Sustainable Roadways: The feasibility of Recycling Plastics into Asphalt Materials
(Technical Paper)

Paradigm Shift: How Single Use Plastics Can Be Transformed from Waste to A New Commodity
(STS Paper)

A Thesis Prospectus
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On my honor as a university student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Prospectus

Introduction

Plastic waste in the United States is proliferating at a rapid rate that according to the environmental protection agency (EPA), in 2018, there were an approximate 35.6 million tons of plastics that were categorized as a municipal solid waste. However, only 3.09 million tons of these plastics were recycled out of the gross 35.6 million while 6.62 million were used in energy recovery via combustion and the rest were landfilled (EPA, 2018). Perhaps the most famous example of plastics waste accumulation and their environmental impacts is the Pacific Ocean Garbage Patch that covers an estimated area of 1.6 million square kilometers (Lebreton, 2018). This plastic waste is not biodegradable and has toxic effects on marine life which would propagate risks of pollutant exposure through the food chain to human consumers of seafood. The increase in plastics municipal solid waste has been exacerbated by the rise in single use plastics (SUP) that became inherently part of everyday life in terms of water bottles, plastic bags, etc. The SUP growth trend presents environmental challenges with post-consumer disposal where annually 400 million tons are produced, half of which are single use plastics (Lindwall, 2020).

Moreover, the plastics waste accumulation in the United States increased following the Chinese government ban on importing plastic waste from other countries in 2018 which prompted the exploration of possible means of plastic reuse for the 106 million tons of plastic waste that are accumulating annually with no consumption decrease in sight (Brooks, 2018). There have been some initiatives to mitigate the harmful impact of SUP excess waste such the executive order 77 issued by previous Virginia Governor, Ralph Northam, in March 2021, which mandated that Virginia state agencies to start the phaseout of SUP to eliminate their use by 2025.

The executive order was reversed by the current governor, Glenn Youngkin who seeks to implement a better recycling policy for post-consumer plastics.

One of the viable recycling potentials for SUP waste is asphalt, considering that asphalt is the most recycled material in the United States and has a versatile mixture design range to incorporate a variety of materials into its formula. The resiliency of asphalt mixture enables the use of most common types of plastics found in municipal solid waste which are High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), and Polyvinyl Chloride (PVC) to name a few. The Virginia Transportation Research Council (VTRC), a division of Virginia Department of Transportation (VDOT), has been conducting research on making asphalt production green and more sustainable by using recycled materials such as SUP. VDOT has been testing the performance of its Recycled Plastic Modified (RPM) asphalt which was placed for a road segment just under one mile in Chesterfield County, Virginia. As their mantra states, VDOT seeks to keep Virginia moving by implementing sustainable practices and solutions to the transportation network and infrastructure. The core mission of VTRC's research aims to introduce viable asphalt design mixes that are more durable and have optimal performance that results in saving time, money, and human lives. The sustainable roadways project seeks to test RPM asphalt samples and create Life Cycle Assessment (LCA) that would demonstrate the economic and environmental feasibility of recycling SUP into asphalt mixture.

Technical

The Virginia Transportation Research Council (VTRC) conducts all aspects of technical consulting and material testing of structures, pavement, concrete, safety, environmental issues, and systems operations. The asphalt laboratory at VTRC is accredited by the American

Association of State Highway and Transportation Officials (AASHTO) for binder and mixture testing in laboratory setting as well as on-site field testing and sample collection using coring equipment. VDOT has conducted field trials of RPM asphalt that go as far back as 1994 but over the past year, VTRC started evaluating the RPM asphalt in terms of rutting (longitudinal depression resulting from surface pavement deformation due to applied loading), fatigue, and thermal cracking for both short-term and long-term performances (Habbouche, 2022).

The 2022-2023 "Sustainable Roadways" capstone project team consists of two members conducting lab testing and LCA research. The team will create asphalt samples using the dry process which incorporates the crushed recycled plastic fines as an auxiliary material to aggregates directly into the asphalt design mixture. The dry process was selected over the wet process, because of its relative ease of implementation, the possibility to consume higher recycled plastic amounts, and avoiding the issue of storage instability. Both high- and low-density Polyethylene (PE) were chosen as the targeted type of recycled plastics for the project due to their abundance in both post-industrial and post-consumer waste streams (Rangelov, 2021). Under the advisory of VTRC lab technicians and research scientists, the team will select performance tests based on the superpave mix design specifications to establish whether the RPM asphalt's performance is superior to the conventional asphalt mix design for the short-term tests. The team will conduct site evaluation of where RPM asphalt has been placed in road segments in Chesterfield County, Virginia to better assess and document field performance.

One of the team's main objectives is to construct Life Cycle Assessment (LCA) for the RPM asphalt and compare it to the control LCA for the conventional asphalt mix design. The intended purpose of the RPM asphalt LCA is to provide a thorough analysis of the sourcing of plastics and other asphalt materials, energy GHG emissions, transportation GHG emission, field performance, durability/lifespan, and end-of-life recyclability. It will be difficult to examine the

performance over time given the relatively short timeframe of less than a year to complete the project. However, the team seeks to simulate the long-term performance of asphalt samples by using the asphalt pavement analyzer equipment in the VTRC laboratory as well as use the previous testing data as the control for the LCA. In order to construct the LCA, the team must define the system boundaries and declare the functional unit as well as consider the relationship between the performance parameters of the functional unit such as pavement thickness, roadway length, and rubber-on-asphalt coefficient of friction (Yin, 2020).

The team seeks to create RPM asphalt samples using the post-industrial recycled plastics supplied by VTRC and using the post-consumer plastics that are hand-sorted at the University of Virginia (UVA) recycling center while concurrently initiating LCA for each RPM asphalt case and conducting a comparison with the conventional asphalt design mix as the control. The teams' choice for the functional unit declaration for the various LCA's seeks to frame the analysis of each case to be fair and equal evaluation while keeping in mind that these asphalt mixtures can be used in different contexts while undergoing a variety of applied loadings throughout the life cycle (Rangelov, 2021). The parameters which the team will use to define the LCA's by are the global warming potential (GWP) in kg Carbon Dioxide-equivalent (CO2-eq), energy in megajoule (MJ), and cost in U.S. dollars (USD). These parameters would render data analysis for the best comparison standards for the various asphalt design mixtures which would help VDOT make an informed decision about future asphalt mix selection and material sorting.

STS Topic (Just One word… Sustainability)

The plastic proliferation and mass consumption since the 1950's have established an age that is equal in its sociotechnical and material dependence to that of the bronze age. The proposed STS research topic will address the recent paradigm shift in plastic consumption and recycling policies worldwide via exploring alternative options and solutions in terms of product packaging,

consumer behavior, health hazard awareness, and other governmental and societal mitigation approaches. The definition of circular economy considers the efficient design of products by enhancing and prolonging the durability of its various components for as long as possible because "This implies full systemic change, and innovation not only in technologies, but also in organization, society, finance methods and policies" (Wilts, 2016). Since the second half of the 20th century, plastics have become an integral part of everyday life. The inception of plastics as a petroleum-based product has a direct relationship with the mass automation of transportation and the reliance of the new mechanized land, aviation, and naval modes of transportation on petroleum to fuel their engines to propel the wheel of industry.

The popularity of plastics gained special significance during the Second World War when plastics were implemented in every facet of the war effort from helmet liners to the atomic bomb (Freinkel, 2011). The United States military took special interest in plastics as it reformed the logistics doctrine post 1945 to accommodate better nutrition rations for the deployed troops. The plastic packaging technology led to the Meal Ready to Eat (MRE) rations that were easily sterilized, carried, and saved weight and space in deployment (Technical Data Package, 2016). The case for plastic publicity is deeply rooted in American popular culture in films such as *It's a Wonderful Life* where one of the characters, Sam Wainwright asks the film's protagonist, George Bailey about investing in a plastic factory (Capra, 1947, 0:48:12). Another notable film which helped normalize plastics as the new artifact of chemical engineering marvel is The Graduate, where the main character Benjamin Braddock played by Dustin Hoffman gets a job offer to work in the plastics industry as it has a great future (Nichols, 1967, 0:06:05).

The positive perception of plastics in these films as a new artifact is taken for granted due to its malleability and perceived user-friendly applications ranging from nylon stockings in *The*

Graduate to director Frank Capra's chemical engineering background influencing his film storyline in *It's a Wonderful Life* to be skewed in favor of the plastic industry narrative (Miel, 2021). The global production of plastics has increased from 2 million tons in 1950 to 368 million tons in 2019. The rapid mass production and consumption resulted in plastic pollution on a grand scale. Plastic wastes are not biodegradable, and they emit toxic gases when incinerated. Most of the waste plastic ends up in the ocean, causing severe problems in the planet's aquatic ecosystem (Saadeh, 2021). The continuous dependence on fossil fuel products shifted the cultural behavior towards a near total dependence on plastics for its simplicity and low cost and introduced sociotechnical paradoxes towards the environmental cost of such artifact (Freinkel, 2011).

In his book The Structure of Scientific Revolutions, Thomas Kuhn defines the paradigm shift theory as change stemming from the subsets of paradoxes that defy the traditional norms when enough new scientific data gains traction and supports the basis for contradicting the prevalent paradigm (Kuhn, 1962). However, the criticism towards Kuhn's theory is that it portrays the accumulation of new raw data that trigger the paradigm shift as a radical change that encompasses all-or-nothing in a manner similar to the artificial intelligence method of problem-solving as one or zero. The paradigm shift will be implemented in the analytical framework of mitigation approaches to plastic waste management.

To address the plastic conundrum, the STS research theory of wicked problem framework portrays the societal problems that are hard to solve because there is no simple economic, political, or societal solution that would persuade all the actors involved to reach a common ground. According to Melvin Webber, wicked problem is described as symptoms of other problems that do not have an enumerable set of potential solutions (Webber, 1973). One point of criticism towards the wicked problem framework is that it fails to generate a precise definition of

the solution without tipping the balance for one of the stakeholders involved. To reconcile this bias, the presence of an overriding social theory such as paradigm shift would diversify the decision-making authority to achieve the fulfilment of various stakeholder's values (Turnbull, 2018). The wicked problem framing of plastics is constrained by the unclear definition of plastic end-of-use byproduct as being either a waste or a resource. The plastic complexity stems from the fact that it has always been viewed as a product with no clear sustainable vision for its end-of-life phase, a problem that is difficult to define and describe especially with the increasing growth of world population and the corresponding increase in plastic consumption rate. According to the OECD, plastic waste is projected to increase from 353 million tons in 2019 of which 33 million tons or 9% were recycled, to 1014 million tons in 2060, with two thirds of the plastic waste comprising packaging, consumer products, and textiles (OECD, 2022). The competitive approach in the wickedness of the plastic waste is further complicated by the continued socio-economic growth, following the recovery from the COVID-19 pandemic where the emerging economic trend in developing countries is expected to grow rapidly to catch up with economies of western-industrialized countries, suggesting that plastics use will increase faster in developing countries in pursuit of economic boom with few mitigation policies implemented to address the plastic waste (OECD, 2022).

The differing perspective of economic visions can be seen in developing countries trying to meet their market demand for plastics and form their independent industrial infrastructure while the developed countries are trying to cap the GHG's via policies that would slow down the economic boom in developing countries such as the United Nations Environment Assembly's (UNEA-5) resolution establishing a legally binding agreement on plastic pollution by 2024 (United Nations Environment Program, 2022). The wicked problem STS theory will bridge the

gap between plastic waste management and the changing cultural perception towards plastic as an environmental risky byproduct of single-use activities than a source of convenience in daily life situations. Additionally, the conceptual framework introduced in wicked problem theory will help in developing an understanding towards a paradigm shift in terms of fundamental change of socioeconomic behavior and environmental policy seeking to explore and implement diverse solutions that avoid being redundant to each other.

Methodologies

To answer my research question regarding how sustainable is the transformation of recycled plastics from the waste stream into a new commodity? I will use a combination of the Paradigm Shift and Wicked Problem theories. I will use the wicked problem framework to assemble the evidence that supports potential solution pathways for converting plastic waste into a valued resource that can spur a greater community engagement in recycling feasibility. I will supplement the wicked problem framing by a historical case study about plastic waste management and prevention. The paradigm shift theory will be used as the analytical framework to showcase examples of plastic waste mitigation via measures of reduction, substitution, and even imposing fee on using single-use plastics. The paradigm shift framework will attempt to reassign the waste stream responsibility from consumers to producers that maintain responsibility for their products even when they enter the end-of-life phase. The paradigm shift of plastic waste to the producers would stimulate them to redesign their products for better recyclability at the waste stream. Finally, I will connect the wicked problem approaches with the paradigm shift of consumer behavior, projected population growth, and producer responsibility into making plastics a reusable material.

Conclusion

The Virginia Transportation Research Council (VTRC) is currently testing Recycled Plastic Modified (RPM) asphalt mixtures using the superpave design mix specifications. The VTRC project involves documenting and assessing RPM field trials conducted in Virginia. This includes evaluating the constructability, laboratory performance, and initial field performance of RPM asphalt mixtures. The capstone design deliverable addresses both post-industrial and post-consumer recycled plastic sourcing and methods of incorporating, laboratory and field produced recycled plastic modified (RPM) asphalt mixtures that simulate the short- and long-term performance. It is still unclear if producing and paving RPM mixtures would necessitate any changes to typical paving practices in Virginia. Therefore, our capstone will contribute to the VTRC project on RPM asphalt mixtures largely through the construction of a life cycle assessment (LCA) of the RPM asphalt to make an informed decision. The formulation of LCA is important to avoid environmental tradeoff on the long-term. Along the technical application of plastic waste into construction materials, the STS theories used in this paper explore the future projected solutions for the paradoxical problem of plastic usage in addition to exploring new sociotechnical paradigm shift in waste management and prevention. This research will identify methods for plastic waste mitigation both locally and nationwide.

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