogical points of the current bridge management system, and achieved a considerable increase of efficiency when making priority lists.

The paper presents the proposed methodology based on the results of bridge monitoring over a period of several decades which was used to provide bridge condition assessment and its maintenance perspectives in the city of Nis.

Key words: Bridge management, priority evaluation, analysis, assessment, forecast.