Hindawi Publishing Corporation
Chinese Journal of Engineering
Volume 2014, Article ID 618109, 12 pages
http://dx.doi.org/10.1155/2014/618109

Research Article

The Design of an Urban Roadside Automatic Sprinkling System: Mitigation of $PM_{2.5–10}$ in Ambient Air in Megacities

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Received 1 April 2014; Accepted 6 July 2014; Published 23 July 2014

Academic Editor: Zheng-Hong Huang

The objective of this research paper is to describe the system architecture for an urban roadside automatic mist-generating system. Its primary purpose is to mitigate particulate matter especially $PM_{2.5–10}$. In this paper, four graphs are provided to exhibit the constituent elements of this system. This paper also discusses the functional extensions of this system for alternative uses in civil engineering which include winter road deicing and desnowing with added salt; clean-up of street dust; lowering of temperature of a "hot island" during the summer; the addition of humidity in an arid area; and the suppression of flu virus in the winter season. The structure and function of this system are comprehensively discussed in this paper. This system is compared to existing and other proposed systems in terms of control options, efficiency, and primary functional issues. The unique design of the road automatic sprinkling system renders itself a prominent option. Although there are no data available for this conceptual system, some expected qualitative and quantitative outcomes are provided and justified. The paper concludes with some potential research areas and challenges associated with this system architecture.

1. Introduction

Much attention has been given to the issue of urban air pollution caused by ambient particulate matters as it causes more health issues and even premature deaths in many megacities of the world [1, 2]. Nevertheless, pollution levels are still escalating as is indicated with a recent case of $PM_{2.5}$ hitting the shocking level of 900 micrograms/m^3 on January 12, 2013, in several places of Beijing, which is nearly 36 times the required safety level designated by the WTO [3].

Particulate matter pollution, according to the definition of the U.S. Environmental Protection Agency (EPA), can be categorized into two groups [4]. The first group is comprised of fine particles found in smoke and haze with diameter equal to or less than 2.5 microns, which come from emissions of coal-fired power plants, emissions from coal-burning heating, wood smoke, and some factories, whilst in urban areas mainly originating from diesel engine exhaust, gasoline-powered vehicle emissions, and paved road dust. The second group is comprised of inhalable coarse particles with diameter between 2.5 and 10 microns that originate from dusty industries [5–8]. Health concerns are raised for $PM_{2.5–10}$ as particles can penetrate the body's natural defenses in the nose and throat and enter the lungs. Research shows that short exposure to high levels to these particulate matters can aggravate lung disease, can cause asthma attacks and acute bronchitis, and might increase the chance of respiratory infection as well [9–12]. Long exposure to high level of $PM_{2.5–10}$ might cause more serious problems, especially, for children and older people, such ascardiorespiratory disease, lung cancer and the development of chronic bronchitis [13–15], and even premature death [16, 17].

Rapid economic growth brings accelerated urbanization and motorization that leads to increased air pollution caused by particulate matter. Most importantly, the sprawl and unscientific urban design of megacities exacerbate air pollution. There are three facets, that is, city street canyons formed by high-rising buildings, elevated roads, and high density of buildings that actually help create stagnant environmental conditions allowing air pollutants to be trapped near the road surface and space below the overbridge [18, 19]. Another case is the city sunken tunnel road that leads to other forms of stagnant environmental conditions [20]. Because $PM_{2.5}$ is so small, such an environment facilitates the particle air suspension that can be very long. This impact is generally intensified by certain conditions particularly in the winter when the weather remains cold and air stagnation exists for weeks. This accelerates the buildup of particles and the subsequent level of pollution. That is why hospital admission for asthma cardiorespiratory and other pulmonary diseases is very high during the winter days that have heavy smog and haze [21].

The other condition that aggravates the PM pollution is the existence of pollution-intensive factories near the city fringe, which was ever a symbol of modern industrial metropolitan megacities without zoning laws introduced in some countries. Another important factor that expedites PM buildup and worsens pollution level is the basin location of many cities such as Los Angeles, Chengdu, Urumqi, Mexico City, and Sydney, where polluted air is trapped beneath and within temperature inversion layers because of their particular geographic features [22–25].

Given the health care concerns arising from the public with respect to the impacts of PM on human heath, many cities have adopted different strategies and technologies to mitigate the ambient particulate matter [44]. Measures include but are not limited to the design of ecofriendly and sustainable cities [45–47], moving heavy factories out of city fringes [48, 49], promoting the use of green energy cars and improving emission standards [50], introducing traffic congestion charging to reduce standby emission and vehicle use [51], and using mobile sprinkling vehicles for suppressing dust among others. However, progress is not clear at least in the short term given the material and information delays that exist in engineering systems. It is much easier said than done when redesigning a city given its limited resources and the complexities of existing megacities. The adoption of new green energy vehicle requires very long time. Traffic congestion pricing policies have very limited impacts on pollution mitigation. Driving mobile sprinkling vehicle creates congestion itself while it is being operated; and it cannot approach an area as frequently as desired [52].

Given the limitations of the current measures of mitigating ambient particular matter in an urban city, this research proposes a design of an integrated system that can not only handle current pollution issues but also serve multiple functions for the urban area in a cost-effective way. This system is called the roadside automatic sprinkling system (RASS) and it exhibits the following functions. First, multiple sprinkling nozzle orifices can generate streams for different flow rates, coverage, height, and directions to suppress particulate matter suspended in the air. This happens as long as the $PM_{2.5-10}$ reaches certain levels in the air since particulate matter is negatively related to precipitation [53–56]. Second, this system is designed to be used in the winter to generate salty streams to deice and desnow roads. RASS also generates mist in the summer for the purpose of cooling the urban heat island [57]. Actually, in Beijing, some pedestrian streets already have mist-generators that work as cooling devices in summer. In addition, the system sprinkles fresh/salty water mist to kill the influenza virus suspended in air when cold and stagnant weather lasts for days in the winter. Some literature has already shown that the influenza virus suspending in the ambient air reacts to absolute humidity [58–61].

2. The System Design

This section depicts the system architecture of the RASS. Figure 1 presents how to fit the RASS into the existing civil infrastructure. Aside from the control system, there are very limited additions needed to be included to the current design. Therefore, the operation cost is minimized. For the urban street canyon formed by high-rising buildings on both sides, the sprinkling devices are installed on the road stripping area and curb trenches. Water feed and high pressure water pumps are used to power the sprinkling system. The adjustable arc and flow rate adaptable sprinkling nozzle are used to guarantee that the generated stream or mist can cover the whole space above road. The water sources in this system could come from the current municipal water supply system, from the fire sprinkling system, or from the water recycled from precipitation.

Figure 2 shows how the system is controlled and operated. The system structure is illustrated from the bottom. The right bottom area depicts the general purpose water supply where water is pumped from the fresh water cistern that connects to the municipal water supply system or other sources of water. The left side of this system graph displays that the deicing salt is being added to a water cistern for purpose of using during the winter. Apart from this basic concept, a more advanced structure could be designed in a way that fresh water passes through a salt container or sifter and reaches a gate valve controlled by the center control computer system. That is to say, when the temperature reaches below or close to 0°C or when salt water is needed, the valve will be turned on and the valve for controlling fresh water will be turned off. It is necessary to note that the salt container or sifter has a sensor or detector that monitors the amount of salt, which can be added from a salt inventory system once the sensor sends a low level signal to the relevant control system. Moreover, the concentration of salt water will be regulated by another control system in which the sensor directs the servo motor to control the amount of salt required based on actual needs.

Referring to Figure 2, the center of the system graph is the sprinkling system control station (SSCS) that handles multiple tasks. Task 1 is to communicate with the data processing center (DPC) and to receive processed information from it. The SSCS subsequently translates the information to specific commands to start up or turn off the water feed pumps and high pressure water pump. Which water feed pump will be switched on or off depends on the actual needs, that is, whether salt water or fresh water is needed. The SSCS system then transmits a signal to the programmable logic controller (PLC) that is responsible for controlling the characteristics of generated stream/mist. It simultaneously sends instructions

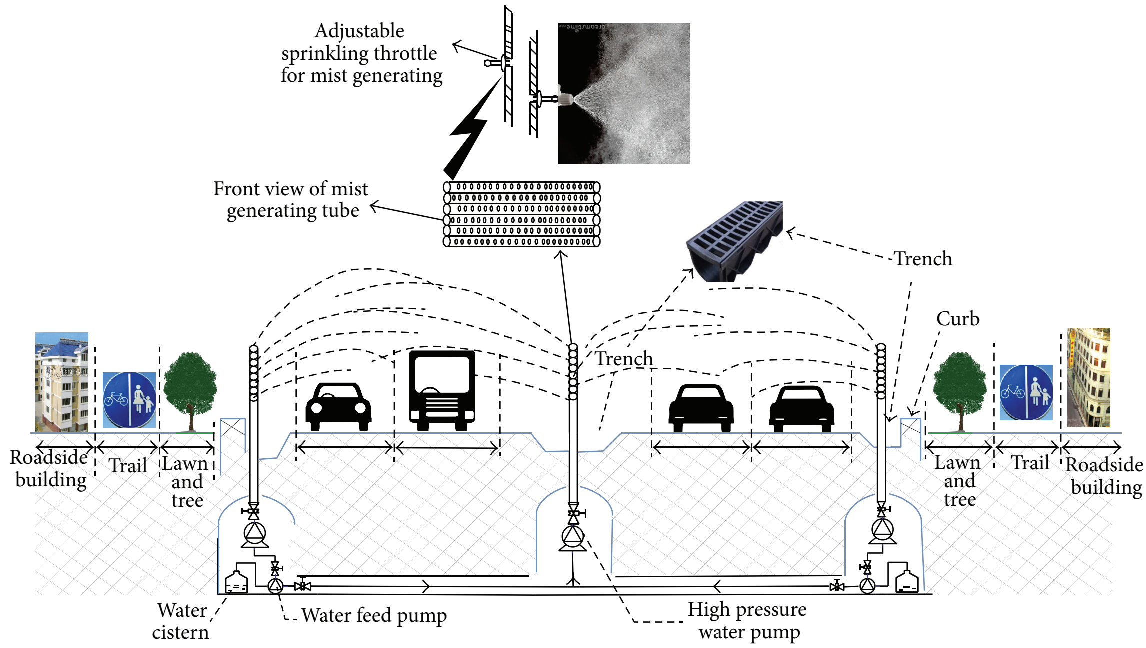

Figure 1: Holistic view of the roadside automatic sprinkling system.

to the hydraulic cylinder for controlling the expanding and contracting of the arc of sprinkling throttle.

The DPC receives data from several sources and processes them according to different needs. One source of data comes from air analyzer (top left of Figure 2) that tracks the quantitative pollution level. The air analyzer collects and processes data from a mobile air quality monitoring center, fixed air sampling points, and roadside air sensors. Based on the level of air quality, the DPC determines, by sending instructions to the SSCS, whether it is necessary to activate sprinkling system or not. For the purpose of sprinkling salt water for the deicing/desnowing of the road in cold weather, the DPC collects data related to meteorological conditions from weather satellites, Doppler radars, weather stations, roadside ice and snow sensors, and processed data by technicians that observe road surface ice accumulations surveillance cameras. Once it is determined that the salt stream/mist is needed, the SSCS will activate the salt water feed pump and regulate the PLC to produce stream/mist with the desired features (coverage, direction, pressure/speed, droplet size, etc.). In addition, meteorological information, namely, wind, temperature, relative humidity, and air pressure, will be used to determine the relevant parameter settings for the PLC to generate stream/mist achieving the optimal result of suppressing the $PM_{2.5-10}$ and at the same time to save water.

With an extension, referring to small dashed square, the DPC will receive information from the influenza virus detector/sensor wherein air is sampled and analyzed for identifying the level of the virus suspended in the air. Following the same procedure as described previously, the SSCS will determine if salt or fresh stream/mist will be generated depending on the temperature.

Figure 3 depicts the structure of the hydraulic system and the stream deflector working together to form an adjustable sprinkling nozzle.

As shown in Figure 3, high pressure pump pushes water to the tube that provides water for the sprinkling system. The tube has the second major function of working as the shaft of the hydraulic cylinder. The hydraulic gear is operated through a servo motor and controller that expands and contracts the arm that connects the sprinkling throttle. The sprinkler head has multiple rows of throttle orifices mounted on the RASS [62–64]. The detailed description of the working mechanism of this equipment is beyond the scope of this paper.

Figure 4 presents the cases where the RASS is installed to the overbridge and traffic tunnel structures that are two major civil infrastructures trapping polluted air in urban areas.

3. Discussion

As a system of systems (SoS), an urban system is an emerging and ever-evolving metasystem composed of many autonomous constituent systems including a socioecological system, a socioeconomic system, a sociotechnical system, a geographic system, and a meteorological system where interconnections exist among them (Figure 5). The function of an urban SoS is to achieve the objectives of the urban metasystem as well as its constituent systems through the dynamic interactions and interoperations of its different systems [65–67]. The objectives of an urban SoS in the long run are to create a robust context in which constituent systems working together reduce the vulnerability of the city and increase urban resilience. In this context this system increases an urban area's capability to forecast, prepare for, react to, and restore its function from multiple major detrimental events

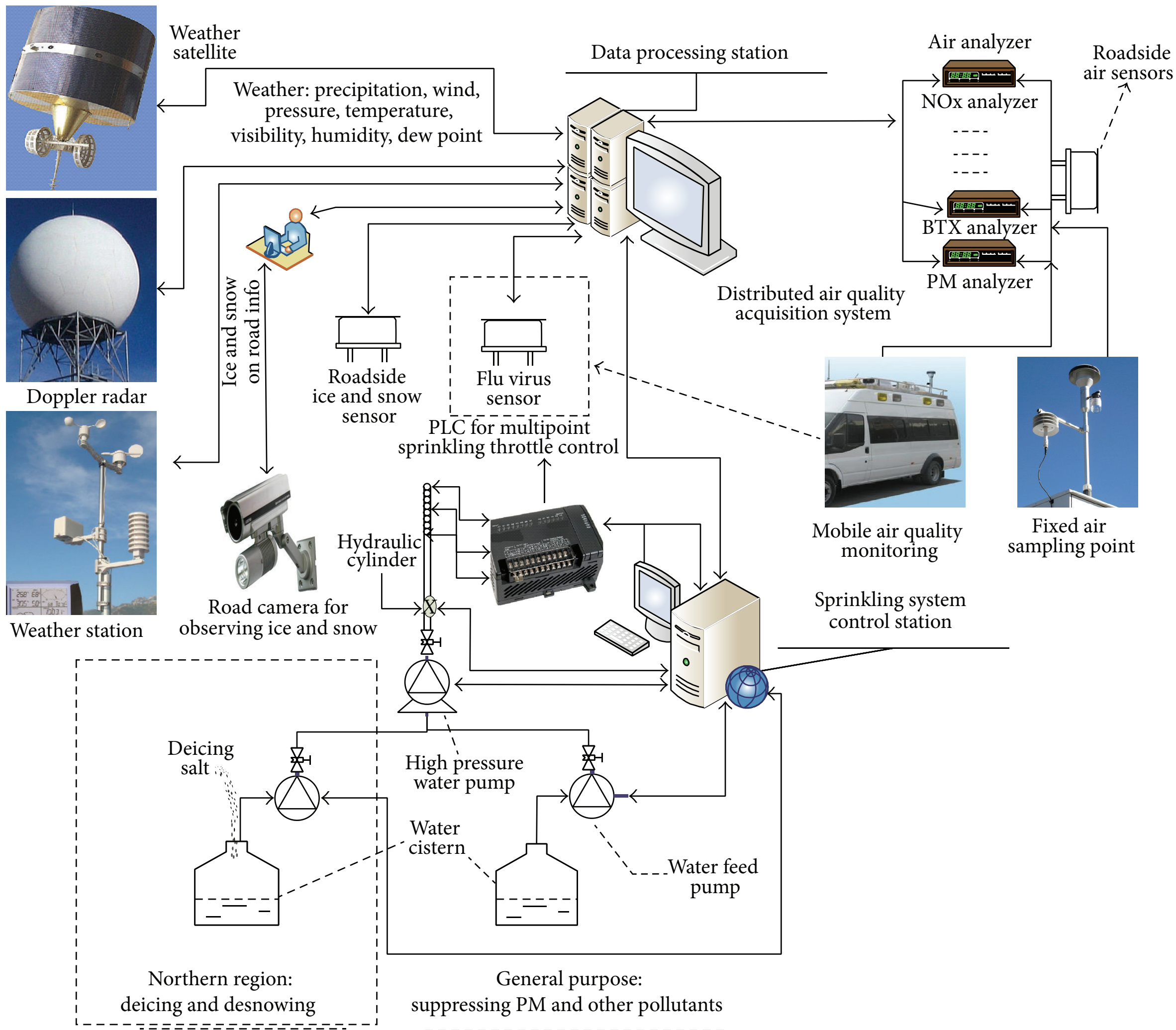

Figure 2: The control system and the different functions of the RASS.

with minimum consequences for public safety, security, economy, ecology, and quality of residents' lives [68, 69]. However, for any given urban area, constituent systems may have conflicting objectives and functions that compete for resources making it difficult to achieve the synergy required to achieve the goals of the constituent systems and of the SoS as well [70–72]. Therefore, malfunctioning SoS leads to undesirable negative externalities for certain constituent systems although they are bounded within the SoS context [73]. In Figure 5, we highlight a few malfunctions that our proposed RASS is designed to address, which are a high level of concentration of $PM_{2.5-10}$, urban hot islands, snow/ice on the road, and flu virus in ambient air.

In order to achieve a sustainable urban SoS, many newly designed systems are integrated as constituent systems of the emerging SoS. Nonetheless, seldom can integration of a single man-made system into an urban engineering system solve several distinct issues within the urban area. However, in this research, in addition to serving the primary function of mitigating the concentration of $PM_{2.5-10}$, RASS can handle multiple negative externalities caused by the interactions of the constituent systems of an urban SoS, namely, urban hot islands, snowy/icy roads, and flu virus suspended in ambient air. This proposed system can offset the negative externalities created by existing urban SoS. The advantage of this unique design is that it avoids integrating man-made systems serving different singular functions into current urban SoS, which reduces more possible emerging characteristics of urban SoS due to the new connections, interaction, and interoperation established between newly introduced systems and prior constituent systems. It thus reduces complexity and increases the controllability associated with integrating this system in the current urban SOS's dynamic emergent context. It also reduces both short and long term side effects. This proposed system could increase affordability while addressing multiple urban critical issues due to reduced complexity and increased controllability, which considers the life cycle costs in design, operation, maintenance, and administration [74].

Since the removal of haze and smog in metropolitan areas is an enormous systems engineering challenge, it needs the contribution from different constituent systems of the urban SoS. Great efforts have been made to control the

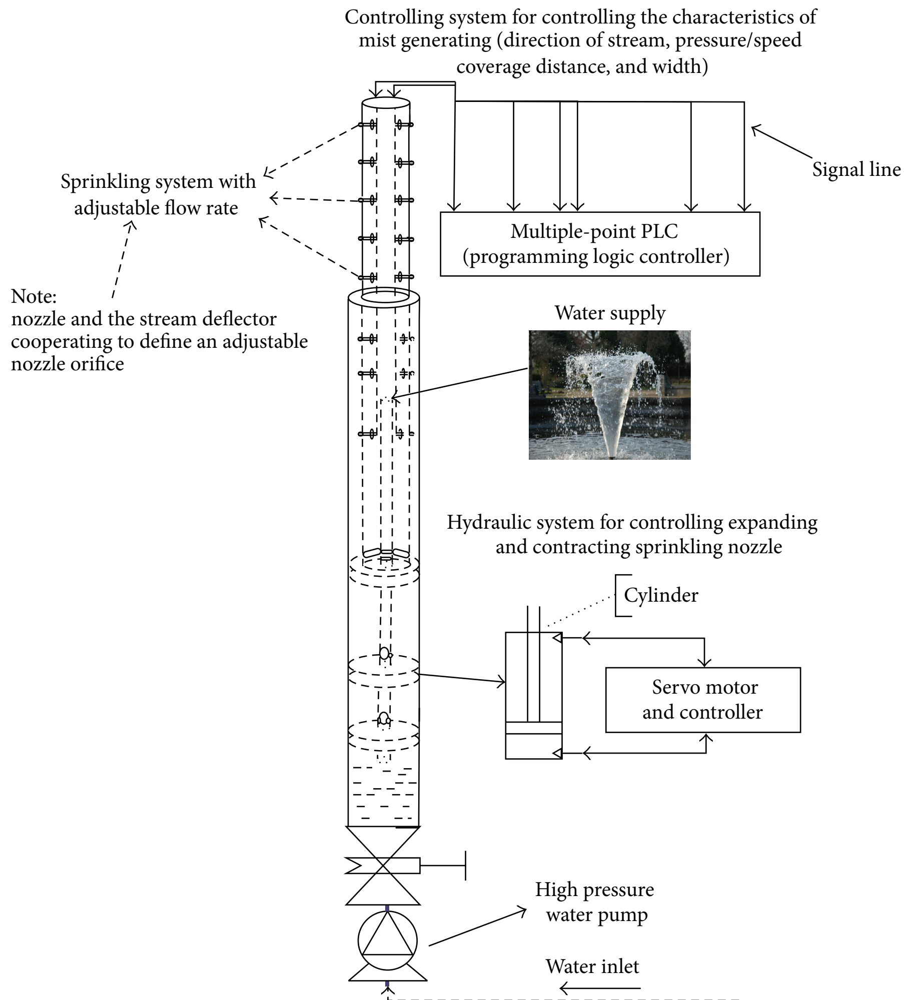

Figure 3: Flow adjustable sprinkling system for the RASS (source http://www.freepatentsonline.com/6651905.html/).

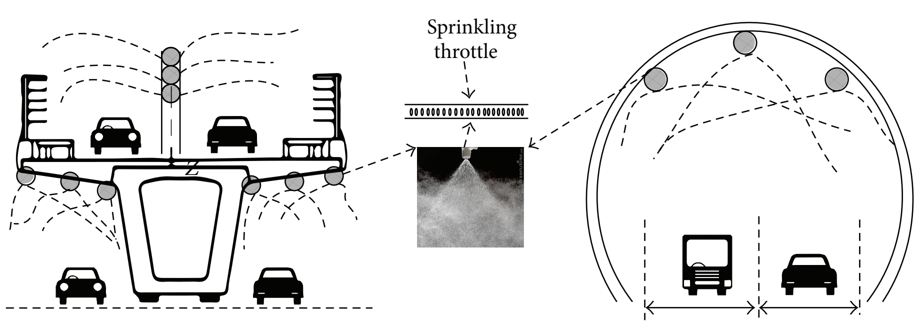

Figure 4: Application of the RASS to the overbridged and tunnel structures.

emission of fine particles from their origins for the sake of mitigating the concentration of $PM_{2.5-10}$ in urban areas where measures were taken to control its origins including but are not limited to road traffic, construction activities, residential coal combustion, pulverized coal boiler activity, diesel engine combustion, and waste incineration [26]. Nonetheless, haze and smog are more often not present in large cities such as Beijing due to the emission and wind resuspension of coarse and fine particles caused by the more than 5 million running vehicles plus geographical and meteorological conditions. Some built and proposed pollution mitigation systems are being, and would be, used by large cities to resolve aforementioned issues (Table 1). Hereby, we compare our proposed system with water flushing and vacuum sweeping [26–29], artificial precipitation [30, 31], a recently proposed urban air cleaning system using electrostatic mechanism [32, 33,

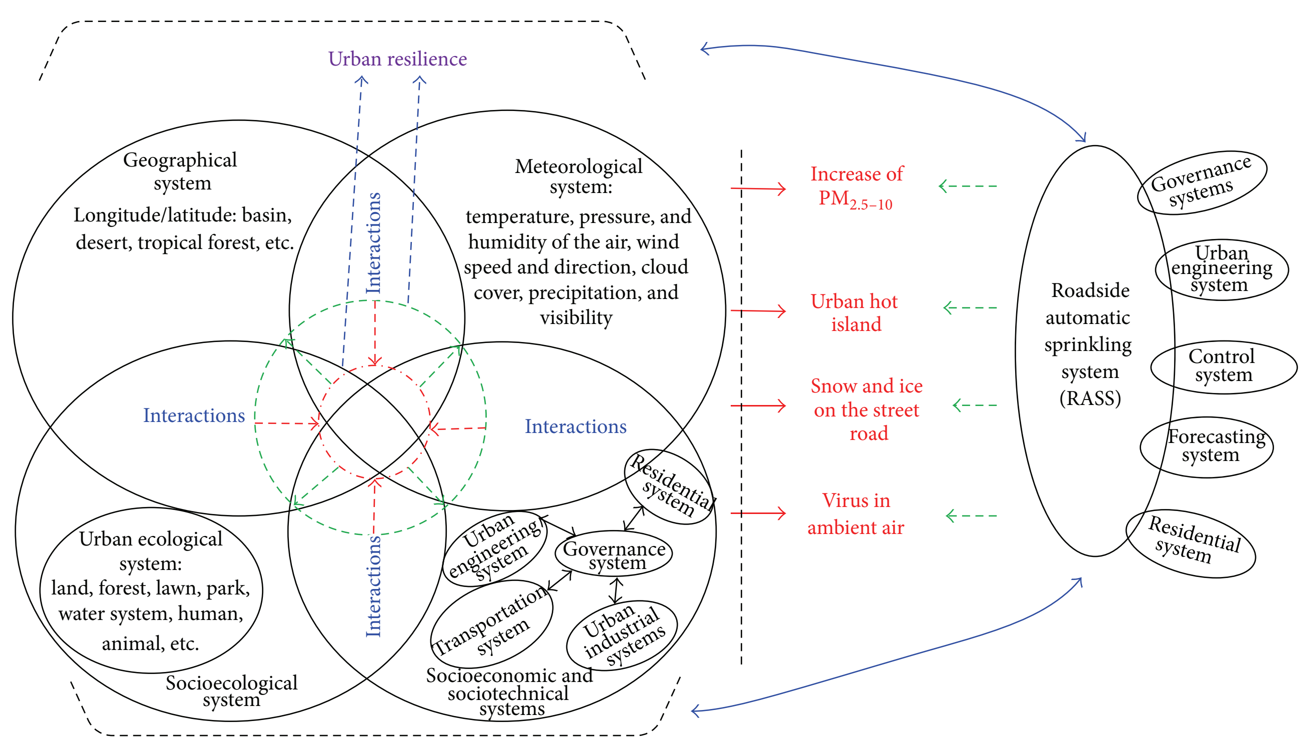

Figure 5: Urban SoS perspective and uniqueness of RASS (source partially from Resilience Alliance, 2007, http://www.resalliance.org/index.php/urban_resilience/).

75], and other measures [26]. They are compared in terms of their primary functions, estimated functioning efficiency, life-cycle cost of deployment and operation, advantages, and possible issues as well, which also demonstrates the uniqueness of the RASS. As our proposed system can be extended to tackle not only merely urban air pollution but also other issues such as acting as a snow-melting system, we also compare it with existing installed desnowing and deicing system (Figure 6).

Compared to other systems, the primary control option of RASS is very simple to utilize and deploy while having very high operational efficiency and fewer limitations. RASS is estimated to have an efficiency of 85% to 100% in mitigating the concentration of $PM_{2.5-10}$ and 95–100% efficiency in removing snow and ice on the road [26, 42, 43]. The other three options in Table 1 have more potential problems and limitations during operations even though they have good efficiency score and some advantages. Depending on man-driving truck, the labor-intensive water flushing and vacuum sweeping cannot be operated synchronously across the whole urban area. It is not only affected by the traffic flow but also affected by the influence traffic. Therefore, the operation frequency will be limited. During the operation, it also causes resuspension of fine and coarse particulate matters and is unable to deal with particulate matters in the ambient air. Artificial precipitation can create a very good outcome once initiated successfully. However, it is a high-cost mechanism with low controllability because of its reliance on availability of seed clouds. It also has a side effect of possible soil pollution caused by materials used for condensation nuclei [30]. The third mechanism is a proposed system called electrostatic air cleaner, which uses the same mechanism for industrial applications [32, 33, 75]. Even though this system has some advantages such as low operational cost, good controllability, no effect on traffic flow, and being able to operate at any frequency, its side effects can cause severe issues for the urban area. The side effects include the impacts of electrostatic discharge on electronic communication and devices [34–36], safety issues [37–40], and adverse effect on human health.

Because there are very limited published data available, we schematically show the expected quantitative and qualitative outcomes after the deployment of the RASS (Figure 7). Two of the most significant improvements are with respect to the environment and attractiveness of the city. With the deployment of the RASS, it can significantly reduce the $PM_{2.5-10}$ and coarse particulate matters caused by several million running vehicles. As a result of reduced fine and coarse particulate matters in the ambient air, the chance that haze and smog will occur will be noticeably reduced. Hence, people susceptible to $PM_{2.5}$ will be able to have more outdoor activities without worrying about air quality. And clear day also reduces people's depression and bad mood, which is beneficial to people's mental health. Additionally, transportation especially air traffic which is vulnerable to low visibility will also benefit from this system. Since RASS can suppress fine and coarse particulate matters and detrimental vehicle emissions such as nitrogen oxide and sulfur oxide (SO_x), it reduces the chance of acid rain which contributes to accelerated weathering of the urban buildings and infrastructures [76]. Taking into account the

Table 1: Comparison of RASS with existing systems for tackling negative externalities of urban system.

Strategies and systems	*Primary control option efficiency for removal $PM_{2.5–10}$	Lifecycle cost of deployment and operation	Advantages	Possible issues
RASS	Sprinkling system is used to purify air, washing away dust content and preventing generating and resuspending particulate matters caused by running vehicles, efficiency (85%–100%); function in removing snow and ice on the road, efficiency (95–100%)	Initial cost will be high to moderately high depending on the scale of installation. Operation cost and maintenance are small to moderate dependent on frequency of event, traffic volume, and situation of inclement weather.	(i) Can be operated at any frequency if needed (24/7) (ii) Labor cost is minimal (iii) Has multiple functions (iv) Does not affect traffic flow when being operated (v) Ex-ante intervention (vi) Cover as many areas as possible (vii) Can be operated synchronously and asynchronously (viii) Good controllability (ix) Preventive action (x) Without causing ice in winter (xi) High robustness	(i) Water dependent (ii) Need to be integrated into current urban engineering system (road infrastructure, underground utility system) (iii) Some blind areas may not be covered
**Vacuum sweeping water flushing and sweeping	Man-driving truck sweeper and sprinkling pressure water in all traffic lanes and sidewalks; vacuum sweeping (0–50%), waster flushing and sweeping efficiency (0–96%) [26–29]	Initial cost will be high depending on the number of trucks and drivers needed; operation and maintenance cost will be moderate to high depending on the size of the city	(i) No need to change current urban engineering system (ii) Saving water (iii) Mobility of sweeper truck enables it to work at locations where RASS cannot be installed	(i) Ex-post intervention (ii) Labor intensive (iii) Affected by traffic situation and influence traffic flow as well (iv) Water dependent (v) Cover very limited areas (vi) Causing resuspension of fine and coarse particulate matters (vii) Cannot be operated synchronously
Artificial precipitation	Using cloud seeding method to increase precipitation (rain or snow), raining or snowing, efficiency (42.6–100%) [30, 31]	Operation cost will be very high	(i) No blind pots within the whole area (ii) Relief pollution, hot weather, and drought as well	(i) Bad controllability (ii) Dependent on the availability of clouds (iii) Possible land soil pollution from chemical materials such as silver iodide [30]
Electrostatic air cleaner	Using the mechanism of electrostatic precipitator, efficiency (76.2%–99.7%) [32, 33]	Building cost is high and operation cost is low to moderate	(i) Low operation cost (ii) Can be operated synchronously and asynchronously (iii) Good controllability (iv) Does not affect ground traffic flow when being operated (v) Can be operated at any frequency if needed (24/7) (vi) Labor cost is minimal	(i) Cannot prevent the fine and coarse particulate matters from resuspending (ii) Effect of electrostatic discharge on telecommunication, air transportation [34–36] (iii) Safety issues: gas station, and other possible dust explosion, electronic and electric equipment [37–40] (iv) Adverse health impact on human being [41]
Other preventive measures, equipment, and systems	Other measures not called system such as covering trucks, improving fuel quality, and reducing emission from waste incineration	Costs ranging from very low to very high	(i) Handling the pollution from the origin of emission (ii) Preventive action	(i) Too much variability (ii) Hard to operate synchronously and synergistically

Table 1: Continued.

Strategies and systems	*Primary control option efficiency for removal $PM_{2.5-10}$	Lifecycle cost of deployment and operation	Advantages	Possible issues
***Desnowing and deicing system with similar mechanism (referring to Figure 6)	Ground-installed warm-water sprinkler (Figure 6) [42, 43], efficiency (90–95%)	Cost is high	Without causing land and soil pollution	(i) System must work continuously; otherwise water may become ice (ii) Depending on the availability of warm water such as hot geyser in Japan where this system has been deployed (or water boiler)

*Since there are very limited data available, efficiency and cost are based on current literature and estimation of authors.
**Tucker reviewed most of the current knowledge on the origin and control strategies of fine particles in both urban and rural areas. Since this research is focusing on the removal and mitigation of $PM_{2.5-10}$ in urban areas, the citywide PM removal systems are compared with our proposed system in terms of the control efficiency, lifecycle cost of deployment and operation, advantages, and possible side effects.
***Having the similar system structure as our proposed RASS but serving different function, artificial snow-melting systems have been employed in countries like Japan to desnow or deice urban area with the capability of increasing urban resilience of megacities when affected by snowfall, sleet, and icy weather.

(a) (b)

Figure 6: Snow melting system using warm-water sprinklers in Japan ((a) http://pds.exblog.jp/pds/1/201103/09/58/b0092858_21205671.jpg, (b) http://hondakenchiku.com/wp-content/uploads/2008/02/080209kokudou.jpg).

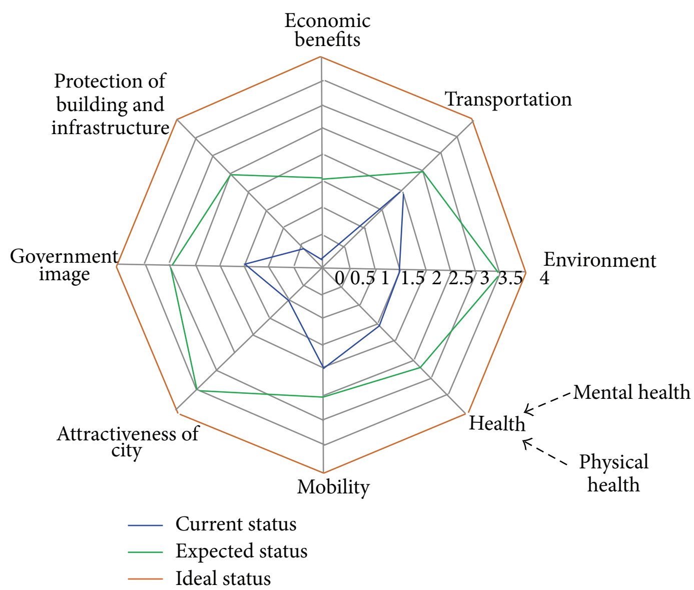

Figure 7: Expected outcomes after the deployment of the RASS.

other three functions (mitigate urban island in the summer, reduce air-borne flu virus in dry and cold winter, and desnow and deice in the winter), the RASS can improve the urban environment during different seasons which undoubtedly increases the attractiveness of cities. This consequently boosts the economy of the city through attracting more businesses, skilled laborers, and tourists.

However, at the time of enjoying the benefits brought by RASS, the operation of this system might generate some potential possible unwanted and unintended effects on pedestrians, drivers, and civil infrastructure or facilities. One of them might be the formation of fog due to the increase of relative humidity and the availability of condensation nuclei, for example, dust, aerosols, and pollutants in the ambient air. Pedestrians, motorists, and cyclists might get wet by sprinkled mist if the roadside walkway is within the wetting circle of this RASS. The third possible side effect is that the operation of RASS increases the burden on water supply for areas which already have very limited water sources. Last but not least is the increased relative humidity which might accelerate the weathering and corrosion of some civil infrastructures particularly in arid regions.

The integration of RASS into existing municipal engineering systems requires comprehensive research and enormous analysis on many "-bilities," namely, feasibility, affordability, testability, traceability, usability, accessibility, integrability, interoperability, reliability, supportability, maintainability, expandability, disposability, and sustainability. The life-cycle system engineering process model proposed by Blanchard [77] and the "V" systems engineering model promoted by FHWA [78] are very useful approaches for incorporating the above-mentioned "-abilities" during detailed system design.

The deployment of RASS also faces additional challenges. First, it is the cost of operating and maintaining such a large scale system. As mentioned previously, water is one major limitation for some arid regions, which will account for very high percentage of the operating cost. Therefore, the system may need to have more support subsystems to enable itself to adapt to different harsh environmental conditions. One possible add-on is the precipitation collection and recycling system. With this system, RASS can recycle the sprinkled water once it finishes washing the condensation nuclei, namely, $PM_{2.5-10}$ and other pollutants. This forms a virtuous water usage. The second challenge is to improve the performance of this system. Further research should be done to explore the impacts of the interactions of meteorological conditions, level of pollution, and the characteristics of the sprinkled water droplet on desired outcomes such as saving water for urban areas particularly for arid regions. And the third challenge is the fit of RASS with existing municipal engineering infrastructures. Given the cost associated with the deployment of this system and possible side effects created by this system, the fourth challenge is how to get support from the public. And the fifth challenge is that the policy makers need to decide if a brand new system will be installed or just integrate RASS into existing municipal engineering systems. The last but not the least challenge is to determine how many pilot operations (how long and where each one) need to be operated in order to guarantee this system can be deployed and sustained successfully during its system life cycle.

4. Conclusion

The research paper describes the system architecture for an urban roadside automatic mist-generating system with its primary purpose to mitigate $PM_{2.5-10}$. This paper also discusses the functional extensions of this system for alternative uses in civil engineering which include winter road deicing and desnowing with added salt; clean-up of street dust; lowering of temperature of a "hot island" during the summer; the addition of humidity in an arid area; and the suppression of flu virus in the winter season.

The introduction of RASS undoubtedly brings more complexities and dynamics to existing municipal infrastructure because dynamic interactions will be established between RASS and existing sociotechnical and eco-technical systems. One example here is that the operation of RASS might be able to create a small urban climate that had not been experienced by this area before because apparently some meteorological variables become dependent on the operation. That is to say, continuous operation of the sprinkling system might change relative humidity, atmospheric pressure, temperature, and concentration of condensation nuclei in the ambient air and possibly the precipitation rate, which ever had a pattern formed over a very long time. More researches need to be done following the operation of this system. In addition, further study can also focus on the customization of this generic design to apply to local conditions. It might also be possible to extend this RASS to roadside or community high-rise buildings for covering more vertical space. Moreover, with the aid of GPS and GIS and more predication functions, the adaptability of RASS can be improved by initiating more ex-ante actions instead of ex-post reactions for preventing accumulation the amount of $PM_{2.5-10}$ in the ambient air.

Abbreviations

RASS: Roadside automatic sprinkling system
SoS: System of systems.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Authors' Contribution

Dr. Liu initiated the concepts and designed the system. Dr. Liu and Dr. Triantis contributed to the writing and editing of this paper. L. Zhang helped edit the paper. All authors contributed equally to the completion of this paper.

Acknowledgments

This work was supported in part by the Project for Young Scholars in Humanities and Social Sciences of MOE (10YJCZH093), Ministry of Education. This paper is based in part on work supported by the National Science Foundation while working at the foundation. Any opinion, finding, conclusions, and recommendations expressed in this paper are those of the authors and do not reflect the views of the National Science Foundation.

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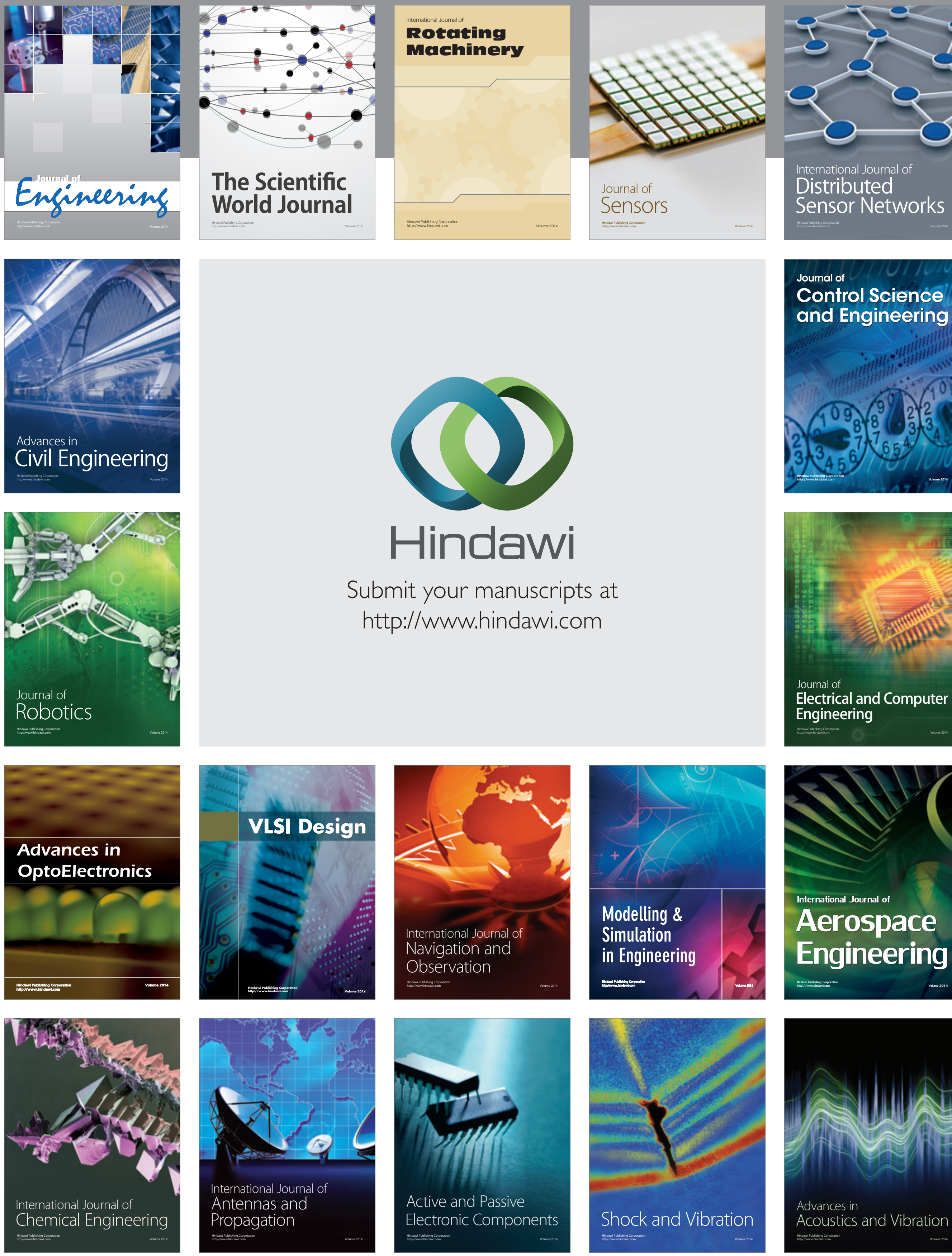
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