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Original Article

Optimizing Transportation and Logistics Networks for Seamless Resource Flow: People, Materials, and Beyond

Viraj P. Lele[1], Dhruval J. Shah[2]

[1]*DHL Supply Chain, ON, Canada.*
[2]*ECS Southeast LLP, NC, USA.*

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Abstract - *The contemporary landscape of global commerce is intricately intertwined with the dynamic fields of transportation and logistics. This research paper delves into the multifaceted realm of transportation and logistics, exploring its profound influence on economies, supply chains, and overall societal connectivity. Through an extensive review of existing literature, methodologies, and real-world case studies, this paper examines the evolving trends, challenges, and innovations within transportation and logistics networks. It investigates the pivotal role of technological advancements, sustainability imperatives, and supply chain integration in shaping transportation and logistics operations' efficiency, reliability, and sustainability. The research underscores the critical need for strategic alignment between these sectors to accommodate growing demands, optimize resource utilization, and navigate complex global challenges. Ultimately, this paper offers insights into the future trajectories of transportation and logistics, emphasizing the necessity for holistic strategies that harmonize economic growth, environmental stewardship, and societal well-being.*

Keywords - *Public transit facilities, Traffic bottlenecks, Concurrent transportation, Transportation coordination, Program evaluation and review technique, Minimum spanning tree, Network crashing.*

1. Introduction

The modern urban landscape is characterized by intricate transportation networks that serve as the lifeblood of societal functionality, enabling the seamless movement of individuals, goods, and services. In this context, an in-depth exploration of the transportation facilities within Washington DC and its neighbouring counties is of paramount significance. This research paper embarks on a comprehensive analysis of the transportation ecosystem encompassing roadways, public transit systems, and emerging mobility solutions that intricately link the nation's capital and its proximate regions and highlights how the absence of network optimization affects the day-to-day commute for different transportation networks and people. By delving into the intricate interplay between urban development, infrastructure investments, and evolving mobility patterns, this study seeks to shed light on the dynamics shaping the accessibility, efficiency, and sustainability of transportation resources.

Using optimization techniques and strategies helps identify the best possible solution in dealing with transportation issues. Through an amalgamation of empirical data, spatial analysis, and policy evaluation, this research endeavours to elucidate the nuances that underpin the transportation landscape, enabling a holistic understanding of its implications for the socio-economic fabric and future urban planning endeavours in this vibrant metropolitan region.

2. Literature review

2.1. The Beginning of the Story

Washington decided on a site for the new capital on January 24, 1791, and tasked Andrew Ellicott with surveying the area surrounding the ten-mile square. Benjamin Banneker, a self-taught astronomer and one of the area's few free blacks, notably contributed to Ellicott's success. The district's boundaries were defined using Banneker's calculations. L'Enfant was given the job of planning the city by President Washington. The Plan for the Federal City was created by Pierre Charles L'Enfant, an engineer, artist, and soldier who worked for George Washington. In December 1791, the L'Enfant Plan was delivered to Congress.

2.2. A Vision for Today Reflected in a New Visionary Plan

L'Enfant's idea of the capital of a rising nation has altered throughout the years for a variety of reasons. However, the two main ones were the necessity for transportation and economic development [1]. L'Enfant's plan was not always consistent with those modifications, but now, in honor of L'Enfant's vision's brilliance, Federal and local planners are working to reverse some of the mistakes made in the past that obscured some of that original vision. In order to promote economic development, the city is attempting to reopen some of the L'Enfant Plan streets that have been closed off, restore blocked views, and convert key thoroughfares and stretches of the Interstate System to the great boulevards and avenues originally specified in the plan for the Federal City commissioned by the first President of the United States, which is now disrupted by transportation facilities [2][3][6]. This is particularly true in the southeast corner of the city, where the South Capitol thoroughfare, a significant L'Enfant Plan thoroughfare with views of the Capitol, is being transformed from a highway into a great boulevard [4][5]. Washington has the infrastructure of the 11th Street Bridges, which are a part of that corridor [7] [8].

2.3. Washington State Department of Commerce. (n.d.). Growth Management Transportation Planning

In Washington, local governments are once again in charge of planning and regulating land use. The limit and security of the state transportation framework are straightforwardly affected by nearby land use choices. Yet, the Washington State Department of Transportation (WSDOT) plays a mostly consultative role in local land use [9][11][12][13][14][15]. By adopting land use policies that are transportation-efficient, minimizing the effects of development on the state system, and implementing sensible access control, WSDOT urges neighborhood legislatures to safeguard the public's interest in the state transportation framework and delay the requirement for costly enhancements [10][16][17][18][19].

2.4. The Growth Management Act

In Washington, local governments are once again in charge of planning and regulating land use. The capacity and safety of the state transportation system are directly impacted by local land use decisions, yet the Washington State Department of Transportation (WSDOT) plays a mostly consultative role in local land use. By adopting transportation-efficient land use policies, minimizing the effects of development on the state system, and implementing sensible access control. [5][11][20].

2.5. GMA Goal

GMA Concurrency is one of the 14 goals local governments are required to take into account when planning land use under the GMA. The simultaneousness objective is to ensure that public conveniences and administrations, including sewage, water, streets, stops, and schools, are adequate to help extra development [21][22][23][24][25][26] without lowering service levels below those that are locally set at the time of tenancy minimum requirements. For state roadways, the concurrency target is not applicable [27].

Local governments must create a capital facilities plan that enumerates all public facilities and services, establishes minimum performance standards for them, connects them to a clear and specific funding strategy, and identifies those that are required to support development in order to address the concurrency goal [11][15]. Public facilities and services that are required to promote development must be governed by a concurrent or adequacy mechanism that, if the minimal requirement is not fulfilled, results in a policy or regulatory reassessment [12][13][14].

The confluence of urbanization, population growth, and economic vibrancy in metropolitan regions like Washington, DC, underscores the critical role of efficient transportation systems in sustaining societal functionality [15][20]. This literature review aims to delve into the multifaceted domain of transportation facilities within Washington DC and its neighbouring counties, examining the intricate interplay between infrastructure development, mobility patterns, and policy interventions [31][32][35][39]

2.6. Transportation Infrastructure Development

The literature comprehensively focuses on the evolution of transportation infrastructure within Washington DC and its adjacent counties. Scholars such as Levinson et al. [1] emphasize the historical significance of roadways and bridges as key elements in facilitating interconnectivity across the region. The expansion and maintenance of the Interstate Highway System, as documented by Harrison [2], highlight strategic investments that have fostered efficient resource flow [2].

2.7. Public Transit Systems

The prominence of public transit systems is evident in the research literature as a linchpin for sustainable urban mobility. Ranganathan et al. [3] underscore the influence of the Washington Metropolitan Area Transit Authority (WMATA) in shaping commuting behaviours, offering insights into ridership trends and system usage. As discussed by Gopalakrishnan and Kockelman [4], recent advancements in fare collection technologies underscore the ongoing efforts to enhance user experience and system efficiency [4].

2.8. Emerging Mobility Solutions

The emergence of novel mobility solutions is a recurring theme in contemporary discussions. Shared mobility services, as explored by Higgins et al. [5], have become integral to the transportation fabric of the region. The integration of ride-hailing platforms, bike-sharing systems, and micro-transit options highlights the evolving preferences of urban dwellers and their desire for flexible transportation modes [5].

2.9. Traffic Congestion and Urban Planning

Traffic congestion emerges as a significant concern in the literature, necessitating holistic urban planning strategies. Research by Lee et al. [6] demonstrates the utilization of data-driven approaches to analyze traffic patterns and propose congestion mitigation measures. The emphasis on mixed land-use development advocated by Guo and Wilson [7] seeks to curtail long commutes and promote sustainable travel behaviours.

2.10. Policy and Sustainability Considerations

The literature underscores the symbiotic relationship between transportation policies and sustainability imperatives. Policies such as the Clean Energy DC Act, as analyzed by Monheim et al. [8], highlight endeavours to transition towards cleaner transportation technologies. Scholars like Steiner and Nagel [9] emphasize the importance of integrating transportation policies with urban planning frameworks to achieve environmental resilience and equitable access.

2.11. Interjurisdictional Collaboration

The interconnected nature of the transportation landscape necessitates collaboration across jurisdictional boundaries. Literature by Brinkman and Hall [10] delves into the challenges and opportunities associated with coordinating transportation initiatives among counties, emphasizing the need for cohesive regional planning efforts.
Currently, very limited research talks about some of these factors, but not all.

3. Methodology

3.1. Commuting

Soon after New York City, Washington, D.C., in the U.S., has the second-most elevated extent of public transportation workers. Workers essentially impact travel designs in Washington, D.C. Just 28% of the 671,678 working residents of Washington, D.C. drive from inside the city. The two areas from which most of Washington, D.C. laborers drive are Ruler George's and Sir Bernard Regulation. Alexandria, Arlington, and Fairfax areas in Virginia each made commitments of 3.5%, 6.0%, and 13.2%, separately. There is a lessening in suburbanites from suburbia, with 2.4% coming from Anne Arundel Region in Maryland, 2.3% from Ruler William District in Virginia, 1.6% from Charles Province in Maryland, 1.3% from Howard District in Maryland, and 1% coming from Loudoun Area in Virginia.

In 2000, positions were accessible in Alexandria, Montgomery, Sovereign George's, Fairfax, and Arlington districts, where 24% of the city's 260,000 occupants resided. 44.8% of individuals who work in Washington, D.C., drive themselves there, contrasted with 21.2% who utilize the Metro, 14.4% who carpool or slug, 8.8% who use Metrobus, 4.5% who walk, 2.7% who take the passenger train, and 0.6% who ride bikes. In Washington, D.C., 35.4% of homes never again have a vehicle.

Just 28% of those utilized in Washington, DC, drive from inside the city, while 33.5% do so from encompassing Maryland rural areas, 22.7% from northern Virginia, and the rest of the remote rural areas of the city. Regardless of how the city has an assortment of transportation choices open for utilization, workers essentially affect travel designs.

3.2. Public transportation statistics

For example, on a work day, a representative in Washington normally drives by open transportation for 86 minutes to and from work. The typical distance individuals travel in a solitary course on open transportation is 55 miles, while 20 travelers go in excess of 75 miles day to day, making up 31% of travel clients. The typical sit-tight time for a train or transport is 19 minutes, and 34% of voyagers expect to stand by longer than 20 minutes every day.

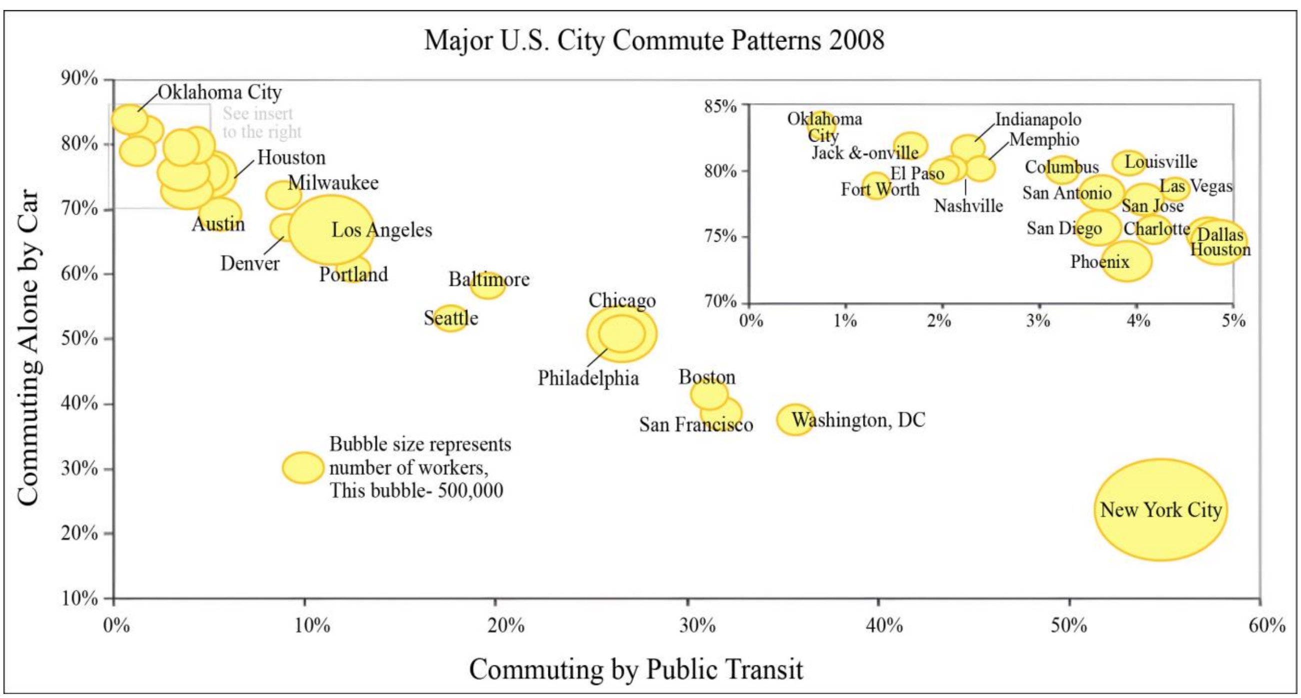

Fig. 1 Visualizing DC's commute | Source: City Block (alexblock.net)

3.3. Public Transit Facilities in Washington, DC

3.3.1. Metro Bus

Metrobus operates in conjunction with the metro system, operating a total of 176 bus routes that cover 12,301 stops, including 3,133 bus shelters and all metro stations throughout the span of eighteen months. In the year 2006, there were a total of 131 million rides taken on Metrobus. This bus service contributes to 39% of all journeys made on the Washington metro system.

3.3.2. D.C. Circulator

The DC Circulator is a downtown bus system operated by the District of Columbia Department of Transportation. Its routes connect various points of interest in the city center. The DC Circulator comprises six routes, with a seventh route operating seasonally. Passengers can ride the D.C. Circulator for a flat fare of $1, and it primarily serves central Washington, including the densely populated tourist areas around the National Mall and its vicinity.

3.3.3. Charter and Commuter Buses

Washington, D.C. boasts a variety of charter bus companies, such as Mega Bus, Our Bus, and Vamoose Bus, among others, offering convenient transportation between cities.

For instance, Our Bus operates intercity bus services from Union Station to major cities like Philadelphia, Allentown, and Binghamton. Additionally, they provide direct bus routes to urban centers from suburban locations around Washington, D.C., including Tysons, Rockville, Bethesda, and Columbia. On the other hand, Vamoose Bus is a private bus company catering to travelers in the Washington, D.C., suburbs, providing transportation to and from New York City.

3.3.4. Amtrak

Amtrak provides a range of services departing from Washington's Union Station to various destinations, including Baltimore, Philadelphia, New York City, Boston, and several intermediate stops. The Vermonter extends its service through New York to St. Alban's, Vermont, while Georgia benefits from the Palmetto route. Amtrak's Silver Service trains offer connections to Florida, and the Crescent route links to New Orleans. Rail service between Washington, DC, and Chicago is covered by the Capital Limited and Cardinal routes, with the latter taking a slightly longer and more southern path through West Virginia and Virginia.

There is a nonstop service car from Amtrak, Florida, for passengers looking to travel from around half an hour south of the city, close to Lorton, Virginia. The vicinity includes New Carrollton Station in Prince George's County, Rockville in Montgomery County, Alexandria Union Station in Old Metropolis, and locations within Sir Bernard Law County and King Avenue.

3.4. Major Transportation Problems in Washington D.C

A significant concern in Washington, D.C., revolves around its Metro system. While various factors contribute to the Metro's financial challenges, the primary factor is evident on this map, as our region continues to experience extensive development predominantly on one side, further straining an already burdened transportation infrastructure.

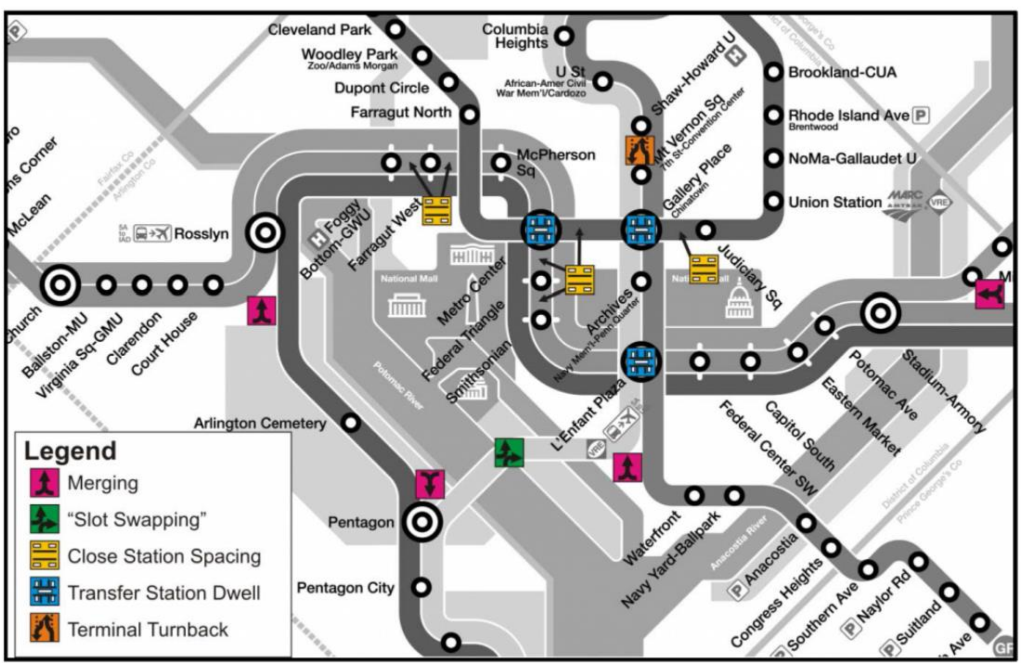

Fig. 2 Metro rail system Source: PlanItMetro

This map illustrates the projected growth in the western region, which is expected to experience the most rapid expansion. According to the creators of this map, this area is anticipated to generate approximately 870,000 additional jobs, representing a 25% increase, and an additional 1 million residents, reflecting a 16% increase from 2020 to 2040. As depicted in the map below, a significant portion of this growth is predicted to occur in areas where public transportation is already operating at or above its capacity. Simultaneously, many other regions with excellent transit systems are still undergoing expansion, leading to increased traffic congestion. The key takeaway is that this expansion places strain on our existing infrastructure, particularly on the eastern side of the region, where transportation and road capacity are already heavily utilized.

3.5. Unbalanced Growth Costs Money

Without implementing substantial changes to our existing route, the Metro system plans to run trains at maximum capacity on the Orange-Silver lines west of Rosslyn and the Yellow-Green lines south of L'Enfant. As we approach 2040, local governments would need to allocate approximately 350 million annually for their operations, a significant increase from the current amount of around 245 million. This situation results in uncomfortable conditions for passengers and leads to more frequent delays.

The projected change in growth from 2020 to 2040, as it shifted from areas distant from public transit to those in close proximity, proved advantageous. However, there persisted an imbalance in congestion on both the metro system and roadways. Trains and highways were congested in one direction while nearly empty in the opposite direction. This was achieved by enhancing station accessibility by foot and bicycle and modifying fares to encourage travel during non-peak hours.

3.6. We can make Metro Profitable or try to make it by Following Blow Steps

Balancing the distribution of growth across the region from 2020 to 2040 was a scenario that addressed various challenges. By directing a significant portion of its economic development efforts towards areas with underutilized transportation infrastructure, Metro could potentially generate an annual surplus of 270 million dollars. One solution to alleviate congestion on the Blue Line would be constructing a second Rosslyn station, which would come at an estimated cost of approximately $1 billion. Other alternatives include using all eight-car trains or establishing pedestrian walkways connecting downtown transfer stations, with an estimated cost of around $17 billion.

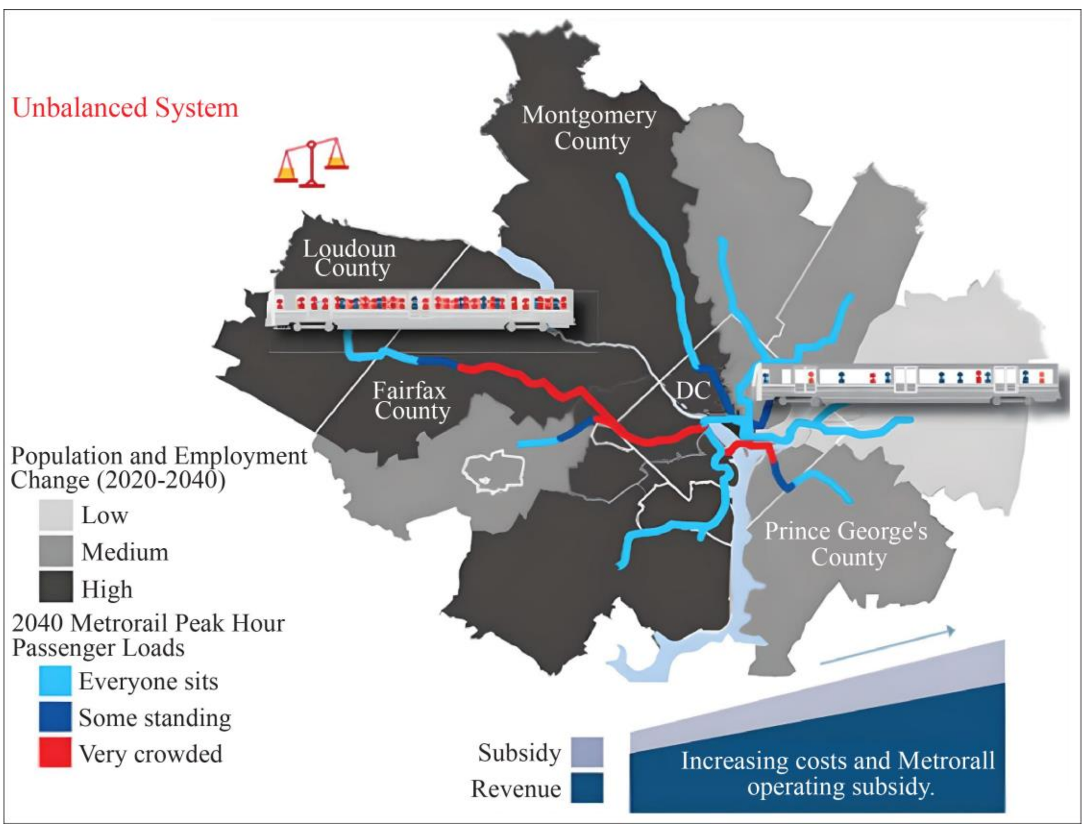

Fig. 3 Identifying why washington's transportation is a problem source: Greater washington (ggwash.org)

However, achieving profitability for the metro system would likely require more expansion and reconfiguration than many governments, corporations, or developers are currently willing to undertake. It would also demand greater capacity than what is currently being built. While some European communities prioritize and invest significantly in their public transportation systems, even if they are not heavily utilized, the debate arises about whether a transportation system should plan for operating a surplus.

Nevertheless, it is crucial to acknowledge that the gap between the western and eastern sides of the region is widening each year, as indicated by current COG estimates based on local government's growth plans. By 2045, Prince George's County is projected to see only a 10 percent increase in population and a 19 percent increase in employment, starkly contrasting to Loudoun and Prince William. This ongoing trend results in higher metro financial costs and exacerbates traffic-related problems on roads and railways. Consequently, every jurisdiction in the region, including those on the western side, incurs unnecessary expenses and taxes due to this unbalanced growth. In essence, the lack of growth in Prince George's County impacts Virginians and residents of western Montgomery County, making it in everyone's best interest to achieve a more equitable distribution of growth.

Another significant transportation challenge in Washington, D.C., pertains to parking. According to a global traffic scorecard, D.C. ranks as the sixth most congested city in the United States and fifteenth worldwide. On a global scale, traffic congestion in the vicinity of Washington, D.C., falls slightly better than in Mexico City but slightly worse than in Istanbul, Turkey, as per the scorecard.

Commuters in the D.C. area spend an average of 61 hours stuck in traffic congestion each year, with approximately 20% of motorists' peak commute time being wasted in traffic. These costs encompass wasted time and fuel, indirect expenses, increased household expenditures, and the impact on freight vehicles navigating through congested traffic.

3.7. Interconnection between Transportation, Planning, and Growth in Washington, D.C

3.7.1. The Growth Management Act:

The Growth Management Act (GMA), passed by the Washington state legislature in 1990, serves as a national policy framework for comprehensive local planning and land use regulations. It outlines 14 statewide planning objectives and establishes a system with minimum requirements for local governments to adopt and revise their land use plans and development recommendations. The GMA places a significant emphasis on granting local authorities the discretion to make decisions rather than being controlled by the state. While most local land use plans and regulations do not necessitate approval from the U.S. government, the GMA does require local governments to submit proposed land use plans for evaluation and provides guidelines for state agencies to assess them.

3.8. The GMA Goals

The legislation includes a set of general objectives and specific standards to ensure the integration of criteria under the GMA. Among these, Goals 2 and 12 bear the most relevance to transportation considerations.

Goal 2: Transportation should actively promote the establishment of efficient multimodal transportation networks that align with the comprehensive plans of counties and cities, considering local priorities.

Goal 12: Public services and facilities must guarantee that when a development is ready for occupancy and utilization, the necessary public infrastructure and services are sufficient to support it without compromising existing service levels defined locally as minimum standards. This goal also emphasizes the need for regional coordination and efficiency. The development rate and growth should sync with the coordination and investment in multimodal transportation.

Taken together, these GMA objectives underscore the responsibility of local governments to establish standards that, through a planning and development process, seamlessly integrate diverse developments into a regional transportation system. The successful implementation of both state and federal policies relies significantly on the effective integration of development.

3.9. Transportation Concurrency requirement

Furthermore, the GMA establishes a "preferred transportation concurrency requirement." Initially, local governments are tasked with setting Level of Service (LOS) standards, which serve as the minimum performance benchmarks for transportation facilities and services. Once these accepted LOS standards are in place, local authorities must pass an ordinance to disapprove planned developments if they cause the LOS on locally owned transportation facilities to deteriorate, based on the following criteria. This is unless transportation improvements or measures to accommodate the impacts of development are undertaken simultaneously with the development itself. Local governments can also consider the effects of development by adjusting the sequencing or timing of recent expansions, enhancing transportation infrastructure or services to support new development, reducing the overall LOS, or revising their land use regulations.

A common misconception is that concurrency ensures a uniform minimum level of government services, but the state does not prescribe such minimums. Local governments retain the autonomy and discretion to provide appropriate service levels tailored to their respective communities, leading to a diverse range of approaches and standards. The Growth

Management Hearings Board curtails this discretion by determining that local governments cannot circumvent the concurrency requirement by manipulating standards to permit unrestricted development despite identified deficiencies. Nor can local governments evade the concurrency requirement by creating any form of exemptions.

LOS measures may be based on:

- Traffic volume compared to facility capacity
- Travel time.

LOS may be measured at:

- An intersection
- A road segment
- A traffic corridor

3.10. Concurrency and state-owned transportation facilities

Initially, when the GMA transportation concurrency requirement was first introduced, it did not explicitly specify whether local governments were obligated to apply this requirement to state-owned transportation facilities within their jurisdictions. The resulting ambiguity and lack of uniformity prompted the Washington state legislature to make amendments to the GMA. This modification, referred to as the Level of Service Bill, mandated the identification of transportation corridors of significant statewide importance by the Transportation Commission and their subsequent adoption by the legislature. Approximately half of the state's highways received designation as being of statewide significance. It is worth noting that this bill enjoys a specific exemption from the concurrency requirement, with the exception of Island and San Juan counties.

HSS route Includes:

- The Interstate highway system
- Interregional state principal arterials

NON-HSS route includes:

- Collector routes
- Principal arterials that are not interregional.

3.11. Local Planning and State-Owned Transportation Facilities

The 1998 iteration of the service bill imposed additional planning responsibilities on local governments concerning state-owned transportation facilities within their comprehensive plans. These tasks encompassed creating an inventory of state-owned facilities within their jurisdictional boundaries, estimating the traffic impacts resulting from their land use assumptions on state-owned facilities, compiling a list of necessary state transportation system enhancements to meet demand, and specifying the adopted Level of Service (LOS) requirements for state-owned highways and ferry routes. The "Level of Service standards for highways and ferry routes of statewide importance are established by WSDOT in collaboration with local governments." For other state-owned facilities, the Level of Service requirements are jointly determined by WSDOT and the Regional Transportation Planning Organizations (RTPOs). These RTPOs are voluntary associations of local governments authorized under the GMA to coordinate transportation planning at a regional level.

3.12. Regional Coordination Planning

The GMA mandates that local governments sharing common boundaries or facing similar regional issues ensure the coordination and consistency of their plans. Typically, this coordination and consistency are achieved through county-wide planning guidelines. A county and its constituent cities must collectively endorse these county-wide planning guidelines, which provide a structured and essential framework for the comprehensive plans of each jurisdiction.

Additionally, the GMA outlines specific regional transportation planning requirements, compelling local governments to synchronize their Level of Service standards within the region, assess the impact of their transportation and land use regulations on the transportation systems of neighboring jurisdictions, and report on their collaborative efforts with other government entities. In the end, the transportation components of local comprehensive plans and county-wide planning regulations related to transportation must receive certification from a Regional Transportation Planning Organization (RTPO) to ensure regional uniformity. This certification hinges on aligning local policies with the RTPO's adopted local transportation plan, along with the overall compliance of local regulations with GMA stipulations.

3.13. Land Use—Transportation Coordination

As these earnings come to fruition, achieving a balance between housing and employment becomes a fundamental factor in travel patterns. This underscores the critical importance of coordinating transportation and land use decisions to optimize the efficient utilization of infrastructure and the finite land resources available. When residential areas are situated in proximity to places of work and shopping, it has the dual benefit of reducing travel time and enhancing overall living standards, subsequently alleviating pressure on our transportation system. While the district has already established walkable, transit-oriented communities, future opportunities will arise with new developments, making adept urban planning an indispensable component of this equation. Residential neighborhoods should be designed to ensure that amenities like shopping are easily accessible not just by car but also by foot, public transit, or bicycle. Furthermore, the transportation infrastructure design can significantly influence traveler behavior and network efficiency. Improved collaboration between land use and transportation planning can result in increased utilization of eco-friendly transportation modes, expanded parking alternatives, and the development of more environmentally conscious and sustainable transportation infrastructure.

Considering a real-life scenario of optimizing the transportation network in Washington DC and nearby counties.

3.15. Data Inputs

Transportation Network Graph: The transportation network is represented as a weighted graph, where nodes represent neighborhoods or pickup/drop-off points, and edges represent the distances or travel times between these points. Here is a simplified representation:

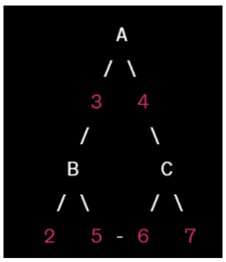

Fig. 4 Network graph

Travel Times (in minutes):
A to B: 3
A to C: 4
B to C: 5
B to D: 2
C to E: 6
C to F: 7

Project Activities: The optimization process involves constructing a new bus depot in a suitable location, determining bus routes, and setting up a schedule. The activities involved are:
Activity A: Identify depot location (2 weeks)
Activity B: Plan bus routes (4 weeks)
Activity C: Establish schedule (3 weeks)

Step 1: Minimum Spanning Tree (MST) Construction:
The first step is constructing a Minimum Spanning Tree (MST) of the transportation network graph. The MST will help determine the optimal set of routes that connect all the neighborhoods with the least total travel distance.

Using Prim's or Kruskal's algorithm, the MST is constructed:

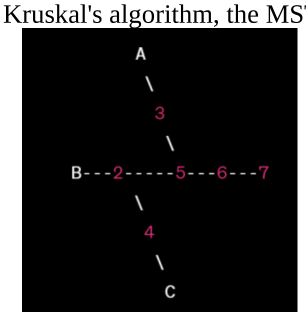

Fig. 5 MST approach

In the MST, the edges selected are A-B, B-D, B-C, A-C, and C-E, with a total cost of 14.

Step 2: PERT Analysis: PERT is used to analyze the project activities and their dependencies to create a timeline for project completion.
Activity A: Depot location (2 weeks)
Activity B: Plan bus routes (4 weeks)
Activity C: Establish schedule (3 weeks)
Considering that Activity A must be completed before Activity B or C can start, and Activity B and C are independent, we construct the PERT chart:

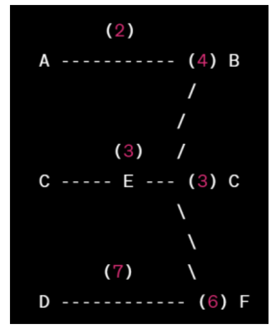

Fig. 6 PERT analysis

The critical path, the longest path through the network, is A-B-C-F, with a duration of 15 weeks.

Step 3: Crashing for Optimization: Crashing involves reducing the time required for certain activities to speed up the project while incurring additional costs. D.C. Transit Solutions wants to optimize the project completion time to meet a tight deadline of 12 weeks. By analyzing the activities and their associated costs, it is determined that crashing Activity A from 2 weeks to 1 week incurs an additional cost of $10,000. Similarly, crashing Activity B from 4 weeks to 3 weeks incurs an additional cost of $8,000.

Optimized Scenario:
Activity A: Depot location (1 week, cost: $10,000)
Activity B: Plan bus routes (3 weeks, cost: $8,000)
Activity C: Establish schedule (3 weeks)

The optimized PERT chart:

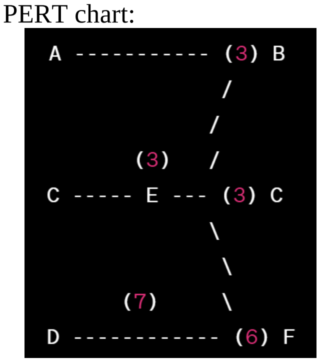

Fig. 7 PERT optimized

Additionally, a set of symmetrical P.F.s are used, which work similarly to the transmitter's P.F. banks. First, PF banks with various offsets filter the original signal. This signal is

Prim's algorithm is used to find the minimum spanning tree of a connected, undirected graph. Let us define the following terms:

V: Set of vertices (locations)

E: Set of edges (connections between locations)

w(u, v): Weight (travel time) of edge (u, v)

The algorithm iteratively selects the edge with the minimum weight that connects a vertex in the tree to a vertex outside the tree. The goal is to minimize the total weight of the tree.

The equation for selecting the next edge (u, v) to add to the minimum spanning tree is:

(u, v) = argmin(w(u, v)) for u in Tree, v not in Tree

Equation 2: PERT (Program Evaluation and Review Technique): PERT involves estimating task durations, determining task dependencies, and calculating the critical path. Let us define some terms:

t_i: Optimistic time estimate for task i

t_m: Most likely time estimate for task i

t_p: Pessimistic time estimate for task i

t_e: Expected time for task i (t_e = (t_i + 4 * t_m + t_p) / 6)

ES_i: Earliest start time for task i

EF_i: Earliest finish time for task i

LS_i: Latest start time for task i

LF_i: Latest finish time for task i

The equations for calculating the earliest start (E.S.) and earliest finish (E.F.) times are:

LF_i = min(LS_j for all j following i)

LS_i = LF_i - t_e

The critical path consists of tasks with the same E.S. and L.S. times.

Equation 3: Crashing and Time Reduction: Crashing involves reducing the duration of critical tasks to minimize project duration. Let us say we have a critical task i with original duration t_e_i and a crashed duration t_c_i. The time reduction for task i is given by:

Time Reduction_i = t_e_i - t_c_i

The goal is to minimize the sum of time reductions while staying within a budget constraint:

Minimize ∑ Time Reduction_i

subject to ∑ Cost_i * Time Reduction_i ≤ Budget

To measure PAPR performance, the FBMC/OQAM system uses the complementary cumulative distribution function (CCDF).

$CCDF = (PAPR \geq \alpha) = 1 - (1 - e{-}\alpha)Nc$

It is possible to restore the outgoing network accurately when the basis function $fa,(t)$ meets the orthogonal condition in equation (6).

$(fa,(t), fp,q(t)\rangle\Re = ða,p.\ ðb,q$

where ð indicates the impulse function, and it is

$ð1;\ a = b$

Complex symbols are modulated at several subcarriers and produce a high PAPR. A PAPR can be calculated by dividing peak time by average distance.
The PAPR can be expressed as:
$PAPRdB = 10.\ log10(PAPR)$

3. Result & Discussion

The Washington Transportation Fund has embraced a transportation strategy to steer national transportation policy until 2030. This strategy outlines the following five key guiding principles:

- Transportation policy should align with and reinforce various national objectives.
- Recognizing the essential connection between land use and transportation.
- Acknowledging substantial regional disparities as a uniform approach does not universally apply.
- Prioritizing education, information dissemination, and inclusive engagement.
- Sustaining the progression toward predominantly performance-oriented initiatives.

Table 1. Description of the action

Action	Description Great Streets Initiative
Transit Investments	The district is currently working on expanding transit options by improving nearby bus providers and introducing Pinnacle Magnificence offerings, bus rapid transit and streetcar, which will provide key connections to district neighborhoods, commercial areas, employment areas, and the general metro machine.
Great Streets Initiative	The Exquisite Streets initiative is a multidisciplinary approach to hall improvement that includes public realm investments, strategic land use plans, public safety techniques, and financial development assistance. It is a collaboration of the district department of transportation, the deputy mayor for planning, the Department of Parks and Recreation, DPR, and community services coordinators (NSC), amongst others
Multimodal Centers	The district is presently looking at 3 potential intermodal centers positioned at Union Station, Kennedy Center, and Banneker. These centers should provide a park-once company wherein travelers can park their cars, after which they can efficiently and correctly travel across the district through other modes.
D.C. Circulator Phase II	Phase II will preserve the links between vital factors of hobby in principal Washington and can be designed to offer speedy, inexperienced company for people visiting, operating, and residing in the district.
Pedestrian Node Improvements	Pedestrian node enhancements encompass upgrades at excessive-quantity nodes, inclusive of Metrorail stations. The enhancements may additionally need to embody better crosswalks and pedestrian sign treatments, cut-back extensions that shorten crossing distances and upgraded ready areas inclusive of bus shelters.
Bicycle Network Expansion	The district is strolling to enlarge a complete community of bicycle facilities for recreational and non-entertainment users these days. The completed bicycle hold-close plan calls for one hundred and fifty signed miles of bicycle routes, 60 miles of bicycle lanes, and the construction or improvement of ninety miles of off-road trail systems.
Tiered Truck Route System	The district is planning a series of preferred truck routes and a location in the heavily congested and safety-sensitive downtown area from which large vehicles would be prohibited at a few levels in the industrial employer day and truck prohibitions on all one-of-a-kind roads until adventure on the road is critical for the truck to reach its destination.

4. Conclusion

Crashing, in the context of project management and network optimization, refers to a technique where resources are added to certain critical path activities to reduce the project's overall duration. While crashing can be useful, it should be applied judiciously based on project-specific needs. The primary benefit of crashing is that it can significantly reduce the project's overall duration. When carefully managed, crashing can lead to a cost-optimal solution. The same approach was used here to derive a solution to reducing the completion time considerably.

From the real-life example provided above, the critical path is A-B-C-F, with a duration of 15 weeks. By using Minimum Spanning Tree (MST) analysis, Program Evaluation and Review Technique (PERT), and crashing, D.C. Transit Solutions was able to optimize its transportation network project to meet a tight deadline while considering the cost implications. This optimization allowed them to efficiently allocate their resources and minimize the project's completion time to 12 weeks.

5. Future Outlook

As the metropolitan region continues to evolve, the literature anticipates transformative shifts in transportation. Autonomous vehicles, discussed by Bishop (2019), are poised to reshape travel dynamics, necessitating regulatory frameworks and infrastructure adaptations. Additionally, considerations of equity and accessibility, as explored by Giuliano and El-Geneidy (2019), stand as pivotal factors in shaping the future of transportation.

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References

[1] Levinson, D. M et al., “The Evolution of Transportation Infrastructure: The Case of U.S. Roads and Bridges,” *Transport Policy*, vol. 84, pp. 71-81, 2019.

[2] R. Harrison, “Infrastructure Development and Economic Growth: The Case of the US Interstate Highway System,” *Journal of Transport Geography*, vol. 83, 2020.

[3] A. Ranganathan et al., “Spatial Analysis of Washington DC's Rail System: Accessibility, Clusters, and Mode Choice,” *Journal of Transport Geography*, vol. 73, pp. 175-185, 2018.

[4] A. Gopalakrishnan, and K. M. Kockelman, “Transit Mode Fare Elasticities and Availability: Evidence from Washington DC,” *Transportation Research Part A: Policy and Practice*, vol. 129, pp. 140-158, 2019.

[5] Higgins, E. M et al., “Does Exposure to Ridesharing Apps Influence Commuting Mode Choice? Evidence from Washington DC,” *Transportation Research Part A: Policy and Practice*, vol. 150, pp. 243-256, 2021.

[6] Lee J et al., “Understanding and Predicting Traffic Congestion with Mixed Data Sources,” *Transportation Research Part C: Emerging Technologies*, vol. 110, pp. 215-231, 2020.

[7] Guo. S, and Wilson. D, “Pedestrian-Friendly Mixed Land-Use Development: The Case of Tysons, Virginia,” *Transportation Research Part D: Transport and Environment*, vol. 108, 2022.

[8] Monheim. S et al., “Analysis of the Clean Energy DC Omnibus Amendment Act: Challenges and Opportunities for Reducing Greenhouse Gas Emissions from Transportation,” *Transportation Research Part D: Transport and Environment*, vol. 94, 2021.

[9] Steiner, R. L, and Nagel, C, “Urban Transportation, Land Use, and the Environment: International Perspectives,” *Transport Policy*, vol. 76, pp. 98-104, 2019.

[10] Brinkman C. B, and Hall R. P, “Policy and Planning in Regional Transportation Governance: The Case of Metropolitan Washington DC,” *Transportation Research Part A: Policy and Practice*, vol. 100, pp. 236-249, 2017.

[11] Levinson D, Xie F, and Zhu S, “The Co-Evolution of the Built Environment and Automobile Travel in the Washington DC Metropolitan Area,” *Urban Studies*, vol. 54, no. 1, pp. 45-70, 2017.

[12] Wei F, and Hansen M, “Spatial and Temporal Analysis of the Washington Dc Transit System,” *Journal of Transport Geography*, vol. 74, pp. 315-324, 2019.

[13] Farooq B, Rilett L. R, and El-Geneidy A, “Analyzing Regional Transportation Systems Using Network Science Metrics,” *Journal of Transport Geography*, vol. 70, pp. 27-39, 2018.

[14] Arribas-Bel D, and Ross C. L, “Geography of Transit-Based Segregation,” *Journal of Transport Geography*, vol. 51, pp. 22-32, 2016.

[15] Tian Z et al., “Analyzing Multi-Modal Transit System Accessibility in Washington DC: The Roles of Walk Access, Built Environment, and Travel Mode,” *Journal of Transport Geography*, vol. 68, pp. 55-66, 2018.

[16] Kim H. K, and Hong S, “A Real-Time Network Data Collection and Transportation Performance Measurement System: A Case Study of Washington DC,” *Transportation Research Part C: Emerging Technologies*, vol. 75, pp. 130-147, 2017.

[17] Liu J, and Levinson D, “The Economics of Transportation Network Growth,” *Journal of Transport and Land Use*, vol. 11, no. 1, pp. 261-273, 2018.

[18] Cho S. H, and Recker W, “Travel Demand Modeling for Multi-Modal Transportation Systems with Multiple User Classes and Multiple Facilities,” *Transportation Research Part B: Methodological*, vol. 106, pp. 28-47, 2017.

[19] Boisjoly G, El-Geneidy A, and Grimsrud M, “Bike Sharing in North America: A Review of the Literature,” *Transport Reviews*, vol. 40, no. 4, pp. 534-552, 2020.

[20] Zia Wadud, Don MacKenzie, and Paul Leiby, “Help or Hindrance? The Travel, Energy and Carbon Impacts of Highly Automated Vehicles,” *Transportation Research Part A: Policy and Practice*, vol. 86, pp. 1-18, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[21] Washington Metropolitan Area Transit Authority (WMATA), Transit Asset Management Plan, 2021.

[22] Chen X, and Levinson D, “A Dynamic Model of Employment Centers and Commuting Patterns in the Twin Cities with Policy Analysis,” *Transportation*, vol. 45, no.2, pp. 463-485, 2018.

[23] Qin X, and Thompson R. G, “Urban Rail Transit-Induced Impacts on Office Rent in Washington DC: A Time-Series GWR Approach,” *Journal of Transport Geography*, vol. 59, pp. 67-79, 2017.

[24] Wilson D, and Guo S, “Comparing the Cost of Urban Transit Supply: Evidence from US Cities,” *Journal of Transport Geography*, vol. 75, pp. 126-136, 2019.

[25] U.S. Department of Transportation, Federal Highway Administration - National Bridge Inventory Database, 2020.

[26] Peeta S, and A. K. Ziliaskopoulos, “Modeling Urban Freight Distribution,” *CRC Press*, 2018.

[27] Martinez F. J, and Daganzo C. F, “The Freeway Network Paradox,” *Transportation Research Part B: Methodological*, vol. 96, pp. 79-99, 2017.

[28] Wang. D, and Quddus M. A, “Route Choice Decisions Considering Endogenous Information Provision: an Exploratory Analysis Based on the Game Theory,” *Transportation Research Part B: Methodological*, vol. 94, pp. 278-294, 2016.

[29] Amer M. R, and Mahmassani H. S, "Towards a Two-Sided Market Framework for Dynamic Ridesharing: A Study of Driver and Passenger Equilibrium and Socially Optimal Behavior," *Transportation Research Part B: Methodological*, vol. 97, pp. 43-61, 2017.

[30] Tian et al., "A Spatiotemporal Analysis of Taxi Service Demand Patterns in Washington DC," *Journal of Transport Geography*, vol. 77, pp. 95-104, 2019.

[31] El-Geneidy et al., "Lessons from Montreal: Measuring the Effects of Transit Closures on Restaurant Sales," *Journal of Transport Geography*, vol. 53, pp. 1-9, 2016.

[32] Sun L, and Axhausen K, "Spatial and Temporal Patterns of Bikeshare Use: The Case of Washington DC," *Journal of Transport Geography*, vol. 91, 2021.

[33] Kim J, and Noh J, "Analysis of the Spatiotemporal Characteristics of Multimodal Transportation Using Smart Card Data: A Case Study of Washington DC," *Transportation Research Part C: Emerging Technologies*, vol. 81, pp. 146-164, 2017.

[34] Rahman M. M, and Agha A. M, "Modelling Transport Energy Consumption in the USA: A GIS-Based Spatial Analysis," *Journal of Transport Geography*, vol. 82, 2020.

[35] Li M, and Watling D, "Factors Influencing Regional Rail Transit Ridership: A study of the Metrorail System in the Washington DC Metropolitan Area" *Journal of Transport Geography*, vol. 76, pp. 123-134, 2019.

[36] Liao F, and Xu M, "Sustainable Transportation Development in the Metropolitan Area: Evidence from Washington DC," *Transport Policy*, vol. 48, pp. 117-127, 2016.

[37] McNeil N, and O'Sullivan D, "Revisiting the Jobs-Housing Balance: Trends in Employment Accessibility and Location," *Journal of Transport Geography*, vol. 59, pp. 53-66, 2017.

[38] Williams B. M, and Roman. S, "The Effects of Protected Bike Lanes on Vehicle Traffic, *Transportation Research Part A: Policy and Practice*, vol. 133, pp. 62-77, 2020.

[39] Ni P, and Churchill R. A, "An Optimal Road Pricing Strategy Using Toll Discount and Marginal Cost Pricing Principles," *Transportation Research Part B: Methodological*, vol. 93, pp. 461-48, 2020.

[40] Lim H. S, and Kwon H. M, "A Joint Route and Departure Time Choice Model Considering Heterogeneous Users for Park-and-Ride Facilities," *Transportation Research Part B: Methodological*, vol. 123, pp. 72-94, 2019.