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Critical Aspects and Technology of Fixed Automated Spray Technology System

İsmet KILIÇ[1] Meral ÖZARSLAN YATAK[2, *] Fecir DURAN[3]

[1]*Ertuğrulgazi Anatolian High School, 41180, Kartepe/KOCAELİ*

[2]*Gazi University, Faculty of Technology, Department of Electrical-Electronic Engineering, 06500, Yenimahalle/ANKARA*

[3]*Gazi University, Faculty of Technology, Department of Computer Engineering, 06500, Yenimahalle/ANKARA*

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Abstract

Fixed automated spray technology (FAST) has been used for years in practice and theory both in Turkey and globally as an alternative to the conventional method for struggling against snow and ice on highway superstructure. The purpose of the FAST system is a proactive approach to reduce or even eliminate the impact of snow and ice factors that negatively affect the skid resistance on highway superstructure. This approach also plays an important role in decreasing the traffic accidents occurring on highways, prolonging the service life of the construction, and minimizing the damage to the environment caused by the conventional system. In light of this information, in this study, critical aspects of FAST system, its components, technological features, design, and installation in terms of environmental factors are investigated. In addition, the advantages and disadvantages of the system in the struggle against snow and ice have been revealed. As a result, the superiority of FAST, which is a product of a multidisciplinary study, in the prevention of accidents caused by low skid resistance on the highway for the struggle against snow and ice over the conventional methods, economic evaluation of the FAST system, assessment of the components as technically, and criteria of determination of FAST components are put forward.

1. INTRODUCTION

Road transport is one of the most important transportation modes in Turkey and the world. The relationship between a safe drive and skid resistance on highways has been the subject of research from the past to the present day scientists. Safety, one of the most important parameters of engineering, is an inevitable parameter in terms of safe driving on highways. The three main factors that affect safe driving are people, vehicles and roads. When the road factor is considered, the value of skid resistance is in the foreground. To ensure a safe drive, the skid resistance between the vehicle's road surface and wheel bandage must be at a specific level. Studies have shown that there is an important relationship between the decline in skid resistance and traffic accidents [1].

Preventing icing on critical road sections, especially bridges and viaducts, is one of the most important issues to facilitate transportation in winter and ensure traffic safety. In winter months, the slip ratio-friction coefficient decreases considerably due to the icing on the bridges that lowering traffic safety. Studies show that the reduction in friction resistance increases traffic accidents. Xiao et al. [2] examined the relationship between skid resistance and traffic accidents. They showed that traffic accidents decrease by 60% when the skid resistance value of the road surface increases from 33,4% to 48%. The causes of 10%–15% of all traffic accidents are serious weather conditions and this leads to tremendous economic losses and casualties [3]. To eliminate negative effects on the road surface such as snow and icing, physical and chemical struggle methods are traditionally applied after the snowfall and for this reason these methods are called passive. The most effective method for snow-ice struggle is to employ an active melting system that starts operating before the snow-ice event occurs. The most important anti-icing and de-icing system technology are called as Fixed Automated Spray Technology (FAST). The FAST system was developed to struggle against snow

*Corresponding author, e-mail: ozarslanm@gazi.edu.tr DOI: 10.29109/gujsc.1116292

and ice. This is a method that can obtain data from the ice warning system and intervene instantly. An appropriate amount of anti-icing chemical is sprayed from nozzles to the pavement automatically and thereby preventing ice adhesion to the pavement by creating a chemical layer between ice and pavement [4, 5].

Struggle against snow and ice is very important for safety but the damage of excessive use of chemicals to the environment, the coating, and the other structures shouldn't be ignored. Attention should be paid not only to the struggle against to snow and ice but also to the conditions after this process. Nowadays, innovative studies to eliminate the problems caused by traditional methods in preventing icing and eliminating the deficiencies of existing systems are being carried out rapidly to optimize the amount of chemicals. FAST uses the optimum amount of chemicals for struggle and so it is very environmentally friendly.

There are two ways to struggle against icing [6]. The first one is the process of removing ice and snow after formation called "de-icing" and the second one is the process of precaution for the pavements before icing called "anti-icing. De-icing needs more sources of chemicals, cost, human force, time, etc. than anti-icing. So anti-icing is more friendly to the environment than the other methods. Applying chemical freezing-point depressants to the pavement in advance of or during deteriorating weather conditions is called Anti-icing. Black ice formation and the bond between ice and the road surface are prevented or weakened with anti-icing [7].

Winter maintenance activities are analyzed from the perspectives of materials and costs and this is greatly beneficial to providing agencies with correct snow and ice control instructions [8]. FAST systems take place in markets especially in North America and Europe implemented with the support of universities and/or transport ministries. Veneziano et al. [9] used the empirical Bayes technique for the before-after study, so they could determine the effect of FAST systems on crash frequencies. The results showed that at sites where crashes were reduced, FAST systems contributed to an annual reduction of 2% of crash frequency on multilane rural highways, 16% to 70% on urban Interstates, 31% to 57% on rural Interstates, and 19% to 40% on interchange ramps between Interstates. This study presented that high-traffic, high-crash severity locations are most suitable for FAST deployment. Akin et al. [10] measured snow–pavement bond strength and static friction to determine the effectiveness of anti-icing with salt brine and deicing with dry and pre-wet solid salt on permeable friction course surface (PFS). They showed that compacted snow bonds more strongly to PFSs, yet friction of PFSs was significantly greater than dense-graded pavements after snow removal, even without the use of salt. Hereby, practitioners may apply unnecessarily high application rates of salt. To overcome this, field testing is proposed to better understand the frictional behavior of PFSs during a variety of winter storm conditions and deicer application strategies. In addition, there are other potentially useful attributes such as decreasing the corrosion potential on a given structure through the use of low corrosion snow and ice control materials, and decreasing the deleterious effects of winter maintenance activities on the surface and groundwater quality through the use of alternative snow and ice control materials [11].

Development of system components, decrease in cost, and reduction in traffic accidents with death and injury caused by icing, traffic accidents, and benefit-cost ratio reveal the importance of the system. Eliminating even one accident in one year would provide a benefit-cost ratio greater than 1 for two automated systems installed for the Minnesota Department of Transportation bridge locations [12].

Ratkevičius and Laurinavičius [13] claims that cost-benefit analysis results showed that the road maintenance costs in the winter season of 2011–2014 made up only approximately 4% of the total societal expenses compared to the expenses incurred by the society during road accidents and travel time expenses. So FAST is a system that is worth studying and whose critical expectations should be taken into account in the design.

Sand-salt mix and applying anti-icing chemicals to road by trucks have many disadvantages. Particularly damage to the environment and infrastructure, requirement of human source, and struggling after ice forming are serious drawbacks. Applying anti-icing chemical to roads by trucks has some problems such as the requirement of human source, not struggling immediately, and not adjusting the amount of chemical. The bottom heating system doesn't affect the environment adversely. But the long time for the de-icing duration, the excess infrastructure cost, and practice cost are disadvantages of this system. Despite the infrastructure cost of the FAST system, it is the most effective method. Methods of struggle against icing show differences in relation to response time, de-icing duration, effect duration, temperature, cost, environmental effects, etc. FAST and the other methods are presented in Table 1 comparatively.

Table 1. *Properties of anti-icing and de-icing methods*

METHOD	HUMAN FORCE	RESPONSE TIME	DEICING DURATION	EFFECT DURATION	EFFECT TEM PERTURE	INFRASTRUCTURE COST	PRACTICE COST	IMPACT ON ENVIRONMENT & INFRASTRUCTURES TRUCTURE	ANTI ICING / DEICING
FAST	***No***	***Immediately***	***Short***	***Long***	***-40 ºC***	***Medium***	***Low***	***Harmless***	***A-icing D-icing***
SAND-SALT MIX	Yes	Late	Long	Short	-7 ºC	Very low	Medium	Very Harmful	D-icing
CHEMICL BY TRUCK	Yes	Late	Short	Long	-40 ºC	Very low	Medium	Less Harmful	A-icing D-icing
THERMAL HEATING	No	Immediately	Medium	Short	Depend on system power	High	Low	Harmless	A-icing D-icing
GRPHITE ASPHALT PAVMENT SYSTEM	No	Immediately	Short	Short	Depend on system power	Very High	High	Harmless	A-icing D-icing
HEATING BY ELECTRIC CABLES	No	Immediately	Long	Short	Depend on system power	Very High	High	Harmless	A-icing D-icing

In this paper, FAST systems' technology, critical aspects of FAST and system components are analyzed. The main contribution of this is to put forward an instruction guide on determining and designing components of the FAST system. Although FAST systems have been evaluated from various visions, this paper will clear up important deficiencies in the critical aspects of FAST. Consequently, this study is also important for conveying the experience gained by the authors while FAST was implemented in Turkey to the other designers and researchers in terms of overcoming the difficulties encountered in design, material selection, and installation process. Various experiences and evaluations on FAST systems can be acquired with the FAST reports. Before arising an ice problem, system can solve the application of chemical liquid on roadways without any need for maintenance personnel. It is an inevitable fact that the development and determination of the system components will help to solve several problems encountered in the implementation of the system as well as increase the service life of the structures where the system is used and where there are high investment costs. However, the reports mentioned don't contain critical aspects for FAST, development of system hardware, and the system components technology and so this study will meet this deficit.

2. TECHNOLOGY AND CRITICAL ASPECTS OF FAST

FAST composes of interdisciplinary fields such as electronics, mechanics, chemistry, construction, communication, and data processing technologies. Also, the FAST design methodology requires focused attention while determining the components according to the conditions at the location where the system is installed, the weather conditions, and accident statistics. Therefore, there are many criteria while determining components.

The first phase of FAST installation is to determine where the system should be installed. To ensure future road safety, identification of previously existing traffic accident hotspots is necessary [14]. Criteria for installation FAST specifically on the bridge deck are listed below [15]. These are applicable for roads as well.

- Accident frequency;
- Accident rate;
- Accident loss ($);
- Distance to bridge from maintenance yard;
- Travel time to bridge from maintenance yard;
- Bridge functional classification;
- Bridge Average Daily Traffic (ADT);
- Bridge truck percentage;
- Bridge span;
- Bridge alignment;
- Bridge surface type;
- Bridge approach width;
- Presence of water under the bridge;
- Number of days with min. temp. < 0 ºC;
- Number of days with max. temp. < 0 ºC.

FAST system generally consists of components and subsystems introduced in Figure 1. The components commonly used in FAST projects are analyzed and the criteria while determining the components are outlined.

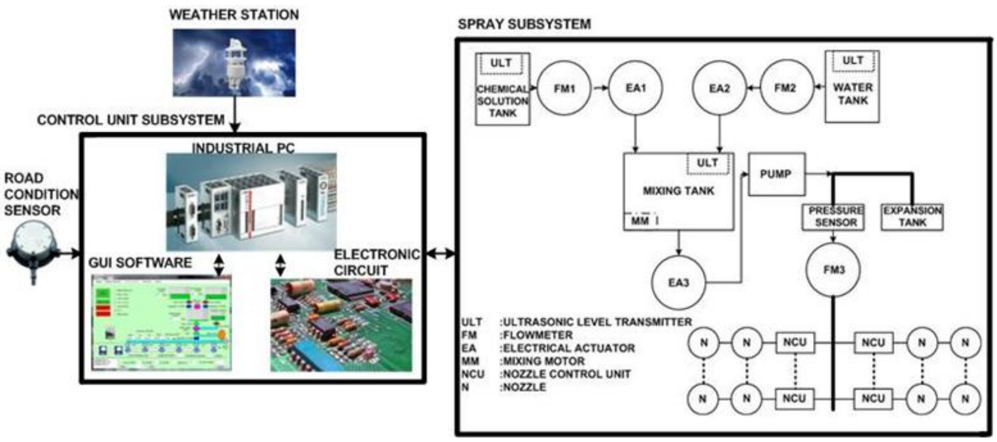

Figure 1. *Components and subsystems of FAST*

2.1. Road Condition Sensors

Measurement of road weather and surface condition are fundamental process while considering when and what kind of road maintenance is needed [16]. Road surface evaluation is the most important requirement for anti-icing and deicing. A road condition sensor is used for determining road conditions. It is important to warn drivers or maintenance staff against icing, black ice and slippery surface.

Road condition sensors may be passive or active in terms of determining road properties by a fixed sensor or heating and cooling with a Peltier element. The passive sensor that makes all measurements in one unit measures road surface temperature, temperatures below the surface, water film level, and road conditions (dry/damp/wet/ice or snow/residual salt/freezing). Passive sensors determine surface current freezing temperature with the salt content only. The active measuring process is implemented by measuring the energy released when the solution is melting. Active road condition sensor is generally used for different anti-icing chemical as NaCl, $MgCl_2$, and $CaCl_2$. This sensor determines a freezing temperature in a period and this process goes on as long as the road is wet and nearby the freezing point. If the active sensor is used, a passive road sensor should be used, too. Because the road condition is changed during cooling and heating and so the other parameters of the road are possibly changed while this process is implemented. New generation road condition sensors are developed as noninvasive and mobile sensors. Noninvasive sensors with optical principle measure road properties optically or spectroscopically different from the flush-mounted sensors. If there is water on the road, this changes wavelength and spectral characteristics.

This technology is preferred when the road reconstruction is repaired and the surface of the asphalt isn't appropriate for flush-mounted sensors. The other alternative, a mobile road sensor, is installed on the vehicle for detection of the road surface properties. It measures the friction coefficient and sends icing data to gritting vehicles and interface protocols. These sensors are generally used on snow removal and spreader vehicles.

- Critical aspects of road condition sensors are listed below:
  - Road condition sensor should measure
  - road surface and below surface temperature with high resolution such as <0.2 ºC.
  - road surface conditions as dry, moisture, and wet.
  - water film thickness.
  - freezing temperature for different de-icing materials.
  - conductivity of road for ice percentage.
- Operating temperature should be selected with respect to the system installation place. However, it should generally be selected between -40 ºC and 70 ºC.
- Sampling rate should be smaller than 10 min and 1 min respectively for active and passive road condition sensors.
- Sensors should be flush-mounted for active and passive sensors and shouldn't create any protuberance on the road. Sensors should be installed outside wheel path with no vibration and water shouldn't accumulate on it.
- Noninvasive sensor's measurement surface should be free of hump and trough, road markings, etc.
- Noninvasive sensor should be tightened the bolts for supplying no vibration and keeping the measurement angle fixed.
- Sensors should have low power consumption.

2.2. Weather Station

The other great common factor of icing is weather parameters on roads. These are weather temperature, relative humidity, precipitation intensity, precipitation type, precipitation quantity, air pressure, wind direction, and wind speed. Therefore, measurement of these parameters is fatal and necessary for struggle against icing. Current FAST systems use RWIS or weather stations to get weather data [17]. It consists of intelligent transducers, digital interface circuits, sensors, Doppler radar, and ultrasonic sensors. Weather temperature and relative humidity are generally measured respectively with NTC and capacitive sensor. Air pressure data is obtained with MEMs capacitive sensor; wind direction and speed are measured with ultrasonic sensors or mechanically. Precipitation is measured with a Doppler radar or mechanically. This data is used for measuring the precipitation type and intensity by calculating the correlation between the quantity and speed. The measurement output data is delivered with special protocols, MODBUS, SDI-12, RS485, etc.

Critical aspects of the weather station are listed below:

- Weather station should measure
  - weather temperature with high resolution such as < 0.2 ºC.
  - humidity with high resolution such as <0.5% RH and scale with 0-100% RH.
  - wind speed with high resolution such as <0.5 m/s and higher range than 1 m/s to 50 m/s.
  - wind direction with high resolution such as <5 º.
  - precipitation type.
- Operating temp. should be selected in respect to system installation place but it is generally selected between -50º C and 60 ºC.
- Sampling rate should be smaller than 1 min.
- The installation place of the weather station must be free of trees and plants.
- It should be tightened the bolts for supply no vibration and to keep the measurement angle fixed.
- It should have low power consumption.

3. CONTROL UNIT SUBSYSTEM

Control Unit and Software take data from sensors, control mechanical hardware of the system and decide system outputs. The spray subsystem, sensors, power units for the whole system, etc. are controlled and monitored by the Control Unit subsystem.

There are many types of controllers used in FAST systems. Current FAST systems commonly use Industrial PC (IPC). It is a computer used especially for process control and in extreme environmental conditions such as too hot or cold weather, humidity, very dusty platform, power supply with big distortion or surges, vibration, etc. Except for operation environment conditions and modular I/O cards, it is similar to PC technology. It has CPU, RAM, flash memory card, Ethernet interfaces, USB interfaces, DVI-I interface fieldbus, serial interface, etc. The industrial PC accessories such as Analog I/O, Digital I/O, RS485, CAN cards, etc. can be connected via the multi-pin terminals.

The Control unit contains electronic circuits too. Connection and communication processes between the controller and electromechanical components are realized via electronic circuits. Communication, valve control, repeating data, motor controls, and fault detection are done with these circuits. The wiring that supplies electricity to the pump, solenoid, and RWIS station is particularly susceptible to corrosion. Under normal circumstances, the wiring should not come in contact with the deicing chemical. The FAST system must have a generator with enough power for all components.

Critical aspects of control unit and software are listed below:

- Control unit should have
  - operating temp. between -50ºC and 60ºC.
  - storage temp. between -60 ºC and 70 ºC.
  - real-time operation.
  - fast response time.
  - high data transmission rate.
  - low power consumption.
  - an EMI filter.
  - automatically reset function for an unexpected situation.
  - different communication protocols support and wired/wireless communication techniques.
  - property of compatible with expansion cards.
  - protection against dust, water, and chemical.
  - safety area for installation.

A software for FAST implements very duties such as data collection from the road condition sensor and weather station, other sensors, data processing, controlling valves, determining nozzles spray number, sequence, and duration, monitoring the conditions of the environmental factors and the condition of nozzles, programming automatic or manual spray prefer, etc. The software also includes a graphical user interface (GUI). GUI provides people to monitor and controls the parameters of the system through various communication ways.

- Software should be:
  - user-friendly.
  - easy adapted to system changes.
  - error-tolerant.
  - hierarchical user panel property.
  - compatible with different unit types.
  - logging property.
  - icing must be sensed correctly and should be predicted with high accuracy.

Figure 2 shows a flowchart of control system software on FAST system.

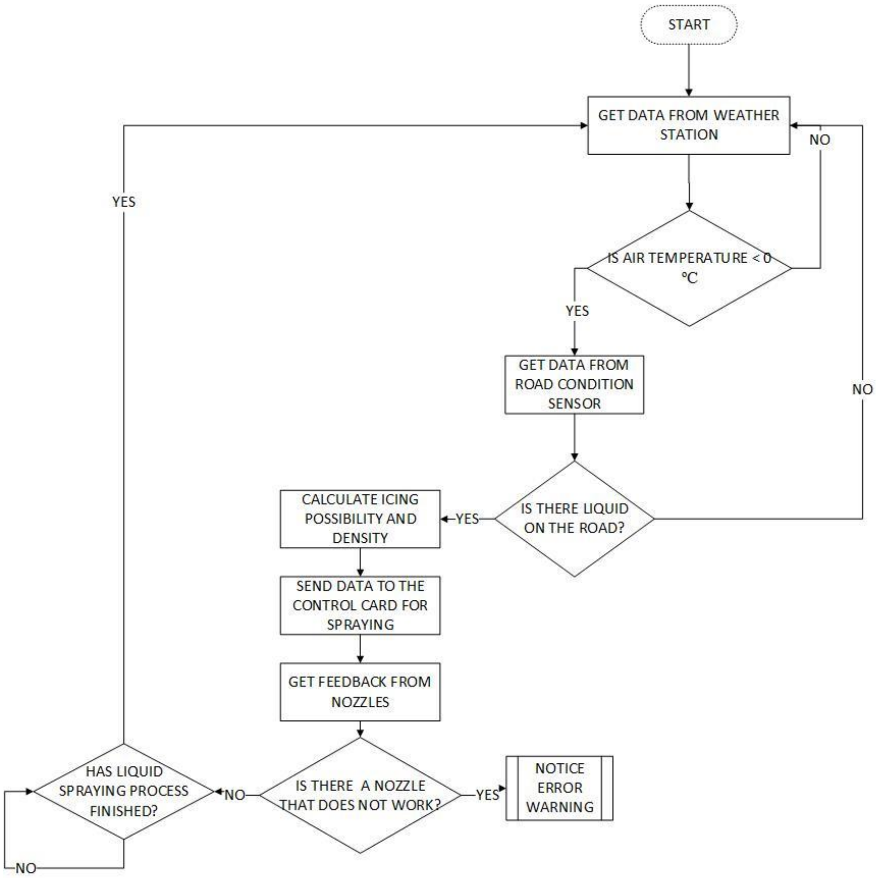

Figure 2. *Flowchart of the control algorithm of the system*

4. SPRAY SUBSYSTEM OF FAST

Spray subsystem is used to store and transfer anti-icing chemicals to the road. According to data from sensors, switches and relays on electronic circuits are triggered and the spray subsystem begins to operate. The spray subsystem consists of water and mixing tanks, ultrasonic level transmitter (ULT), anti-icing chemical, flow meters (FM), electrical actuator (EA), expansion tank with mixer motor, pumps, pressure sensor, valves, nozzle control units (NCU) and nozzles (N). The spray subsystem is shown as a block diagram in Figure 1. As mentioned before, the FAST system was installed in Turkey and the implemented spray subsystem is shown in Figure 3.

Figure 3. *Implemented spray subsystem view*

Water, anti-icing chemical, and mixing tanks of the FAST system should be manufactured from polyethylene material. These tanks shouldn't be reacted with chemical liquid placed in them. The tanks shouldn't leave particles and shouldn't be affected by sunlight or weather conditions. There are generally three polyethylene tanks in FAST systems. The first one is for anti-icing chemical. The second one is for water. The water is for arranging chemical solution anti-icing property according to the freezing point on the road. The third polythene tank is for mixing anti-icing chemicals and water and housing this solution. The other tank is an expansion tank. This tank manufactured from stainless steel is used for ensuring the continuity of the mixture in the pipes of the system with high pressure. This pressure is arranged by changing and balancing the membrane. Mixture tank may not be used for some applications. Instead, water and chemical are transferred to the expansion tank directly. If a mixing tank is used, a mixture motor must be used to prevent precipitation. Low capacity expansion tanks are generally used to fix endpoint pressure before nozzles in Nozzle Control Unit (NCU). The nozzles spray the mixture of water and chemical solution with this pressure. The number of nozzles, length of the system, and the number of average activation of the system per season should be taken into account while determining the size of tanks.

There are three flow meters in the system. A flow meter is used for measuring the volume flow rate of liquid that fills a closed pipeline and flows continuously in it. Turbine type is generally used for FAST applications. It should have low viscosity, anti-corrosion property, high accuracy, and high resolution. Ultrasonic type flow meter isn't preferred as this type must be calibrated for different liquids. The operating pressure and measurement capabilities of the flow meter should be determined according to the spray subsystem.

An electrical actuator or proportional valves are used to scale the amount of water and chemical. This mixture is transferred to the expansion tank directly. The amount of liquid scale is set generally according to the current. This current is 4–20 mA. These parts should have stainless material and fast response time.

An ultrasonic level transmitter is used for sensing the level of liquid by non-contact measurement. The sensor emits high-frequency acoustic waves that are reflected back to and detected by the emitting transducer. The transmitter is usually composed of an ultrasonic sensor, transducer, level controller, and computer interface. The output of the transmitter is DC voltage or 4-20 mA. There are generally three ultrasonic level transmitters in the system. These transmitters are used for determining the level of water, chemical, and mixture solution. Thus, critical levels for the liquids can be tracked.

The mixture solution is absorbed from the tanks by a pump. The pump should be made from titanium (corrosion and wear resistance), should have enough power for the system, and maintenance should be done regularly. The operating temperature should be selected appropriately for the system. The pressure sensor is used for measuring pressures of the expansion tank and pipes. This sensor should measure from 1 bar to 40 bars and should be suitable for operating in hard weather conditions. It must be stainless. The output signal can be selected as 4–20 mA or 0–10 V.

Solenoid valves control order and length of time each nozzle sprays. A solenoid valve is used for fluids. Electrical energy is converted to linear kinetic energy with a solenoid valve with the advantage of the magnetic effect of electric current. These valves are controlled with Nozzle Control Unit and used to transfer solution to spray nozzles. They must be stainless, have a fast response time, and have low power consumption. Piping should be high-pressure polyvinyl chloride piping. Piping is used from pump discharge to solenoid valves, and nylon tubing from the solenoid valves to the nozzle assemblies. Fluid carrying hose and electrical wiring are contained in galvanized steel pipe.

The nozzle control unit contains low capacity expansion tank and electronic devices for communication and control. The low capacity expansion tank should have the same properties as other expansion tank. Electronic devices should have long-range communication lengths. Also they should be selected appropriately for hard weather conditions.

Nozzles are used for spraying solutions to the road. They should be placed at a suitable distance whether mounted on pavement or on parapets. Spray nozzles differ according to the application places and FAST design. There are generally three types of nozzles as in-pavement flush-mounted, guardrail-mounted or parapet wall, and micro spray nozzles. In-pavement flush-mounted nozzle is preferred mostly. This nozzle disk is mounted a few millimeters below the pavement. Spray nozzles may be installed in the center of the lanes and so chemical solution may be covered on all lanes of traffic. It is the disadvantage of this type that all traffic lanes are closed while installation or maintenance. The other flush-mounted type is installed near the shoulder of roadways. It isn't necessary to close all lanes for maintenance and installation but the nozzle top is covered with snow when the weather is heavy snow and snow plough vehicle rakes out snow sides of roadways. Guardrail-mounted or parapet wall installation is cheaper than flush-mounted because of its simple design and maintenance. These nozzles should spray stronger to cover all lanes. The closing possibility of nozzle because of snow plough vehicle is quite high. Micro spray nozzles are generally used in private areas such as airports and viaducts. They spread solution homogenously and installation on road is easy. Manufacturing material of spray nozzles should be resistant to damage and non-corrosive such as stainless steel. Nozzles should be removable for cleaning and maintenance. The number and pattern of nozzles are determined according to the required coverage as shown in the design drawings. Carrying solution with the wheels of vehicles should be taken into account while planning places of nozzles. The height of nozzles in pavement should be adjustable to some degree.

Anti-icing chemical lowers freezing point and this provides road ice to melt at lower temperatures, preventing the accumulation of slippery ice [18]. Chemical liquid that leaves the surface slightly moist will be enough for melting ice in many conditions. When selecting chemicals, their performance characteristics (e.g. effective temperature and ice melting capacity) along with their cost, application rates required for various road weather scenarios, and environmental risks (including those to metals and concrete) should be considered. Anti-icing liquid shouldn't have crystals and foreign objects which may block fine spray nozzles. The anti-icing chemical is determined according to the weather and road temperature where the system is installed. Cost, applicability, environmental impact, and corrosive effect are the most important criteria for choosing a chemical liquid. Chemicals may affect barriers, vehicles, signs, concrete, and asphalt [19]. Besides anti-icing chemical determines the properties of tanks, pipes, and all spray subsystem. To dissolve a certain amount of ice at a specified temperature needs a certain amount of deicing material. The amount should be determined carefully. In case of an insufficient amount of salt for road surface covered with ice, the layer of ice does not always melt away. When an excessive amount is spread over, entire ice melts, but, some part of deicing is wasted unnecessarily, which is an economic loss. FAST systems arrange the optimum amount of chemicals and eliminate these disadvantages. Determining factors of chemicals are speed, the required quantity of material, and duration of melting action. Environmental considerations are also important [20]. Truschke et al. [21] investigated highly concentrated deicer solutions applied through bridge deck deicing and anti-icing systems disproportionately contributed to the deterioration of portland cement concrete bridge decks and adjacent concrete approach slabs in Colorado and mitigation strategies employed by Colorado DOT addressed the problem. The most used anti-icing chemicals for road surfaces are Calcium Chloride ($CaCl_2$), Sodium Chloride (NaCl), Magnesium Chloride ($MgCl_2$), Calcium Magnesium Acetate (CMA) and Potassium Acetate (KAc). Chlorides based chemicals have the most corrosive effects on carbon steel [22]. Acetates are more environment friendly but they are more expensive than chlorides. During the process of melting snow or ice, additional water is produced and the concentration of the deicer is reduced, which may cause the solution to re-freeze. Xie and the others report a comparative study of field cores taken from two select Nebraska concrete decks and from two select Utah concrete decks. This case study sheds some light on this complex issue of concrete durability and raises awareness of the risk of using KAc deicers on concrete structures and components [23].

Critical aspects of the spray subsystem are listed below:

- Mixture amount sprayed from nozzles should be measured and adjusted.
- Spray subsystem should have fault tolerance and fault detection.
- Spray subsystem should be modular.
- Subsystem components should be controlled separately and deactivated.
- Subsystem components should be placed in a safe place.
- Chemical and water amounts in tanks should be monitored.
- Nozzles and sensor's operating temperatures should be appropriate to environmental conditions and placed regularly.
- Subsystem components should be selected according to the chemical used.
- Subsystem should contain a control room and storage room for tanks.
- Property of blocking chemical liquid precipitation should be added.
- All of the components should be selected as corrosion-resistant property.

- Although the system operates automatically, subsystem units should be intervened as manually for unforeseen circumstances.

5. CONCLUSIONS

FAST is widely used to prevent accidents caused by winter conditions. Based on the data obtained as a result of the literature review, the benefit-cost ratio higher than 1 in all applications put forth the superiority of FAST and become more and more widespread day by day. In this study, FAST is compared with other struggling methods. In addition, components constituting FAST are presented in an integrated approach. It has been observed that the usage amounts of chemicals used in art structures such as bridges, viaducts and airports will be optimized with this approach and so the service life of building elements is increased by decreasing corrosion. It also helps to keep the skid resistance value in a safe range by predicting weather conditions.

Benefit-cost ratio of FAST is directly proportional to the critical aspects of the components used in the design. In this study, these critical aspects are presented. Also, the factors that should be considered in selecting each component of FAST are given in detail. FAST is an interdisciplinary application and its design includes many scientific fields.

Not only material selection, but also criteria for control unit and software are put forward. There is no study on the determination of the FAST components taking into account the integrity of the system. Therefore, this study is an important source for filling this deficiency in the literature.

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