DIGITAL TECHNOLOGIES FOR EFFICIENT AND RESILIENT SEA-LAND LOGISTICS: IT-BASED DECISION SUPPORT SYSTEMS TO MANAGE HIGHWAY CAPACITY OF MAJOR GATEWAY PORTS

IAME 2025
BERGEN, NORWAY

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AGENDA

- BACKGROUND AND RESEARCH OBJECTIVES
- LEVELS OF SERVICE (LOS)
- DECISION SUPPORT SYSTEM: THE PROPOSED ARCHITECTURE
- DATA AND IMPLEMENTATION
- MANAGERIAL AND STAKEHOLDERS' IMPLICATIONS
- CONCLUSION AND FUTURE RESEARCH

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BACKGROUND and GAPS

- The **competitiveness** of gateway ports increasingly depends on “external” key success factors (**synchronize** massified maritime flows with atomized inland flows)
- **Severe impact** of **port**-related operations on **landside infrastructures** (e.g., capacity bottlenecks, congestion, etc.)
- Pivotal role of **road transport** (modal split), showing concerns in terms of **capacity/LOS** and **port sustainable development**
- **Main causes**: vehicle density and traffic mix, inadequate infrastructural standards, road accidents, force majeure, roadworks, port-related disruptions, etc.
- Explore the potential of **IT-based DSS**: flexible and adaptive **computer-based information systems**, developed for bringing solutions to managerial problems by utilizing data, providing an easy-to-use interface (Power, 2013).

GAPS:

- in **academic literature**, the special role played by **road transport** and associated **IT-based DSS** in fostering port development has been rather neglected insofar;
- in **business practice**, a few **coordination mechanisms** between ports and motorways have been implemented (e.g., extended gateway).

RESEARCH OBJECTIVES

- Identify the **main concerns** related to the **capacity of motorway infrastructures** in proximity to the **main seaports**;

- Design an **IT-based Decision Support System (DSS)** architecture, validated through a **simulation-based test** using a **synthetic dataset**, that reproduces **realistic traffic dynamics:**

  i) to measure real-time congestion,

  ii) to evaluate Levels of Service (LOS), and

  iii) to support optimized traffic management, maintenance planning, and infrastructure development

- Find a balance between **long-term investments** (timeliness and suitability) and **short-term capacity management** (ordinary maintenance, demand peaks & congestion, accidents, force majeure, etc.)

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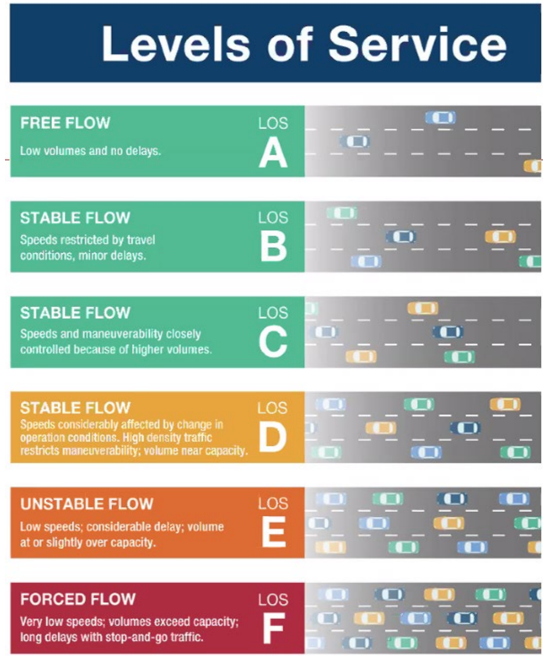
LEVELS OF SERVICE (LOS) and RESILIENT HINTERLAND CONNECTIONS

Level of Service (LOS) is a metric used to **assess the quality of traffic flow on a highway**, using a letter grade from **A** (best conditions) to **F** (the worst). LOS is determined by factors like speed, travel time, maneuverability, and delay.

Traffic disruptions: both exogenous (weather, strikes, geopolitical shocks) and endogenous drivers ("poor" planning, multiple roadworks), that can lead to cascading effects across the supply chain, comparable to the "**bullwhip" effect**.

The proposed DSS tool enables real-time information coordination and proactive decision-making (maintenance and additional investments), minimizing service degradation and enhancing global supply chain stability.



Source: Transportation For America, 2023

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DECISION SUPPORT SYSTEM: THE PROPOSED ARCHITECTURE

The proposed DSS is based on an **asset inventory** *(i)* where the elementary highway sections should be identified and, for each of these sections, several **technical details are collected *(ii)***, including the number of lanes, the width of lanes, the presence of emergency lanes or not, and the maximum speed allowed, etc.

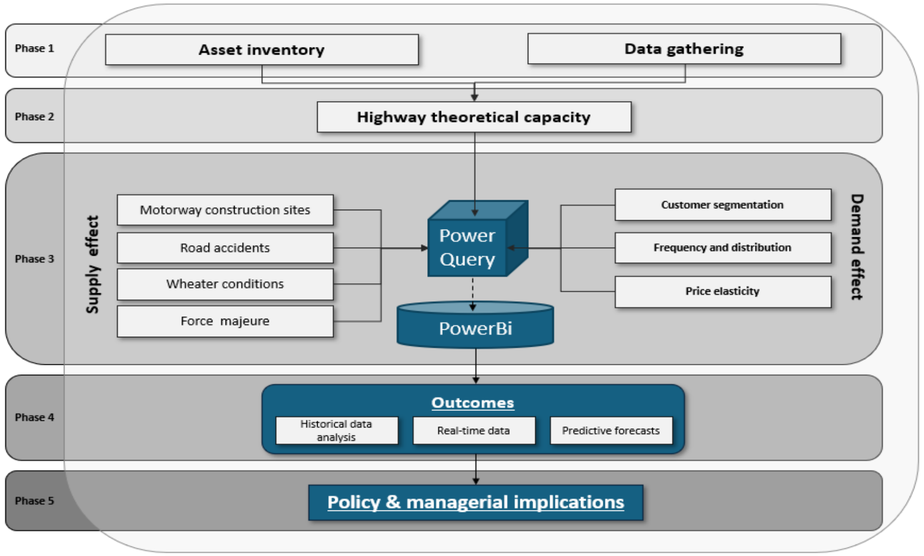
To evaluate highway performance, the DSS architecture distinguishes between **theoretical capacity** (based on geometric standards) and actual capacity, associated to **various LOS**, which is affected by:

Supply-side factors:

- roadworks;
- road accidents;
- weather conditions;
- force majeure.

Demand-side factors:

- Vehicle types (B2B vs. B2C, port-related vs. other flows);
- Temporal patterns (peak/off-peak, seasonal trends);
- Price sensitivity and routing choices.



Source: Own elaboration

Using **Power Query**, data are processed, cleaned, and structured to calculate **effective capacity** and corresponding **LOS** based on **HCM 2000** standards (LOS A–F). This includes traffic volumes, density, flow rate, and user behaviour.

Data are visualized in **Power BI dashboards**, enabling historical pattern analysis, real-time monitoring and predictive congestion modelling.

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DATA and IMPLEMENTATION (Power Query)

To validate the DSS architecture, a **synthetic dataset** was built to simulate realistic traffic dynamics on a number of highway sections.

Timeframe: 31 consecutive days (July 1–31, 2023);

Granularity: Hourly traffic volumes;

Vehicle types: Light and heavy vehicles;

Traffic patterns: Daily/weekly variations (temporal)

synthetic DB

Roadwork site	Date	Hour	From	To	From-To	Direction	Section	Light volumes	Heavy volumes	Total volumes	N. Lane	Speed limits	Theoretical capacity	LOS A	LOS B	LOS C	LOS D	LOS E	% LOS A	% LOS B	% LOS C	% LOS D	% LOS E
No	01/07/2023	0	sect_3	sect_4	sect_3 - sect_4	North	i-th section	226	43	269	1	60	4.300	980	1.540	2.433	3.603	4.300	1	0	0	0	0
No	01/07/2023	0	sect_5	sect_3	sect_5 - sect_3	North	i-th section	283	79	362	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	01/07/2023	0	sect_8	sect_9	sect_8 - sect_9	North	i-th section	207	75	282	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	01/07/2023	0	sect_9	sect_5	sect_9 - sect_5	North	i-th section	226	59	285	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	01/07/2023	0	sect_11	sect_12	ect_11 - sect_1	North	i-th section	200	51	251	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	01/07/2023	0	sect_12	sect_8	sect_12 - sect_	North	i-th section	207	61	268	1	100	4.600	1.400	2.200	3.200	4.130	4.600	1	0	0	0	0
No	01/07/2023	0	sect_14	sect_15	ect_14 - sect_1	North	i-th section	125	33	158	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	01/07/2023	0	sect_15	sect_11	ect_15 - sect_1	North	i-th section	221	152	373	1	110	4.700	1.540	2.420	3.480	4.270	4.700	1	0	0	0	0
No	02/07/2023	0	sect_3	sect_4	sect_3 - sect_4	North	i-th section	719	38	757	1	60	4.300	980	1.540	2.433	3.603	4.300	1	0	0	0	0
No	02/07/2023	0	sect_5	sect_3	sect_5 - sect_3	North	i-th section	1102	77	1179	1	80	4.400	1.120	1.760	2.680	3.768	4.400	0	1	0	0	0
No	02/07/2023	0	sect_8	sect_9	sect_8 - sect_9	North	i-th section	1405	108	1513	1	80	4.400	1.120	1.760	2.680	3.768	4.400	0	1	0	0	0
No	02/07/2023	0	sect_9	sect_5	sect_9 - sect_5	North	i-th section	1112	50	1162	1	80	4.400	1.120	1.760	2.680	3.768	4.400	0	1	0	0	0
No	02/07/2023	0	sect_11	sect_12	ect_11 - sect_1	North	i-th section	736	130	866	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	02/07/2023	0	sect_12	sect_8	sect_12 - sect_	North	i-th section	1038	53	1091	1	100	4.600	1.400	2.200	3.200	4.130	4.600	1	0	0	0	0
No	02/07/2023	0	sect_14	sect_15	ect_14 - sect_1	North	i-th section	388	29	417	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	02/07/2023	0	sect_15	sect_11	ect_15 - sect_1	North	i-th section	789	149	938	1	110	4.700	1.540	2.420	3.480	4.270	4.700	1	0	0	0	0
No	03/07/2023	0	sect_3	sect_4	sect_3 - sect_4	North	i-th section	117	24	141	1	60	4.300	980	1.540	2.433	3.603	4.300	1	0	0	0	0
No	03/07/2023	0	sect_5	sect_3	sect_5 - sect_3	North	i-th section	152	45	197	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	03/07/2023	0	sect_8	sect_9	sect_8 - sect_9	North	i-th section	87	62	149	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	03/07/2023	0	sect_9	sect_5	sect_9 - sect_5	North	i-th section	145	38	183	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	03/07/2023	0	sect_11	sect_12	ect_11 - sect_1	North	i-th section	138	0	138	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	03/07/2023	0	sect_12	sect_8	sect_12 - sect_	North	i-th section	94	38	132	1	100	4.600	1.400	2.200	3.200	4.130	4.600	1	0	0	0	0
No	03/07/2023	0	sect_14	sect_15	ect_14 - sect_1	North	i-th section	64	7	71	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	03/07/2023	0	sect_15	sect_11	ect_15 - sect_1	North	i-th section	96	0	96	1	110	4.700	1.540	2.420	3.480	4.270	4.700	1	0	0	0	0
No	04/07/2023	0	sect_3	sect_4	sect_3 - sect_4	North	i-th section	137	46	183	1	60	4.300	980	1.540	2.433	3.603	4.300	1	0	0	0	0
No	04/07/2023	0	sect_5	sect_3	sect_5 - sect_3	North	i-th section	164	85	249	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	04/07/2023	0	sect_8	sect_9	sect_8 - sect_9	North	i-th section	71	107	178	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	04/07/2023	0	sect_9	sect_5	sect_9 - sect_5	North	i-th section	143	72	215	1	80	4.400	1.120	1.760	2.680	3.768	4.400	1	0	0	0	0
No	04/07/2023	0	sect_11	sect_12	ect_11 - sect_1	North	i-th section	34	19	53	1	90	4.500	1.260	1.980	2.880	3.910	4.500	1	0	0	0	0
No	04/07/2023	0	sect_12	sect_8	sect_12 - sect_	North	i-th section	31	78	109	1	100	4.600	1.400	2.200	3.200	4.130	4.600	1	0	0	0	0
No	04/07/2023	0	sect_14	sect_																			0
No	04/07/2023	0	sect_15	sect_																			0
No	05/07/2023	0	sect_3	sect																			0
No	05/07/2023	0	sect_5	sect																			0
No	05/07/2023	0	sect_8	sect																			0
No	05/07/2023	0	sect_9	sect																			0
No	05/07/2023	0	sect_11	sect_																			0
No	05/07/2023	0	sect_12	sect																			0
No	05/07/2023	0	sect_14	sect_																			0
No	05/07/2023	0	sect_15	sect_																			0
No	06/07/2023	0	sect_3	sect																			0
No	06/07/2023	0	sect_5	sect																			0
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No	06/07/2023	0	sect_12	sect																			0
No	06/07/2023	0	sect_14	sect_																			0
No	06/07/2023	0	sect_15	sect_																			0
No	07/07/2023	0	sect_3	sect																			

Infrastructure scenarios:

1) Normal condition: 2 lanes/direction → 4,800 vehicles/hour
2) Roadworks scenario: 1 lane/direction → 2,400 vehicles/hour

LOS per section without roadwork site

From	to	N. lane	Speed limits	Theoretical capacity	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
sect_1	sect_2	2	120	4.800	1.680	2.640	3.680	4.400	4.800	> 4800
sect_6	sect_7	2	120	4.800	1.680	2.640	3.680	4.400	4.800	> 4800
sect_2	sect_10	2	120	4.800	1.680	2.640	3.680	4.400	4.800	> 4800
sect_10	sect_13	2	120	4.800	1.680	2.640	3.680	4.400	4.800	> 4800
sect_3	sect_4	2	60	4.300	980	1.540	2.433	3.603	4.300	> 4300
sect_5	sect_3	2	80	4.400	1.120	1.760	2.680	3.768	4.400	> 4400
sect_8	sect_9	2	80	4.400	1.120	1.760	2.680	3.768	4.400	> 4400
sect_9	sect_5	2	80	4.400	1.120	1.760	2.680	3.768	4.400	> 4400
sect_11	sect_12	2	90	4.500	1.260	1.980	2.880	3.910	4.500	> 4500
sect_12	sect_8	2	100	4.600	1.400	2.200	3.200	4.130	4.600	> 4600
sect_14	sect_15	2	90	4.500	1.260	1.980	2.880	3.910	4.500	> 4500
sect_15	sect_11	2	110	4.700	1.540	2.420	3.480	4.270	4.700	> 4700

normal

Using HCM 2000 guidelines, **LOS thresholds** were computed to evaluate operational quality under both capacity scenarios. The simulation supports:

- stress-testing of the DSS model (sensitivity);
- assessment of LOS degradation under congestion;
- identification of critical time slots and of the impact of vehicle-types.

LOS per section with roadwork site

From	to	N. lane	Speed limits	Reduced capacity	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
sect_1	sect_2	1	120	2.400	840	1.320	1.840	2.200	2.400	> 2400
sect_6	sect_7	1	120	2.400	840	1.320	1.840	2.200	2.400	> 2400
sect_2	sect_10	1	120	2.400	840	1.320	1.840	2.200	2.400	> 2400
sect_10	sect_13	1	120	2.400	840	1.320	1.840	2.200	2.400	> 2400
sect_3	sect_4	1	60	2.150	490	770	1.216	1.801	2.150	> 2150
sect_5	sect_3	1	80	2.200	560	880	1.340	1.884	2.200	> 2200
sect_8	sect_9	1	80	2.200	560	880	1.340	1.884	2.200	> 2200
sect_9	sect_5	1	80	2.200	560	880	1.340	1.884	2.200	> 2200
sect_11	sect_12	1	90	2.250	630	990	1.440	1.955	2.250	> 2250
sect_12	sect_8	1	100	2.300	700	1.100	1.600	2.065	2.300	> 2300
sect_14	sect_15	1	90	2.250	630	990	1.440	1.955	2.250	> 2250
sect_15	sect_11	1	110	2.350	770	1.210	1.740	2.135	2.350	> 2350

roadworks

Source: Own elaboration

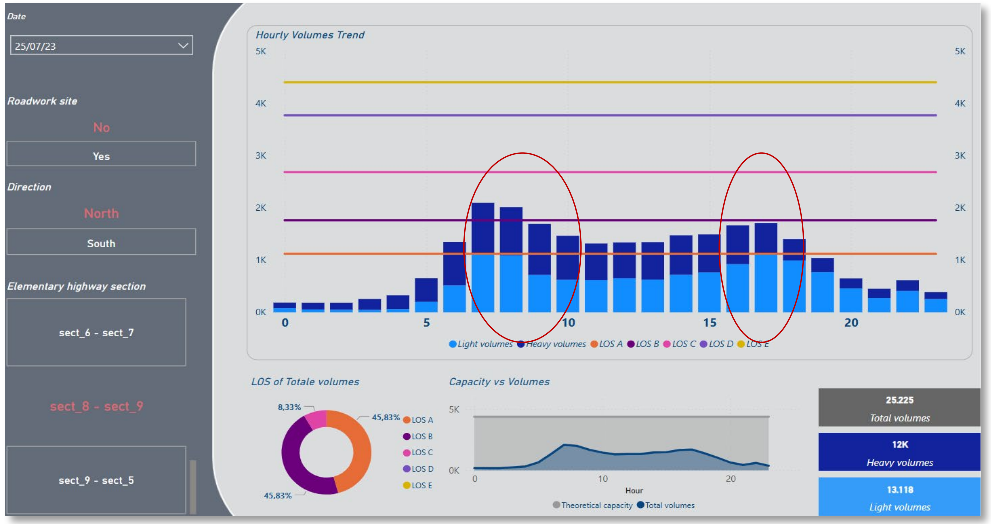
DATA and IMPLEMENTATION (Power BI)

The **Power BI-based DSS dashboard** offers an interactive view of **traffic dynamics** and **LOS** across the highway network. It enables users to:

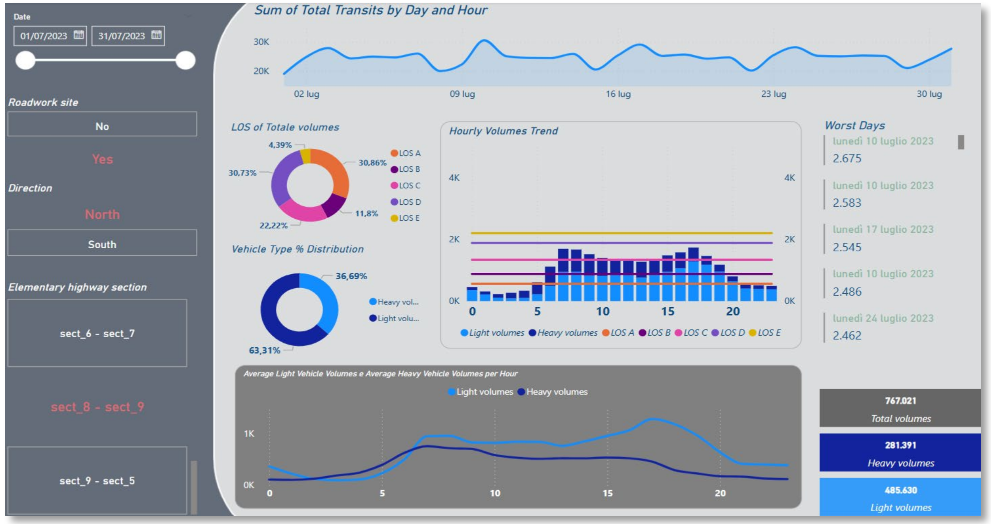
- select temporal range, traffic direction, and highway section;
- view key indicators: total traffic flow, vehicle type distribution, and LOS breakdown (A–F)

In **Scenario 1**, traffic flows are between **LOS B** and **C** during the peak hours (7:00 – 10:00 and 16:00 – 18:00), whereas in **Scenario 2** (reduced capacity) they range between **LOS D** and **E.**

***Scenario 1**– LOS **without** capacity restrictions*

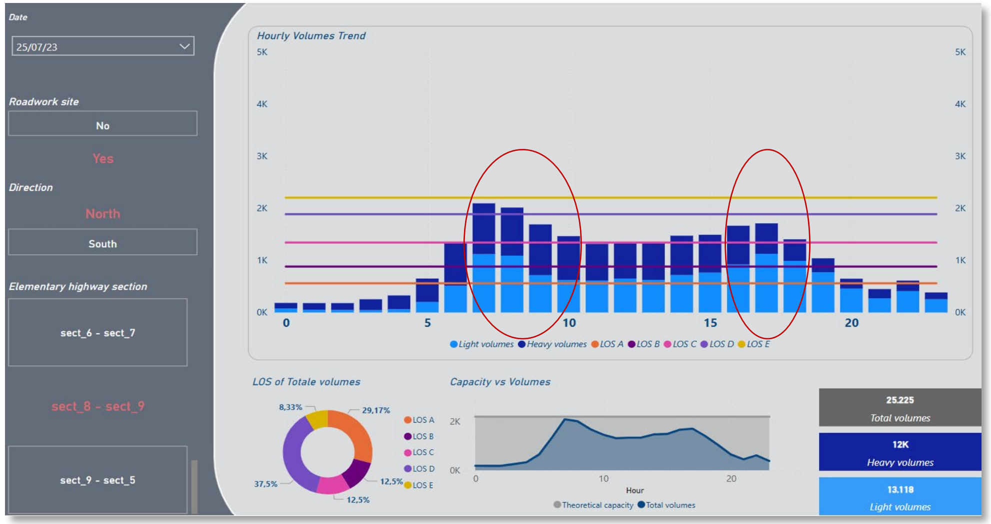


DSS platform overview



Source: Own elaboration

***Scenario 2**– LOS **with** capacity restrictions*



Source: Own elaboration

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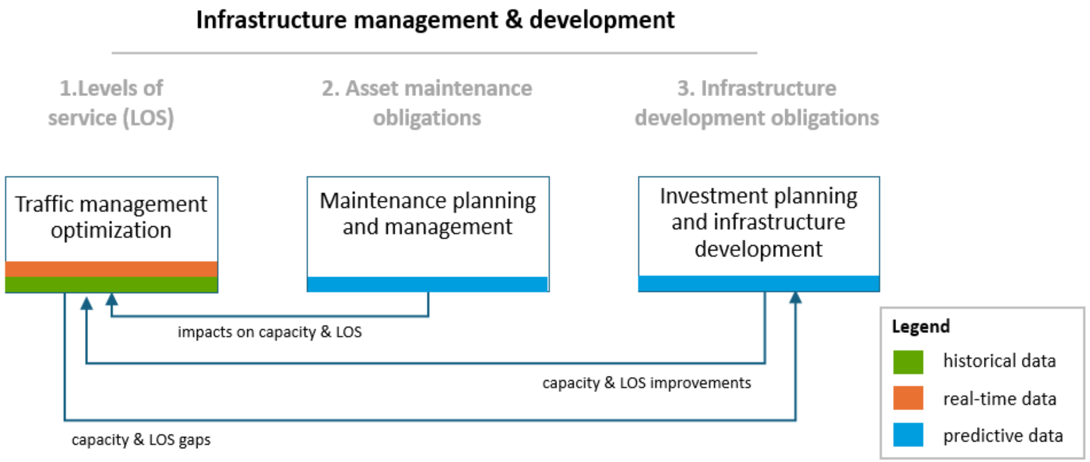
MANAGERIAL and STAKEHOLDERS IMPLICATIONS

- **Traffic Management**
  - Real-time monitoring and information disclosure (per user segment);
  - *Ad-hoc* recovery mechanisms for heavy vehicles and/or port flows.

- **Maintenance Planning**
  - Optimized scheduling to minimize disruption;
  - Lifecycle management of infrastructure assets ("aging" and technical degradation).

- **Investment Strategy**
  - Anticipate bottlenecks with predictive analytics;
  - Support expansion plans and intermodal integration.



Stakeholders' implications

- Highway Concessionaires: smarter maintenance & capacity use, timely and suitable investments;
- Port Authorities & Operators: improved hinterland connectivity;
- Public Regulators: data-informed infrastructure policy;
- Users (B2B & B2C): better journey planning, lower costs;
- Local communities: reduced externalities, better city-port coexistence.

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CONCLUSION and FUTURE RESEARCH

CONCLUSIONS. The proposed DSS can:

- enhance operational and strategic decisions;
- create a “bridge” between port competitiveness and inland infrastructure planning;
- contribute to sustainable, resilient, and efficient logistics networks;
- bring a positive impact on a wide range of stakeholders.

FUTURE RESEARCH

- apply DSS framework to **real-world datasets**;
- assess network resilience in the presence of **disruptive events** (e.g., accidents, strikes, natural disasters);
- test **recovery mechanisms** in seaport logistics systems (truck appointment system, extended gateway, etc.);
- evaluate long-term **investment policy** (rightsizing, timeliness, etc.).

THANK YOU FOR THE ATTENTION!

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(*) The views and opinions expressed in this presentation are those of the authors and do not necessarily reflect the official policy or position of the respective institutions.