

# Smart city ecosystems organising connected intelligence: Lessons from Mobility as a Service

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2023 IEEE International Conference on Smart Mobility, KAUST, Saudi Arabia,  
19 -21 March 2023

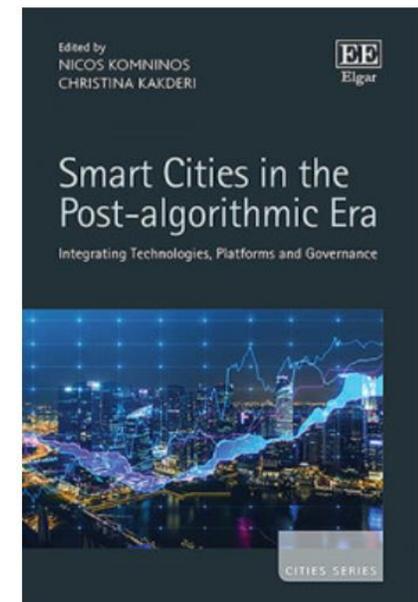
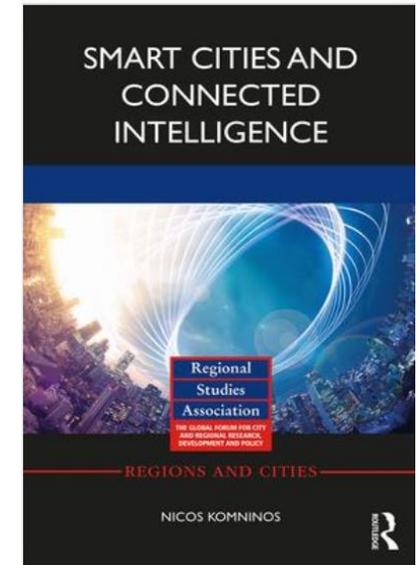
This talk presents our latest work at URENIO Research on smart cities and connected intelligence (see these two books).

There is plenty of evidence that the **smart city is the dominant planning and development paradigm for cities in the 21st century**. In our view, **smart city ecosystems** are the fundamental components of smart cities. They **generate connected intelligence**, networking human, collective, and machine intelligence, which in turn brings system-level changes to their routines, activities, and structure.

This talk focuses on the **MaaS ecosystem**, which in relation to autonomous vehicles, is expected to bring the most radical changes to the organization of cities in the coming years, freeing cities from cars and pollution.

## *Contents*

1. Introduction: The smart city paradigm and main pillars
2. Literature: Connected intelligence components and binary coupling
3. Lessons from a case study: Connected intelligence in MaaS ecosystems
4. Conclusion: Connected intelligence and MaaS innovation



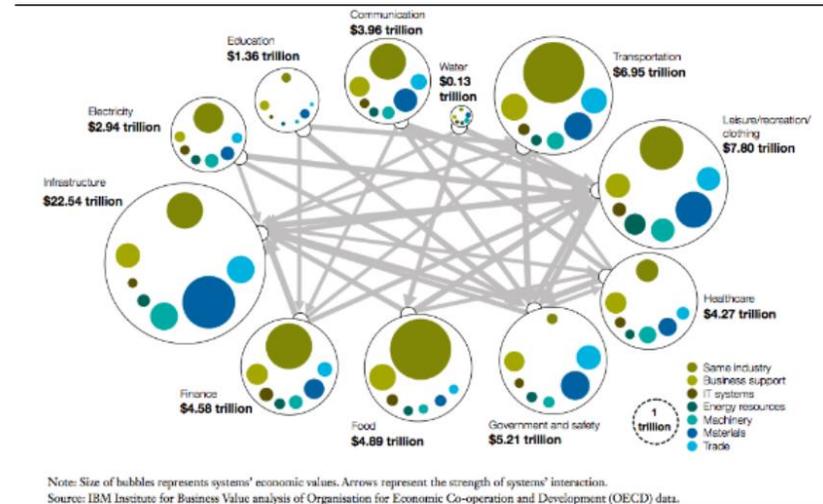
# 1. Connected intelligence in the smart city paradigm



# System-of-systems view. Smart cities are composed of smart ecosystems, which follow their own trajectories of change

## IBM: System of systems

by HOWARD SILVERMAN on 30 JUN 2012 0 COMMENTS



<b>SMART ENERGY: DIGITAL MANAGEMENT OF ENERGY</b>  <ul style="list-style-type: none"> <li>Smart Grids</li> <li>Smart Meters</li> <li>Intelligent Energy Storage</li> </ul>	<b>SMART BUILDINGS: AUTOMATED INTELLIGENT BUILDINGS</b>  <ul style="list-style-type: none"> <li>Renewable Energy Integration</li> <li>Building integrated Photovoltaic</li> </ul>	<b>SMART MOBILITY: INTELLIGENT MOBILITY</b>  <ul style="list-style-type: none"> <li>Low-emission Mobility</li> <li>Integrated Mobility Solutions</li> <li>Multimodal Transport</li> </ul>
<b>SMART TECHNOLOGY: SEAMLESS CONNECTIVITY</b>  <ul style="list-style-type: none"> <li>Broadband penetration rate of over 80%</li> <li>50% of households to have smart home</li> <li>Smart Personal Devices</li> </ul>	<b>SMART INFRASTRUCTURE: DIGITAL MANAGEMENT OF INFRASTRUCTURE</b>  <ul style="list-style-type: none"> <li>Sensor Networks</li> <li>Digital Water and Waste Management</li> </ul>	<b>SMART GOVERNANCE: GOVERNMENT -ON-THE-GO</b>  <ul style="list-style-type: none"> <li>Use of e health and health systems</li> <li>Intelligent and connected medical devices</li> </ul>
<b>SMART HEALTHCARE: INTELLIGENT HEALTHCARE TECHNOLOGY</b>  <ul style="list-style-type: none"> <li>e-Government</li> <li>e-Education</li> <li>Disaster Management Solutions</li> </ul>	<b>SMART CITIZEN: CIVIC DIGITAL NATIVES</b>  <ul style="list-style-type: none"> <li>Use of Green Mobility Options</li> <li>Smart Lifestyle Choices</li> <li>Energy conscious</li> </ul>	

FROST & SULLIVAN

IBM Institute of Business Value (2010): IBM system of systems

Klingberg, D., & Bell, J. (2015). Smart cities habitat master planning framework. *Planning News*, 41(6), 22

Frost & Sullivan (2020). Smart Cities: F&S value proposition

## 20 major ecosystems (domains, subsystems) under transformation

**Area-based ecosystems,** defined by districts & neighbourhoods

1. City centre
2. Marketplace
3. Housing
4. Public space / recreation
5. Natural ecosystems
6. Hub (port / rail / bus)

**Vertical ecosystems,** defined by activities

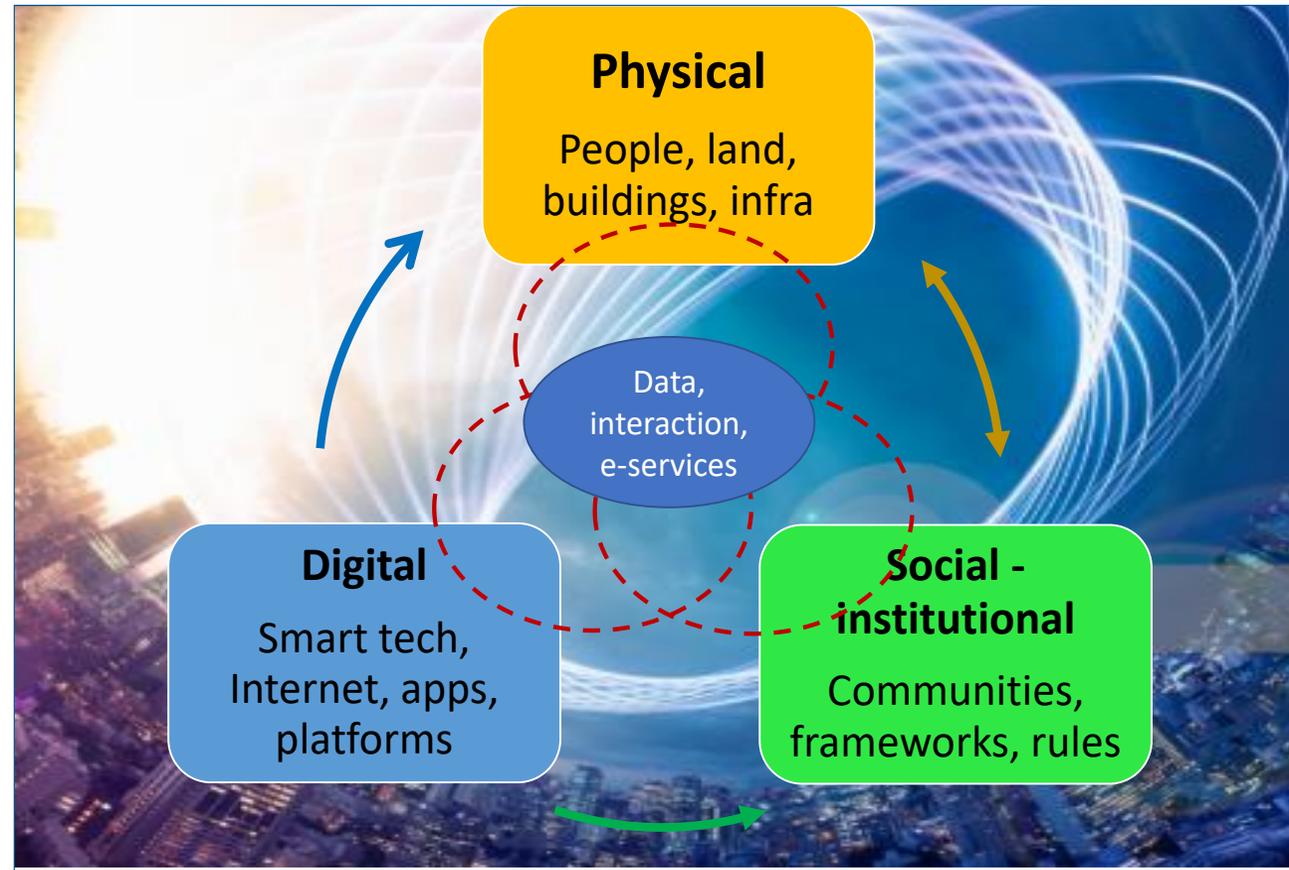
7. Manufacturing
8. Food production
9. Education
10. Tourism, hospitality, etc.
11. Culture and branding
12. Public services & safety
13. Government

**Network-based ecosystems,** defined by utilities and other infra

14. Transportation
15. Energy
16. Water
17. Waste
18. Telecom, broadband
19. Recycling
20. Environment, emissions

# Innovation: Smart ecosystems are formed by planning and projects. Projects' impact range from simple digitalization to system innovation

## Dimensions in smart ecosystems and projects



**DIGITALISATION: E-services in all ecosystems of cities.** Most projects (apps) just transfer activities from the physical to the digital space. Underlying routines remain the same. Usual in e-gov. and e-commerce.

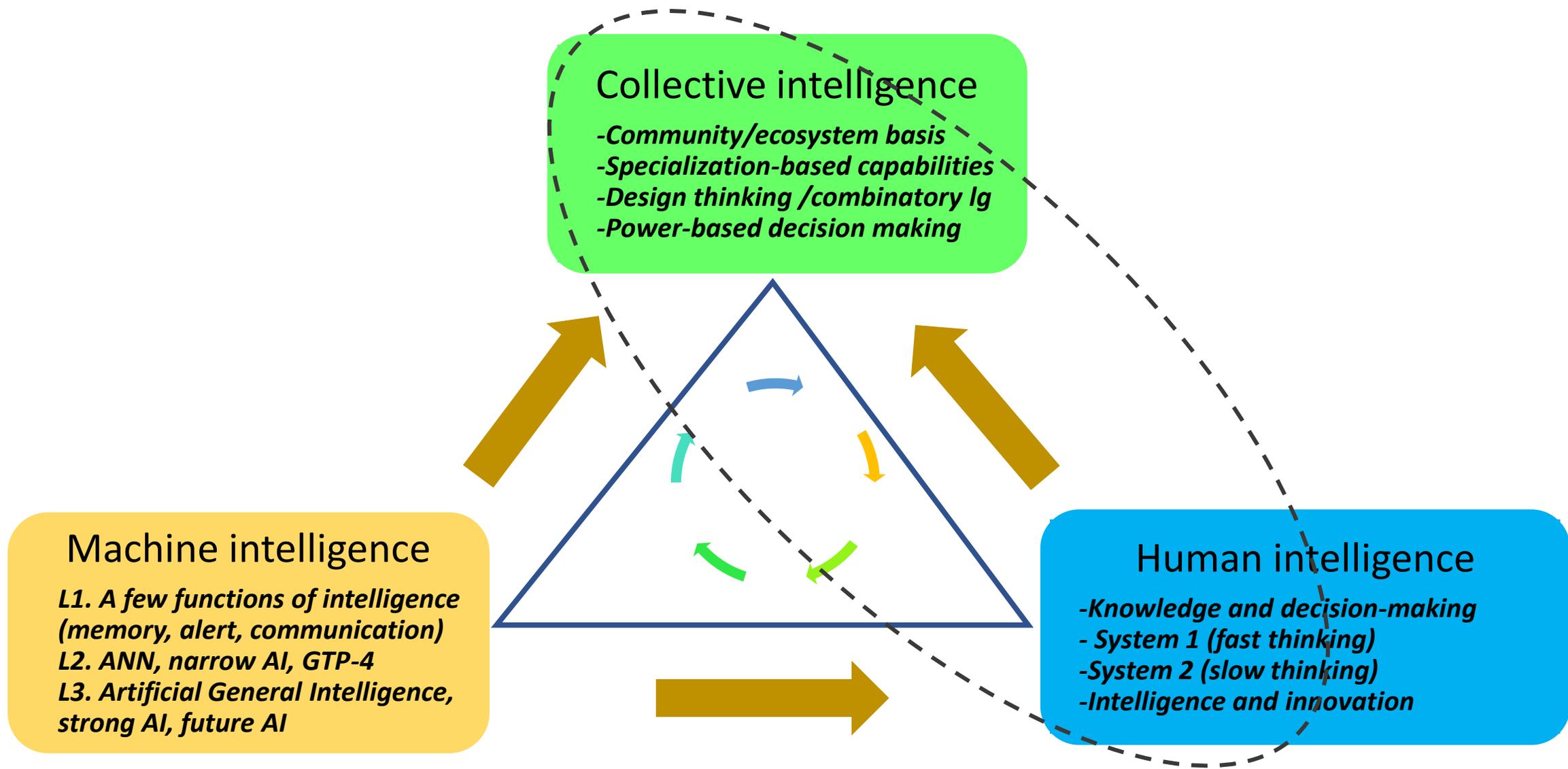


**OPTIMISATION: The city becomes a measured system.** Data, analytics, algorithms can optimize activity routines. GPS, smart meters, virtual assistants, digitally guided behaviour, are examples of optimisation.



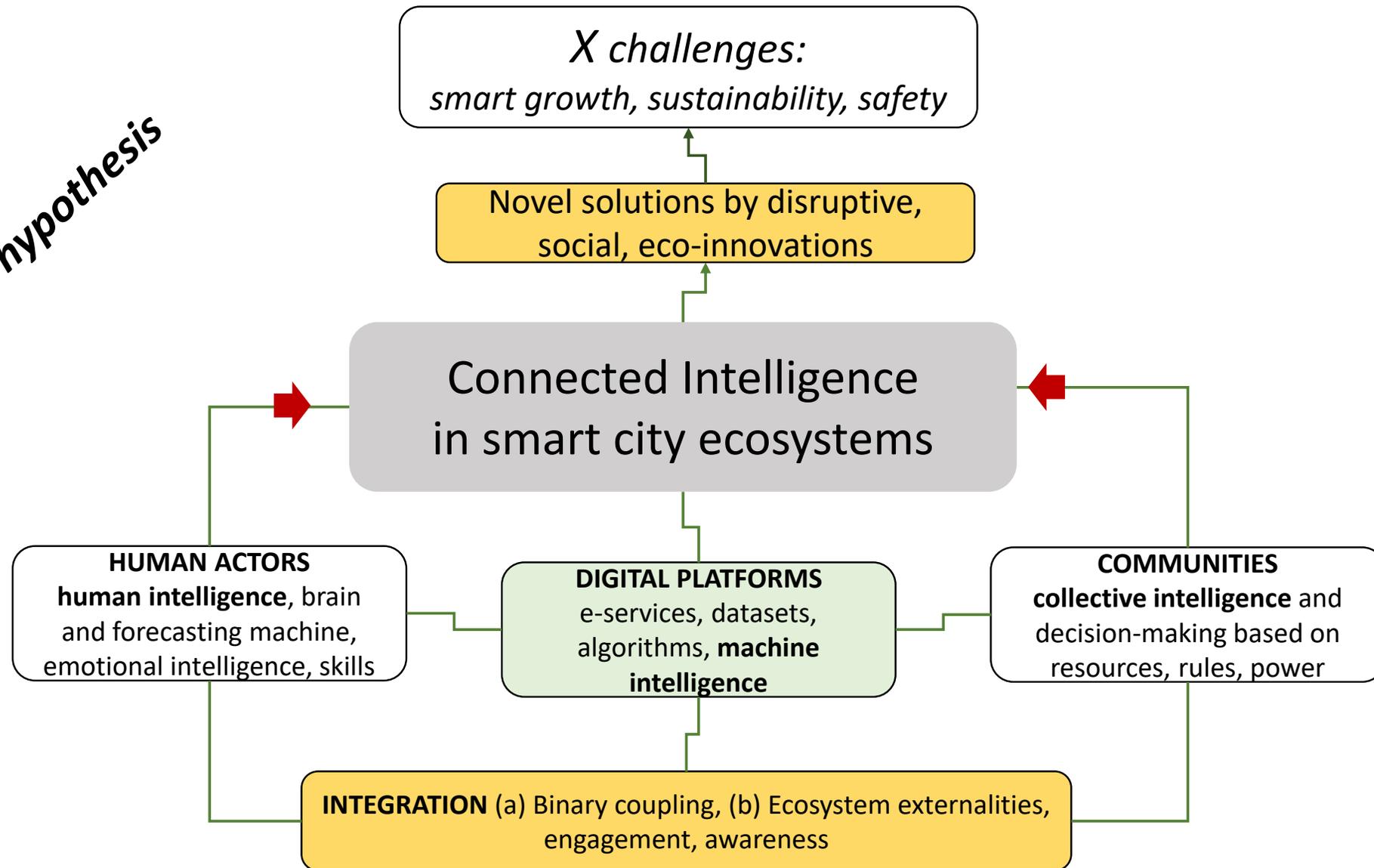
**INNOVATION: Complex cyber-physical projects that change activity routines,** introduce new routines. MaaS, Net zero districts, Vision zero for urban safety are examples of innovation. **Platform ecosystems** re-organize economic activities & services.

# *Connected intelligence: In smart city ecosystems, connected (or hybrid) intelligence is the driver for optimization and innovation*



# Research question: How do human, collective, and machine intelligence work together in smart city ecosystems? How in the mobility ecosystem?

Research hypothesis



## 2. Connected intelligence components and binary coupling

# Types of intelligence in smart cities

**Intelligence** is the ability of an individual agent (a) to interact with its environment (**communication**), (b) to succeed or profit with respect to some goal or objective (**problem-solving**), (c) to **adapt** to different objectives and environments

(Legg, S., & Hutter, M. (2007). A collection of definitions of intelligence. *Frontiers in Artificial Intelligence and applications*, 157, 17.)

- **Human intelligence** refers to the cognitive capabilities of humans, reasoning, problem-solving and innovation skills
- **Collective intelligence** of groups of individuals acting collectively, the wisdom of crowds; a group of average people can outperform any individual in the group or even a single expert
- **Machine intelligence**, IT systems that perform activities we associate with human thinking

(Dellermann, D., Ebel, P., Söllner, M., & Leimeister, J. M. (2019). Hybrid intelligence. *Business & Information Systems Engineering*, 61(5), 637-643.)

**Hybrid intelligence**, the combined human, collective, and machine intelligence can offer better predictions and problem-solving in many domains of human activity

**Hybrid intelligence** can be designed in many ways, depending on the role of the human and the algorithm in the hybrid system

- **Algorithms as assistants**, make it easier for humans to perform complex, lengthy, repetitive tasks by automating some processes
- **Algorithms as peers**, involve algorithms reaching human-like and better-than-human performance in previously human-only domains
- **Algorithms as facilitators**, the algorithm does try to solve the task only but models human behaviour to maximize the chances of good human performance
- **Algorithms system-level operators**, the algorithm observes the full information–task–people–AI system, controls the information flows, and acts to maximize the system’s performance

Pescetelli, N. (2021). A Brief Taxonomy of Hybrid Intelligence. *Forecasting*, 3(3), 633-643.

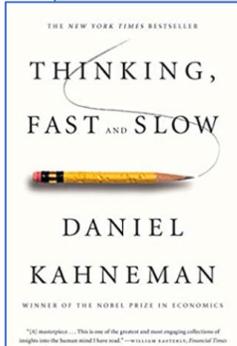
# Human intelligence (HI)

## Individuals of the smart city population

### Two modes of thought

**System 1:** fast, intuitive, stereotypic, emotional, associative, follows routines

**System 2:** slow, calculated, rational (follow algorithms, learning for discovery and problem-solving, IQ tests skills, slow & costly)



- **System 1 is the “normal” decision-making of humans. System 2 only occasionally checks in.**
- **S1** is related to imitation, creativity, innovation, pattern recognition, intuition in problem-solving, reasoning with scarce data
- **S2** is related to analytical thinking, behaviour monitoring, activated when S1 model is challenged
- **S2 endorses S1** and combined they drive decisions
- **THE BLACK BOX: “We still have very little understanding of how the mind actually works”**  
[Geoffrey E. Hinton, 2021 IIT Mumbai](#)
- For Penrose, **consciousness** is not computational; we cannot understand it with current science; originates at the quantum level, at “microtubules” that reside inside the neurons of the brain.

### Brain and intelligence

- Correlation of brain volume and intelligence is low ( 0 to 0.3/0.4)
- Structure is more important: number of cortical neurons, density and efficiency of using neurons, speed of neural transmission, integration of brain regions, the architecture of constellations, how the brain is structured. [Luders, E., Narr, K. L., Thompson, P. M., & Toga, A. W. \(2009\). Neuroanatomical correlates of intelligence. \*Intelligence\*, 37\(2\), 156-163.](#)

### The brain works as a prediction machine

[Hawkins, J., & Blakeslee, S. \(2007\). \*On intelligence\*. Macmillan.](#)

### Intelligence and innovation

- Literature on “intelligence” & “innovation” is large, 3.11 ml results in Google Scholar
- Intelligence is a dimension of cognitive behaviour, the knowledge of the world and how it is used to adapt to changing behaviour  
[Jerison, H. \(2012\). \*Evolution of the brain and intelligence\*. Elsevier.](#)
- Causal relationships: knowledge is the basis of both intelligence and innovation
- Assessment relationship: intelligence is assessed by problem-solving / innovation capabilities

# Collective intelligence (CI)

*Communities, groups, organisations, institutions, smart city ecosystems*

**A system exhibits collective intelligence** not only because it is composed of many interacting components. These components should possess a degree of agency, intelligence, or ability to react to their environment, which allows for the emergence of intelligence in the system as a whole.

Millhouse, T., Moses, M., & Mitchell, M. (2021). *Frontiers in Collective Intelligence: A Workshop Report*. *arXiv preprint arXiv:2112.06864*.

**Collective intelligence is not human intelligence** (as some authors suggest). CI systems, besides humans, also comprise other entities (institutions, hierarchies, resources) that shape the intelligence of the group. While human intelligence evolves according to natural selection, **CI Intel evolves according to human-designed institutions and social mechanisms.**

**Collective problem-solving** examines situations in which communication networks among team members are necessary for discovering innovative solutions. The primary concern for researchers in this field is determining **how the structure, or topology, of communication networks** among problem-solvers may improve (or even optimize) the quality of the solutions they discover.

Centola, D. (2022). *The network science of collective intelligence*. *Trends in Cognitive Sciences*.

**Weighted voting:** CI follows rules, norms, hierarchies and power relations. These create a weighted voting system.

**Power relations:** In companies, shareholder primacy is the prevailing rule that drives CI.

**Specialisation:** In CI, agents work in parallel, specialising in different tasks. No single agent settles on a solution, the agents collectively settle on a working solution after a stochastic process of trial, error, exploration, or other. Mitchell, M. (2021). *Collective Intelligence in a Computer Model of Analogy-Making*. Santa Fe Institute

**Coarser- and finer-grained information** underlies collective computation and intelligence. “Coarse-graining” is distilling micro-scale information into a smaller set of macro-scale variables. Getting information about the behaviour of the system while losing information about the members’ states.

Flack, J. (2021). *Collective Intelligence: Future Directions*. Santa Fe Institute

**Size does not matter. A paradox:** The more individuals each person interacts with, the less cooperation is overall. (Cleotilde Gonzalez Carnegie Mellon University)

# Machine intelligence (MI)

## *Applications and algorithms for smart cities*

### Two levels of intelligence provided by machines

- **L1:** based on functions of intelligence, such as memory, alert, automation, app assisted operations
- **L2:** based on AI, machine learning, Artificial Neural Networks, and autonomous systems

### Weaknesses of AI compared to human intelligence

- AI fails in ill-defined problems
- Artificial Neural Networks need large amount of data
- No auto-evolution, creation of next-generation AI

### Areas of AI use in smart cities

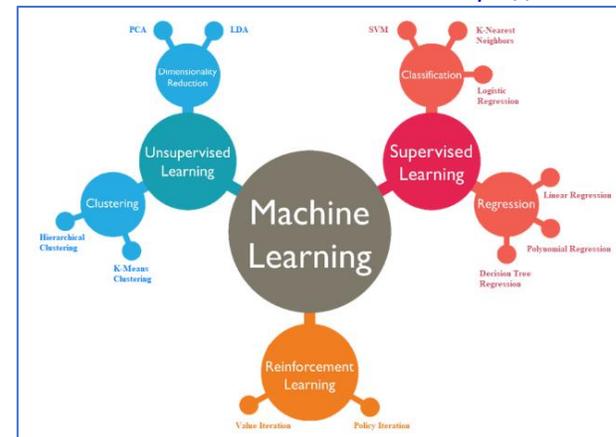
- Intelligent transportation systems
- Self-driving vehicles, security of connected vehicles
- Recommendation systems for passenger hunt
- Energy management, optimisation, sharing
- Advanced health care, health intelligence
- Cyber-security
- Reliable IoT systems
- Crime detection, incident prediction

Ullah, Z., Al-Turjman, F., Mostarda, L., & Gagliardi, R. (2020). Applications of artificial intelligence and machine learning in smart cities. *Computer Communications*, 154, 313-323.

### Common machine learning algorithms

- **Neural networks** to recognise patterns, natural language translation, image/speech recognition
- **Linear regression** to predict numerical values, based on a linear relationship between values
- **Logistic regression** to predict categorical variables (yes/no), classification, quality control
- **Clustering** to identify patterns in data, create data groups, and identify differences between data that humans overlooked
- **Decision trees** to predict numerical values (regression) and classify data into groups
- **Random forests** to predict a value or category combining a number of decision trees

<https://www.ibm.com/cloud/watson-studio/deep-learning>



More detailed classification of machine learning techniques by Ullah et al. 2020

# Connected intelligence is integration of H-C-M intelligence

## *Binary coupling between HI-CI-MI*

### Human intelligence: S1, S2, bounded rationality

- Communication, cognition
- Rational/irrational decisions
- Problem-solving
- Adaptation
- Science and discovery
- Innovation

### Collective intelligence: hierarchy, weighted voting

- Distributed intelligence
- Collaborative problem-solving
- Provision of resources & skills
- Power-based decisions
- Rule-based thinking

### Machine intelligence: algorithmic thinking

- Digital services
- Smart systems and networks
- Data, analytics, optimisation
- AI, machine learning
- Automation
- Autonomous systems

### *Human intelligence & collective intelligence*

- Individual choice & weighted voting
- User motivation and social engagement culture
- Adaptation of human decisions to community rules

### *Human intelligence & machine intelligence*

- Individual choice & algorithmic processes
- Digitally-guided behaviour
- MI-assisted decision-making

### *Collective intelligence & machine intelligence*

- Weighted voting & algorithmic processes
- Platform-based organisation, ecosystems
- Digitally assisted crowdsourcing
- Crowdsourcing-based performance assessment

# Types of binary coupling considering the **direction of interaction**

<b>Human intelligence (HI)</b> Decisions initiated by experts or users	<b>Collective intelligence (CI)</b> Decisions initiated by groups or organisations	<b>Machine intelligence (MI)</b> Decisions initiated by algorithms
HI & HI* HI & CI HI & MI	CI & CI** CI & HI CI & MI	MI & MI*** MI & HI MI & CI
* HI & HI = CI	** CI & CI = CI	*** MI & MI = MI

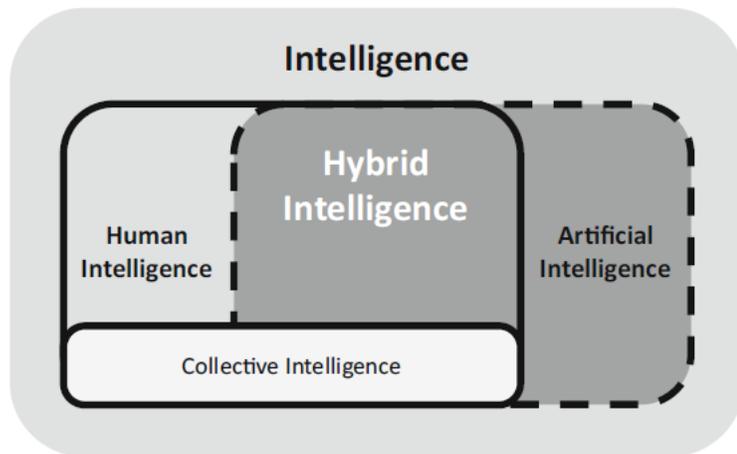


Fig. 3 Conceptual integration of hybrid intelligence

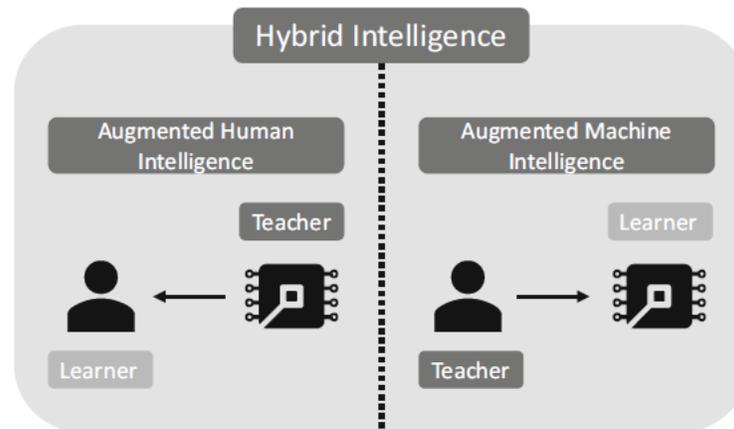


Fig. 2 Distribution of roles in hybrid intelligence

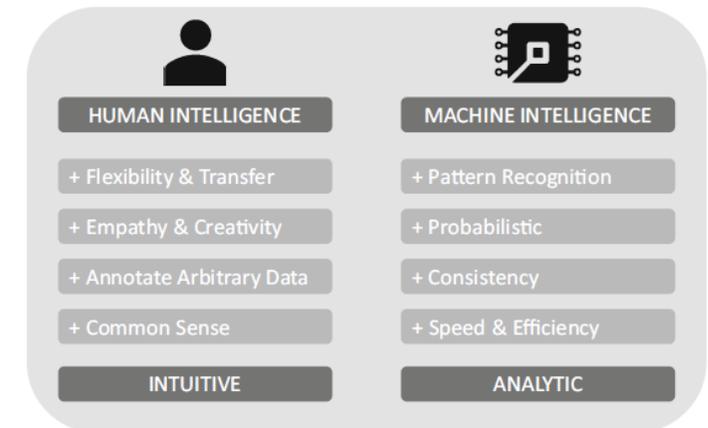


Fig. 1 Complementary strengths of humans and machines

## HI & CI or MI

Systems from various fields

**Human-in-the-loop:** HI integrated into a machine learning system to improve its accuracy and efficiency

**Data analytics:** HI to develop marketing campaigns and target specific audiences & MI to analyze consumer data, identify trends and preferences

**Agent Based Modelling:** HI to augment MI by analyzing the behaviour of different agents and understanding emerging features in collective settings

**Skill evaluation:** HI to evaluate job candidates & MI to analyze resumes and identify relevant experience and skills

**Emergency response:** HI to assess a situation and make decisions & MI to analyze data and identify potential risks and hazards

## CI & HI or MI

Systems from various fields

**Swarm intelligence:** groups of individuals work together to achieve a common goal, solve complex problems that are beyond the capabilities of individual humans or machines.

**Collaborative filtering:** recommendation systems use CI to augment human intelligence by suggesting items based on the preferences of similar users

**Open source software:** allows CI to augment machine intelligence by enabling communities of developers to collaborate on the development of software

**Human computation:** groups of people work together to solve problems, using their CI to augment machine intelligence

## MI & HI or CI

Systems from various fields

**Decision support systems:** use of MI to assist humans in making decisions, with algorithms and data analysis techniques for more informed decisions

**Predictive analytics:** use of MI to make predictions about future events based on historical data and help individuals and organizations make more accurate predictions about future events.

**Sentiment analysis:** use of MI to analyze and understand the emotional content of text and provide insights into public opinion, customer sentiment, and other trends.

**Personalized learning:** use of MI to tailor educational content to individual learners, based on their unique learning styles and preferences.

### 3. Lessons from a case study: HI-CI-MI coupling in MaaS ecosystems

# Mobility as a Service: MaaS

## *Definitions and two emphasis in the understanding*

“MaaS is a mobility distribution model that delivers **users’ transport needs** through a single interface of a service provider” [Hietanen, S. \(2014\). “Mobility as a Service” —The new transport model? \*Eurotransport\*, 12\(2\), 2–4.](#)

“a user centric, intelligent mobility management and distribution system, **where an integrator brings** together the offerings of the multiple mobility service providers and allows end-users to seamlessly plan and pay for mobility through a digital interface” [\(MaaS Lab, 2018\)](#)

“MaaS is the **integration** of various forms of **transport services** into a single mobility service, accessible on demand” [MaaS Alliance, White Paper “Guidelines & Recommendations to create the foundations for a thriving MaaS Ecosystem”, 2017](#)

“Mobility as a Service (MaaS) is **the integration of**, and access to, **different transport services** (PT, ride-sharing, car-bike-scooter sharing, taxi, car rental, ride-hailing) in one single digital mobility offer with an efficient public transport system as its basis” [UITP Report Mobility as a Service, April 2019 \(Union Internationale des Transports Publics\)](#)

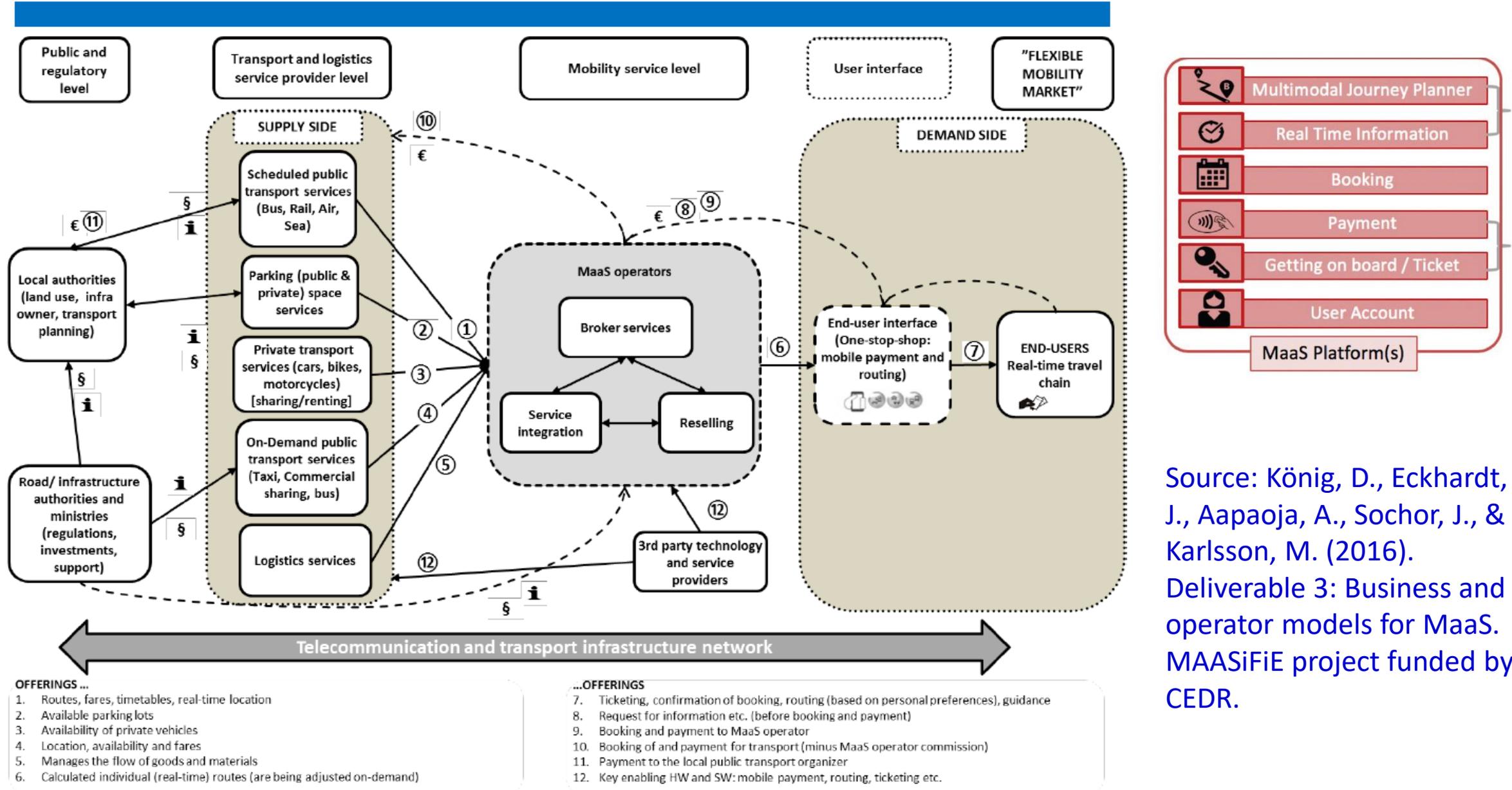
“MaaS integrates transport **modes through the Internet**” [Holmberg, P.-E., Collado, M., Sarasini, S., & Williander, M. \(2016\). \*Mobility as a Service-MaaS. Describing the framework\*. Göteborg, Viktoria Swedish ICT.](#)

“**The main component of MaaS system is the ICT support system** which is dealing with collecting, transmitting and processing information as well as with the presenting of this information in an understandable format for all users.” [Nemtanu, F., Schlingensiepen, J., Buretea, D., & Iordache, V. \(2016\). \*Mobility as a service in smart cities. Responsible entrepreneurship vision, development and ethics\*, 425.](#)

“MaaS combines different transport modes to offer a tailored mobility package, **similar to a monthly mobile phone contract** and includes other complementary **services**, such as trip planning, reservation, and payments, through a single interface” [Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso González, M. J., & Narayan, J. \(2017\). \*Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges\*.](#)

# MaaS

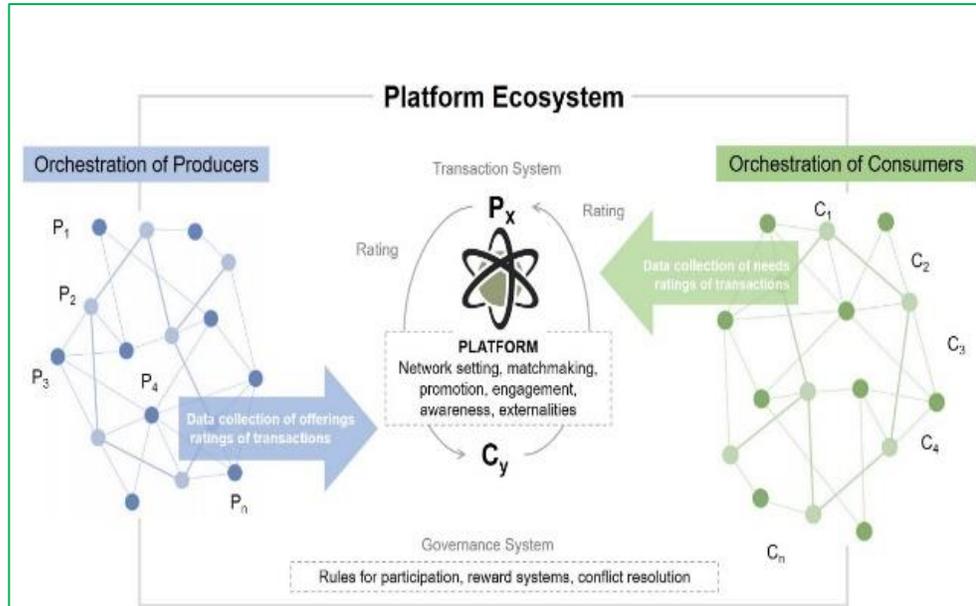
## A platform ecosystem



Source: König, D., Eckhardt, J., Aapaoja, A., Sochor, J., & Karlsson, M. (2016). Deliverable 3: Business and operator models for MaaS. MAASiFiE project funded by CEDR.

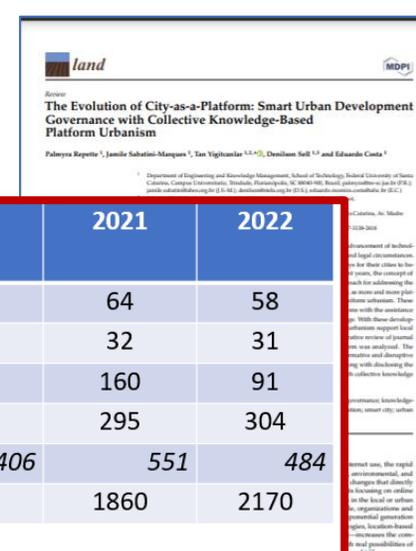
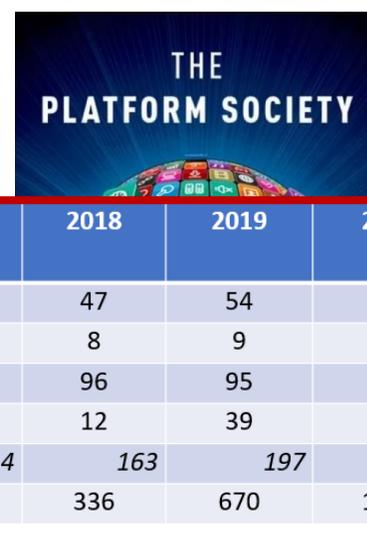
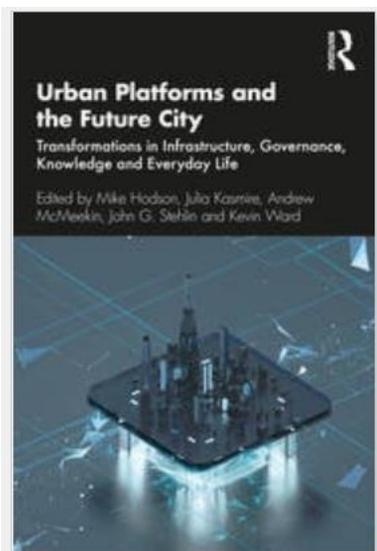
# MaaS

## Within the wider platformization of cities



### Digital platforms enable city ecosystems to evolve into platform-based ecosystems

- **DP are technological building blocks** (that can be technologies, products, or e-services) that act as a foundation on top of which a group of interdependent actors (called complementors), develop inter-related products, technologies and services
- **DP are collaborative business models** that allow multiple participants (producers, consumers) to connect, interact with each other, create and exchange value, create ecosystems



Search terms	2017	2018	2019	2020	2021	2022
"Platform city"	43	47	54	74	64	58
"Platform cities"	8	8	9	23	32	31
"City as a Platform"	59	96	95	135	160	91
"Platform urbanism"	4	12	39	174	295	304
<b>Total</b>	<b>114</b>	<b>163</b>	<b>197</b>	<b>406</b>	<b>551</b>	<b>484</b>
"Platformization"	137	336	670	1100	1860	2170

Source: Google Scholar, 2022-10-17

# MaaS from a platform perspective

## Five critical decisions in setting the ecosystem

### Integration of system entities

#### Physical

- Transport providers
- MaaS operator
- Data providers
- Customers
- City and infrastructure
- Roads, parking, traffic
- Transport fleet

#### Institutional

- Transport legal framework
- Regulators
- MaaS operation rules
- Providers agreements
- Tarif rules
- Customer rights

#### Digital

- MaaS platform
- E-services
- Web and smartphone applications
- Usage datasets & analytics
- IoT network
- Digital twin of the city and infrastructure

### Critical decisions

#### 1. MaaS planning

- MaaS system setting actions
- Multi-level agreements

#### 2. Supply side orchestration

- Fleet management
- Fleet composition

#### 3. Demand side orchestration

- Mobility demand management
- Journey planner

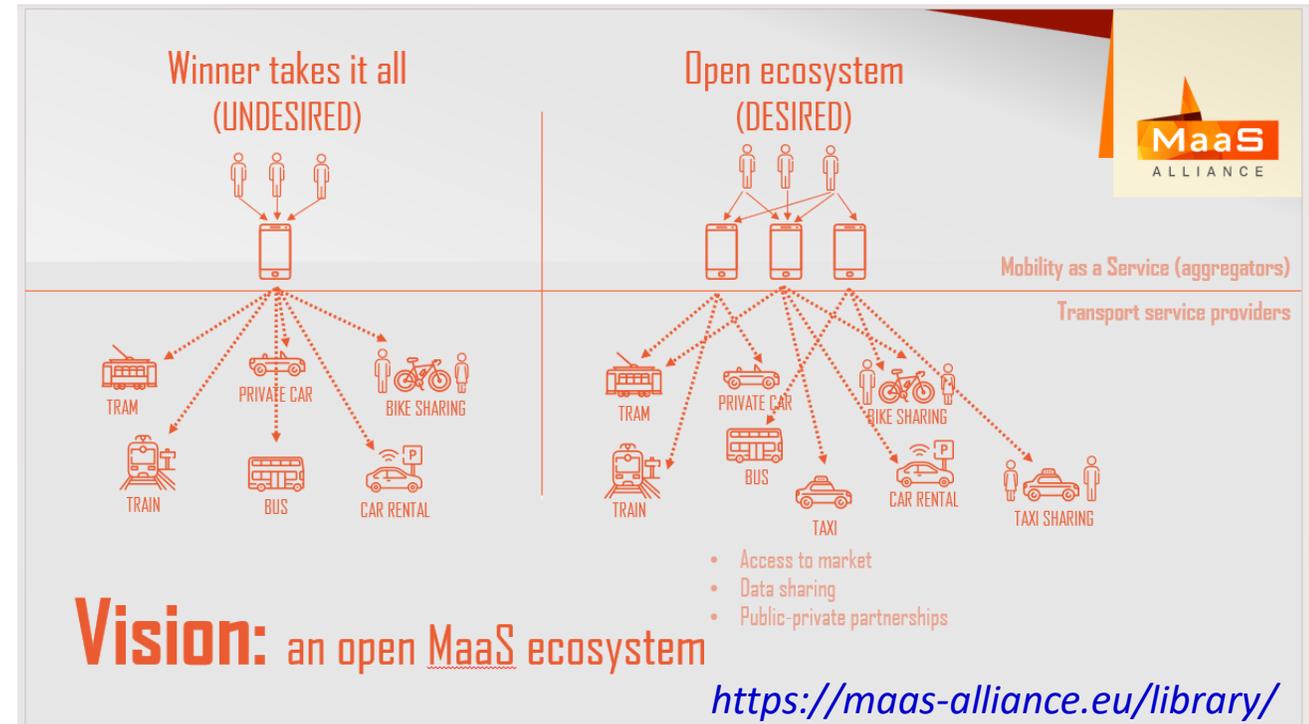
#### 4. Business model

- MO and TSP
- Type: Integrator, reseller, public

#### 5. Integration

- Models of integration
- Outer limits of integration

### Alternative models



# 1. MaaS planning

## Typical strategic planning stages



### Phase 1: Cooperation

MaaS stakeholders have different strategies in terms of governance, business models, interests and objectives that should be aligned

### Phase 2: Common vision, scenarios

Building and jointly assessing future scenarios, developing common vision and objectives, setting targets and indicators

### Phase 3: Agreed measures, actions

Agreed measures packages with stakeholders, agreement on actions and responsibilities, particularly public funding

### Phase 4: Monitor and adapt

Set up organisational structures to manage implementation, monitor and adapt, allow review and lessons learnt.

## Areas of potential binary coupling

- **MI & CI (or HI):** Availability and sharing of data are crucial for well-informed planning and decision-making procedures.
  - **CI & CI:** Stakeholders cooperation, different strategies of governance, business and customer care in mobility .ERTICO – ITS Europe (2019).
  - **CI & CI:** Multi-level agreements of MaaS organisations: TSPs, MO, payment cleaning, insurance, city authorities
  - **MI & HI:** User-centric settings: assessment, personalization of services, dispute resolution, security and insurance
  - **HI & CI (or MI):** Design of digital services: platform, e-services (real-time info, trip planning, booking, ticking, payment).
  - **MI & HI:** Data analytics, visualization, clustering, supporting experts' decision
- Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges.

**Online S3**, a Horizon 2020 project. We developed 28 web applications and 4 roadmaps to facilitate authorities in strategic planning for innovation. Different types of binary coupling can be found:

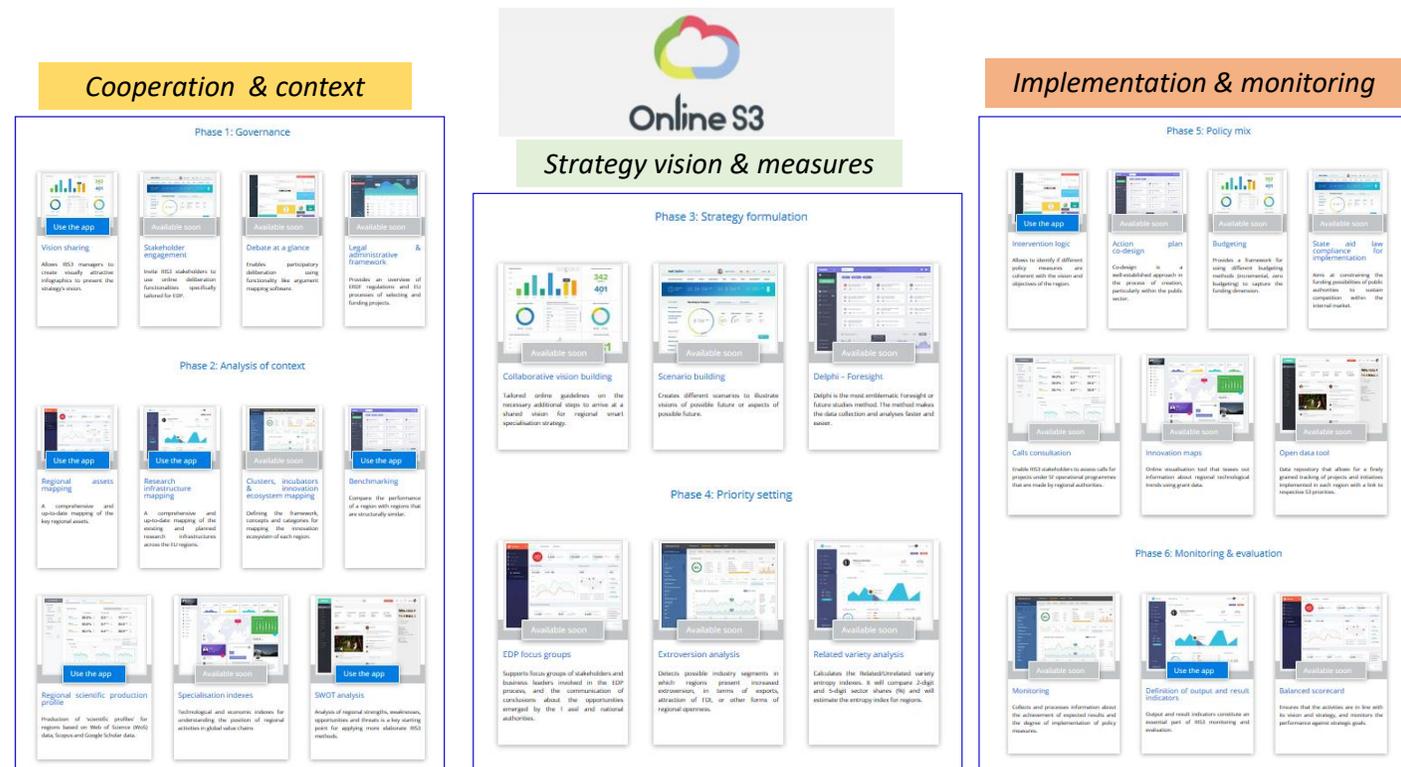
**MI & CI:** Vision sharing app and Debate at a glance app. Invite stakeholders to participate. Visualize dialogue.

**HI & MI:** Regional mapping app. Ecosystem mapping app. Integrate data into a searchable platform. Data visualization.

**MI & HI:** Regional scientific profile app. Bibliometrics of scientific production, typology of regions.

**CI & MI:** Action plan co-design app. Create or adapt an AP

Panori, A., Komninos, N., Kakderi, C. and Fellnhofner, K. (2018). "Smart Specialisation Strategies: An online platform for strategy design and assessment". 17th International Conference Reliability and Statistics in Transportation and Communication (RelStat'17), Springer, Lecture Notes in Networks and Systems.

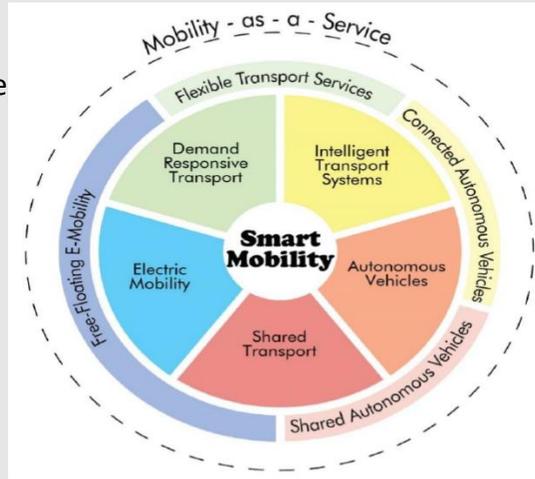


# 2. MaaS supply side orchestration

## Fleet management decisions

### Fleet composition in MaaS

- Public transport (metro, light rail, bus, water)
- Car-sharing
  - station-based / free floating
  - company owned / private owned
- Car rental
- Self-driving cars
- Taxis
  - regular
  - shared
  - on demand
- Bike-sharing



**Fleet management:** The fleet is heterogeneous with a mix of vehicle types, differing in capacity and costs. The fleet composition must be determined (type, number of vehicles per type, rules of use) with the objectives of maximising the service and minimizing total costs.

### Important decisions concern

- Fleet composition: MaaS partners
- Fleet management operations: MaaS partners & Operator
- Design of transport infrastructure: Public author.

Major challenges in the coordination of transport modes are (1) vehicle fleet optimization, (2) relocation strategies, (3) design the routing strategy for vehicles

Many fleet management problems are combinatorial optimization problems, such as vehicle routing and scheduling. Demand for services is not known beforehand and the fleet has to be deployed and managed (re-routed) in real-time. Applicable tools and concepts include those from graph and network algorithms, combinatorial optimization, approximation and online algorithms, stochastic and robust optimization.

Algorithms for the Vehicle Routing Problem include Dial-a-ride problem; Travelling salesman problem; Adaptive Memory Programming (AMP) (Repoussis and Tarantilis, 2010); Memetic algorithms (genetic algorithms hybridized with a local search) (Prins, 2009); Visual interactive approaches based on greedy randomised adaptive memory programming search (GRAMPS) algorithm (Tütüncü, 2010)

Bielli, M., Bielli, A., & Rossi, R. (2011). Trends in models and algorithms for fleet management. *Procedia-Social and Behavioral Sciences*, 20, 4-18.

## Fleet management in MaaS and the classical Vehicle Routing Problem (VRP) have several key differences

The classical VRP is concerned with optimizing the routing and scheduling of a set of vehicles to serve a set of customers. The objective is to minimize the total distance travelled or the total time taken, subject to constraints such as vehicle capacity and time windows for deliveries. In MaaS the challenges are more complex.

- *Coordinate a pool of transport modes*: In MaaS, fleet management involves managing a fleet of vehicles that are part of a larger transportation network that includes various modes of transportation such as buses, trains, and taxis. The objective is to optimize the use of the fleet to provide seamless, integrated transportation services to customers, including route planning, vehicle dispatch, and payment processing.
- *Adapt to volatile demand*: A key difference between MaaS fleet management and VRP is the level of uncertainty in the demand for transportation services. In VRP, the demand is typically known in advance, and the goal is to optimize the use of the fleet based on that demand. In MaaS, however, the demand is often uncertain and can vary depending on a variety of factors such as time of day, weather conditions, and events happening in the city. Therefore, MaaS fleet management must be able to quickly adapt to changes in demand and make real-time adjustments to the routing and scheduling of vehicles.
- *Customer experience*: In MaaS, the focus is on providing high-quality, personalized transportation services that meet the needs and preferences of individual customers. This requires a more flexible and customer-centric approach to fleet management than is typically used in VRP.
- *Differences between transport providers*: Integrate transport MaaS fleet management involves the integration of multiple modes of transportation, which requires coordination and collaboration between different transportation providers. This can be challenging, as each provider may have their own unique business practices, data formats, and technical systems.

## Areas of potential binary coupling

- **HI & CI:** Experts advise TSPs on fleet optimization and strategies
- **HI & MI:** Understanding mobility patterns. Expert awareness of alternative solutions, selection / design of algorithms. There is no certain metric to decide which algorithm to use for a given situation or dataset. Exploratory data analysis (EDA) is data analysis to bring out insights. [Massobrio, R., & Nesmachnow, S. \(2020\). Urban mobility data analysis for public transportation systems: a case study in Montevideo, Uruguay. \*Applied Sciences\*, 10\(16\), 5400.](#)
- **CI & CI:** Fleet composition and routing decisions made by TSPs based on decisions and competition from other partners [Bielli, M., Bielli, A., & Rossi, R. \(2011\).](#)
- **MI & CI (or HI):** Use of metaheuristic procedures to fleet management problems; algorithms designed to search for optimal or near-optimal solutions by iteratively exploring the solution space and improving on previous solutions (Simulated annealing, genetic algorithms, artificial neural networks, tabu search, ant colony optimization, Greedy Randomized Adaptive Search Procedure, Guided Local Search) [Marinakis, Y., Marinaki, M., & Dounias, G. \(2010\). A hybrid particle swarm optimization algorithm for the vehicle routing problem. \*Engineering Applications of Artificial Intelligence\*, 23\(4\), 463-472.](#)
- **CI & MI:** Use of data collected by users, analytics and algorithms for dynamic fleet management decisions by TSPs and MO in order to improve the real-time deployment of transport resources. [Bielli, M., Bielli, A., & Rossi, R. \(2011\). Trends in models and algorithms for fleet management. \*Procedia-Social and Behavioral Sciences\*, 20, 4-18.](#)
- **MI & HI:** Traffic management operators, having access to visualisation of dynamic traffic data (travel time, speed, traffic flow, etc.) and collecting information about scheduled events by network operators, are able to deploy interactive traffic management measures and optimize the traffic flow in the network. [Yang, C., Jiang, R., & Shibasaki, R. \(2022\). MaaS system visualization. In \*Big Data and Mobility as a Service\* \(pp. 245-263\). Elsevier.](#)

# 3. MaaS demand side orchestration

## Demand management & journey planning

### Demand management decisions

Strategies to influence commuting mode and user behaviour, increase the use of transport resources, most often by encouraging modal shifts from one transport mode to another. DM seeks to modify individuals' travel behaviour with incentives or restrictions ([Habibian and Kermanshah, 2011](#)).

**An experiment realised** in the Netherlands on DM measures and choice of MaaS transport mode found that (1) train and car-sharing features, (2) the mobility package price, and (3) the availability of parking are factors that influence user behaviour [Farahmand, Z. H., Gkiotsalitis, K., & Geurs, K. T. \(2021\). Mobility-as-a-Service as a transport demand management tool: A case study among employees in the Netherlands. \*Case Studies on Transport Policy\*, 9\(4\), 1615-1629.](#)

**Demand optimization** cannot be solved with exact methods in real-time systems considering the current computation power and the available solution procedures. The meta-heuristic procedures do not guarantee optimal solutions; they find sub-optimal solutions in a reasonable computation time. [Musolino, G., Rindone, C., & Vitetta, A. \(2022\). Models for supporting Mobility as a Service \(MaaS\) design. \*Smart Cities\*, 5\(1\), 206-222.](#)

DM is moving away from the four-steps modelling process (trip generation, trip distribution, mode choice, trip assignment) [Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharebaghi, S., Alonso González, M. J., & Narayan, J. \(2017\). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges.](#)

### Journey planning decisions made by users

Trip generation engine offering options by integrating different transport modes included in a MaaS, public transport, bike-sharing, car-sharing, taxis, car rental, ride-sharing,

[Georgakis, P., Almohammad, A., Bothos, E., Magoutas, B., Arnaoutaki, K., & Mentzas, G. \(2020\). Heuristic-based journey planner for Mobility as a Service \(MaaS\). \*Sustainability\*, 12\(23\), 10140.](#) Review algorithms for efficient routing (shortest path, graph-based, trip as a sequence of stops, multimodal journey by Analytical Hierarchy Process, etc.) and propose a journey planning scenario heuristic, composed of:

- a) API-based data for unimodal trips (Google, Here, OTP)
- b) Aggregation of unimodal trips and definition of routes, legs, steps
- c) Process of unimodal routes, ranking PT with TOPSIS
- d) Collect data using APIs of Mobility Service Providers for every trip request
- e) Geospatial profiling, finding interchange points for the integration of transport modes
- f) Generate isochrones to compare geospatial profiles using matrix of time & distance
- g) Scenarios of routes optimising journey segments
- h) Rank and filter routes, route recommender
- i) Complete recommended routes with data
- k-n) Invalid routes; Filter routes; Publish routes

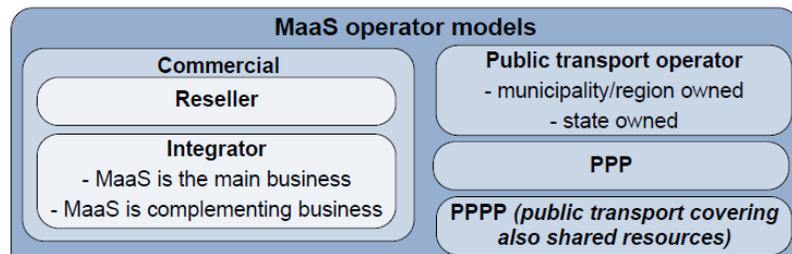
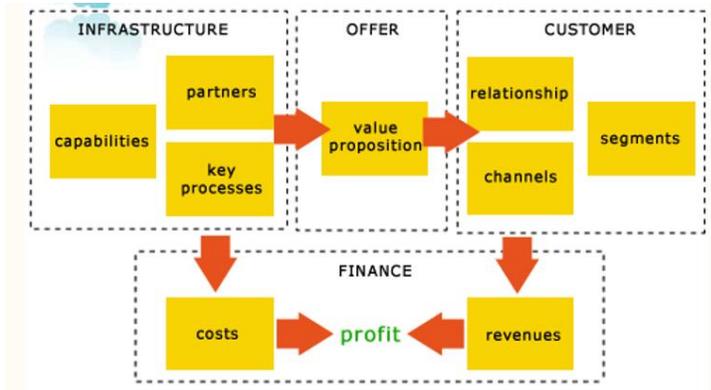
## Areas of potential binary coupling

- **MI & CI:** Journey planner with real-time information and dynamic integration of user generated data in the journey planner
- **MI & HI:** (1) Generation of routes based on the user subscription plan. (2) Redirection of a user prior to boarding. (3) Heuristic-based solutions for journey planning. Georgakis, P., Almohammad, A., Bothos, E., Magoutas, B., Arnaoutaki, K., & Mentzas, G. (2020). Heuristic-based journey planner for Mobility as a Service (MaaS). *Sustainability*, 12(23), 10140.
- **HI & MI:** Design of MaaS e-services, real-time info, trip planning, booking, ticketing, payment.
- **MI & CI:** (1) Smartphone data used to model and predict the sequence between activities and travel events in activity-based modelling of mobility. (2) User mode choice and satisfaction based on UbiGo data to reveal motives for adopting MaaS. Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges.
- **HI & CI:** Modelling of travel behaviour using models of choice and decision making under risk and uncertainty. Rasouli, S., & Timmermans, H. (2014). Applications of theories and models of choice and decision-making under conditions of uncertainty in travel behavior research. *Travel Behaviour and Society*, 1(3), 79-90.
- **CI & MI (or HI):** Study of changes in travel behaviour, choice of transport mode, and user satisfaction by collecting and analysing data from MaaS operators. Sochor, J., Strömberg, H., & Karlsson, I. M. (2015). Implementing mobility as a service: challenges in integrating user, commercial, and societal perspectives. *Transportation research record*, 2536(1), 1-9.
- **MI & CI:** Trip generation engines and recommender systems offering alternative trip options, according to specific criteria of optimisation (time, CO2) and users making the final choice. Sun, X., & Wandelt, S. (2021). Transportation mode choice behavior with recommender systems: A case study on Beijing. *Transportation research interdisciplinary perspectives*, 11, 100408.
- **CI & HI:** TSPs and MO analyse user data to identify patterns and behaviour models to be used as incentives for desired behaviours and disincentives for undesirable behaviours and shape demand with 'carrot and stick' rules. Carran-Fletcher, A., Joseph, C., Thomas, F., & Philbin, S. (2020). *Travel demand management: strategies and outcomes*. Waka Kotahi, NZ Transport Agency.

# 4. MaaS: Business model

“A **business model** describes the rationale of how an organization creates, delivers, and captures value”

Osterwalder, A. (2004). *The business model ontology a proposition in a design science approach* (Doctoral dissertation, Université de Lausanne, Faculté des hautes études commerciales).



Aapaoja, A., Eckhardt, J., & Nykänen, L. (2017, November). Business models for MaaS. In *1st International Conference on Mobility as a Service* (pp. 28-29).

## Key issues in MaaS business models

- **Bundles** of mobility grant the user a defined volume of access to each transport mode, offered at a price as subscriptions or as pay-as-you-go (offer)
- **Budgets** are about end-user preferences and service provision possibilities (demand conditions)
- **Brokers** are platforms connecting demanders of transport services and suppliers of transport modes

Ho, C. Q., Hensher, D. A., Mulley, C., & Wong, Y. Z. (2018). Potential uptake and willingness-to-pay for Mobility as a Service (MaaS): A stated choice study. *Transportation Research Part A: Policy and Practice*, 117, 302-318.

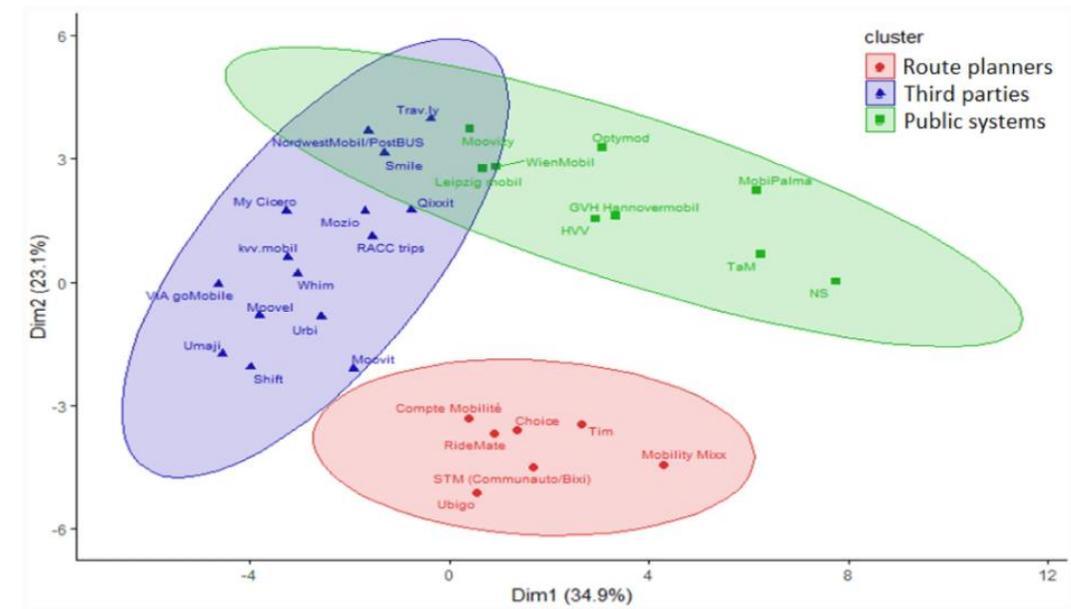
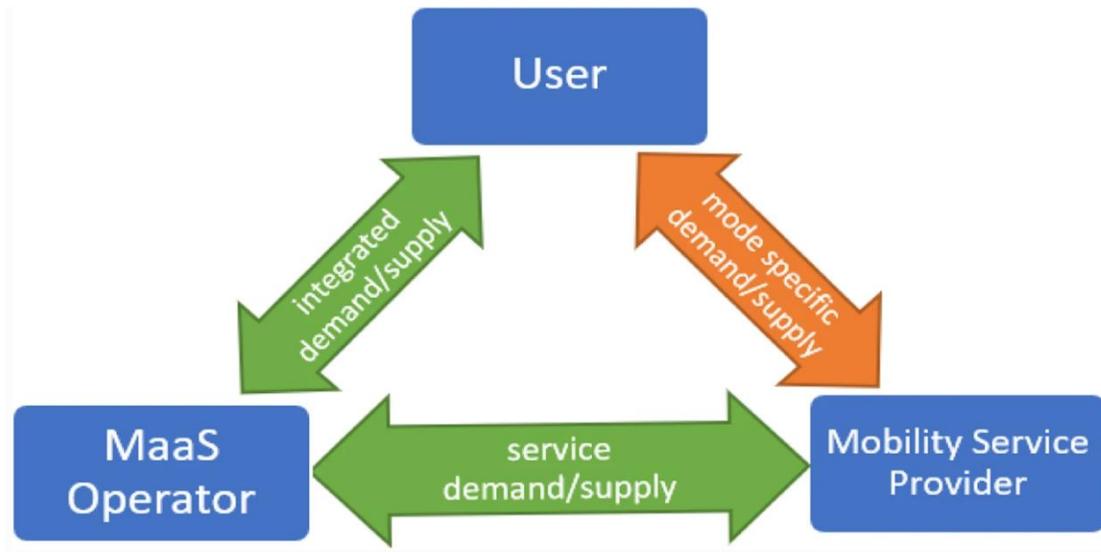
## Platform business models

- Getting a critical mass of users is a key problem of MaaS business model. It is described as a “chicken and egg problem” and is related to network effects of platforms: an increase in users leads to utility increases and more suppliers and services offered.
- MaaS and platform-based ecosystems must resolve the chicken and egg problem to survive. Consumers do not join a platform when there are no producers and vice versa. This problem is common to all platforms, and the key to overcoming it is to subsidize value at the starting stage of a platform. Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges.

## Areas of potential binary coupling

- **HI & CI:** Design by experts of MaaS subscription plans, using choice methods to reveal user preferences, to be adopted by MaaS Operators. Experts create packages to specify what kind of transportation modes are included, to what extent specific modes should be offered (Esztergár-Kiss, D., & Kerényi, T. (2020). Creation of mobility packages based on the MaaS concept. *Travel Behaviour and Society*, 21, 307-317.). Matyas, M., Kamargianni, M., 2019. The potential of mobility as a service bundles as a mobility management tool. *Transportation* 46 (5), 1951–1968.
- **HI & CI:** Practitioners try to drive commuters' choice of alternative modes of transport instead of their private cars, and motivate user demand through charges, taxes and parking fees (Karlsson et al., 2016).
- **MI & CI:** Use of GPS data to identify potential MaaS plans for substitution of car trips by sharing systems (Reck, D.J., Axhausen, K.W., 2020. How much of which mode? Using revealed preference data to design mobility as a service plans. *Transp. Res. record* 2674 (7),494–503.)
- **MI & HI:** Use of MaaS4EU application to collect and analyse travel data (Tsouros, I., Tsirimpa, A., Pagoni, I., & Polydoropoulou, A. (2021). MaaS users: Who they are and how much they are willing-to-pay. *Transportation Research Part A: Policy and Practice*, 148, 470-480.)
- **MI & HI:** digitalisation and e-services enable multimodal travel information and travellers can choose between different options, a platform allows intermodal journey planning and payment (Kamargianni et al., 2016).
- **HI & MI:** In the design of MaaS packages, experts select features of a city and features of travel conditions and use data from large databases (Numbeo, Eurostat, TomTom traffic index, weather data, etc.) which are combined in mobility packages according to mobility modes offered by a MaaS system.
- **CI & MI:** With the creation of user groups, specific travel-related and personalized requirements analysed can be taken into account, when creating mobility packages. Esztergár-Kiss, D., & Kerényi, T. (2020).
- **CI & CI (or HI):** Survey in Greater Manchester on behalf of Transport for Greater Manchester, the responders constructed their ideal MaaS package and allocated a specific price. Use of multinomial logit model to estimate the probability of preferences. (Tsouros, I., Tsirimpa, A., Pagoni, I., & Polydoropoulou, A. (2021).

# 5. MaaS: Integration



Route planners	Third parties	Public systems
Solely route planning was integrated into the services, while payment was usually handled separately. This means that the payment solutions were not implemented in the applications, travel-related transactions could be made via a smart card.	The second group was the most diverse considering most features of the services. Services ranging from non-payment to mobility packages were available. Their common feature was the third party involvement.	The third cluster was characterized by the applications operated by public transport providers or local authorities, usually including ticketing for public transport, while for other transportation modes, the user could get information

## Integration and fuzziness of the MaaS concept

- **Integration through an Integrator:** The Mobility Platform Operator (=MaaS)
- **Integration without Integrator:** De facto cooperation of TSPs. The user establishes connections. The city and the physical proximity between transport modes work as integrator (#MaaS)

### Are both MaaS? No.

MaaS is “a mobility distribution model in which customer’s major transportation needs are met over one interface and are offered by a service provider” (Hietanen, 2014).

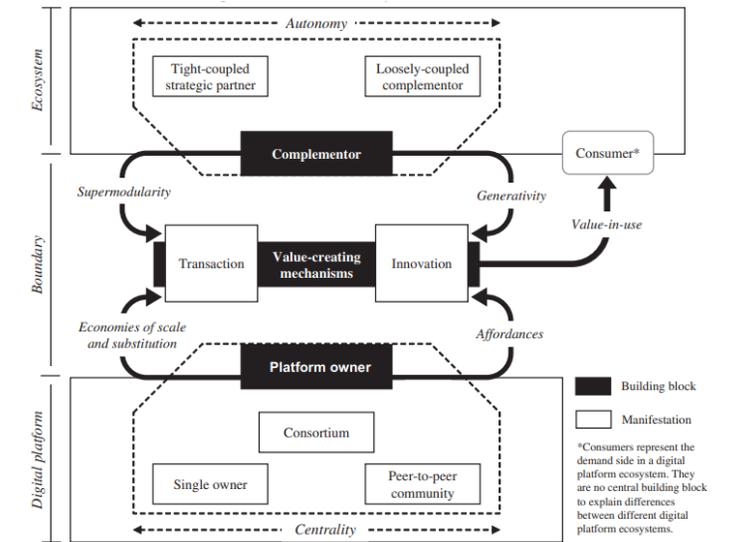
## Areas of potential coupling

**HI & MI** (experts design using software tools and algorithms), **HI & CI** (expert and TPS work together on fleet optimisation or demand incentives), **CI & CI** (collaboration agreements between TSPs, integration of MaaS ecosystem), **CI & MI** (data sharing and analytics), **MI & CI** (reveal demand patterns to optimise fleet)

## Integration in MaaS

- Integration levels: (L1) integration of information, (L2) booking and payment, (L3) service offers, (L4) societal goals
- Common services and information exchange between TSP, Users, MO.
- Data interoperability among MaaS service providers
- The central role of MaaS Operator. Private or public. It is uncertain whether public or private MaaS operators will dominate the market [Esztergár-Kiss, D., Kerényi, T., Mátrai, T., & Aba, A. \(2020\). Exploring the MaaS market with systematic analysis. \*European Transport Research Review\*, 12\(1\), 1-16](#)

## Integration in platform-ecosystems – three blocks



Hein, A., Schreieck, M., Riasanow, T., Setzke, D. S., Wiesche, M., Böhm, M., & Krcmar, H. (2020). Digital platform ecosystems. *Electronic Markets*, 30, 87-98.

Helfat, C. E., & Raubitschek, R. S. (2018). Dynamic and integrative capabilities for profiting from innovation in digital platform-based ecosystems. *Research policy*, 47(8), 1391-1399

# Binary coupling identified in the MaaS literature

Potential binary coupling areas	IQ-IQ	IQ & CQ	IQ & MQ	CQ & CQ	CQ & IQ	CQ & MQ	MQ & MQ	MQ & IQ	MQ & CQ
Ecosystem and platform planning									
Supply side orchestration									
Demand side orchestration									
Business model									
Integration									

In case of many TSP s

Types of coupling	Areas of coupling	MaaS Operators
<ul style="list-style-type: none"> <li>• <b>HI related:</b> expert design of services and bundles</li> <li>• <b>CI related:</b> TPS agreements, crowdsourcing data</li> <li>• <b>MI related:</b> Data analytics, decision support systems, prediction algorithms, recommender systems, data visualization</li> </ul>	<ul style="list-style-type: none"> <li>• <b>High:</b> MI related</li> <li>• <b>Middle:</b> CI related</li> <li>• <b>None:</b> HI-HI, MI-MI</li> </ul>	<ul style="list-style-type: none"> <li>• Do they deploy connected intel coupling</li> <li>• What types and areas</li> <li>• Do they implement successive coupling, such as (xI &amp; yI) &amp; zI</li> <li>• <b>NEED FOR A SURVEY</b></li> </ul>

## 4. Conclusion: Binary coupling and MaaS innovation

# MaaS challenges & new trends: An extremely complex environment

- 1. Promote MaaS as platform-based distributed ecosystem** having many TSPs, open to inclusion of new partners and services, under a user driven perspective
- 2. Integration of micro-mobility:** e-scooters and e-bikes are becoming increasingly popular in urban areas. MaaS providers are integrating these options into their platforms, providing users with a wider range of transportation choices.
- 3. Integration of autonomous vehicles:** As autonomous vehicles become more widespread, MaaS providers are exploring ways to integrate them into their platforms.
- 4. Shared mobility optimization:** provide carpooling and ride-sharing, by matching users with similar travel routes or preferences. This can reduce the number of vehicles on the road, reduce traffic congestion, and decrease emissions.
- 5. Real-time traffic management:** Data from multiple sources, including human inputs, can be collected and analyzed to optimize traffic flow. For example, if a large number of people report congestion on a particular route through a MaaS platform, the platform can reroute other vehicles to avoid the area.
- 6. Personalized recommendations:** By analyzing user data and preferences, personalized recommendations for transportation options can best fit the user's needs.
- 7. Dynamic pricing:** By analyzing data on supply and demand, dynamic pricing for transportation services can be offered. Encourage users to choose less congested routes or travel at off-peak times, ultimately reducing traffic congestion and improving overall efficiency.
- 8. Focus on sustainability:** As environmental concerns continue to grow, MaaS providers are placing a greater emphasis on sustainability. This includes incorporating low-emission vehicles, promoting walking and cycling, and supporting public transportation options.

# (1) Design of new services using properties of HI, CI, MI

## *Introduce binary coupling in the MaaS ontology - Create new service ideas*

### MaaS ontology

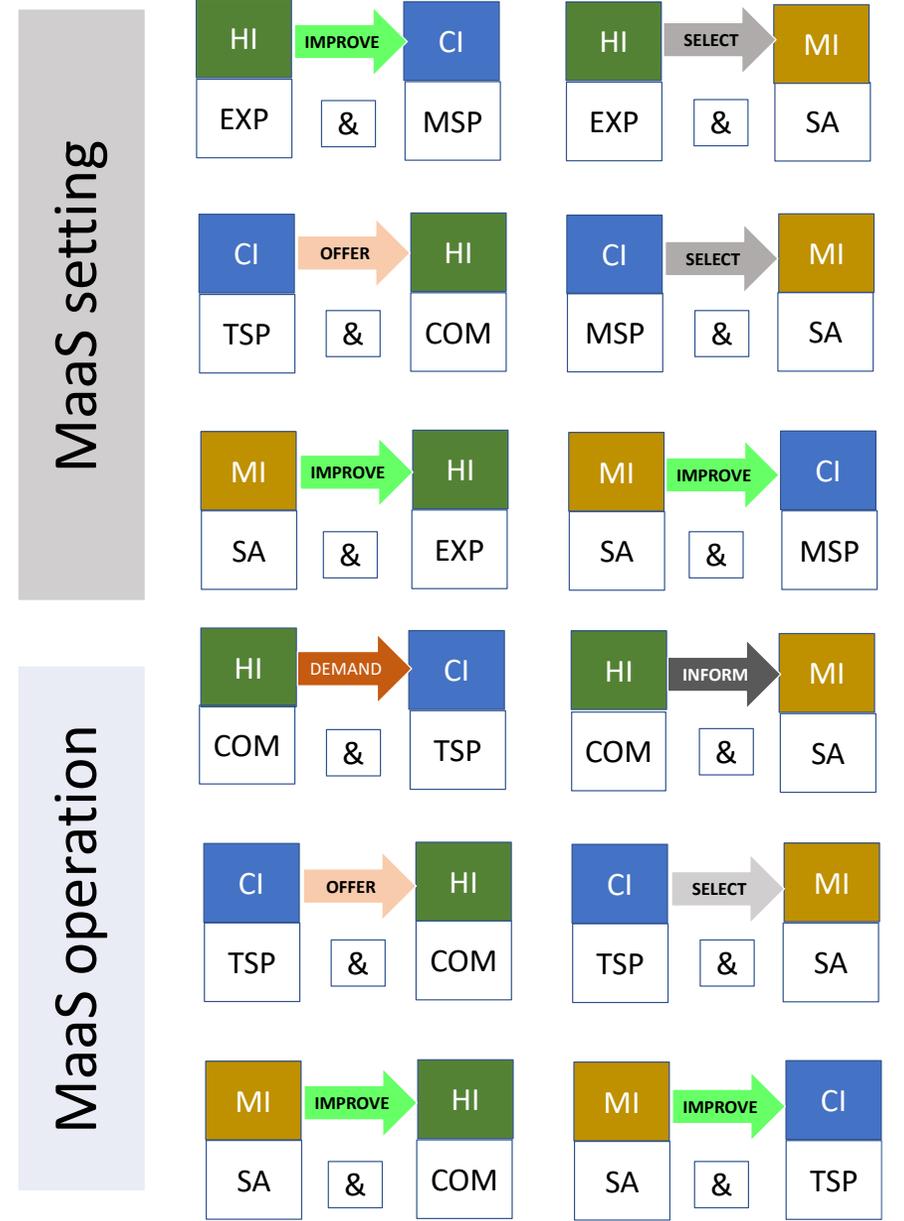
- **Agents:** Commuter (COM), Expert (EXP), Crowd (CRW) Transport Service Provider (TSP), MaaS Operator (MO), Software Agent (SA)
- **Transport modes:** PT, car sharing, bike sharing, taxis, etc.
- **E-services:** Journey planner, information, ticketing, payment, etc.
- **Subscription:** Bundle, Pay-as-you-Go, other
- **Stops:** Bus, train, bike, taxi, car rental
- **Parking:** Car parking, bike parking
- **Object properties:** between Agents, between Agents and Transport modes, between TM and E-services
- **Data properties:** number of commuters, % of users, equivalent car travels, travel time, investment cost

### Redefine / simplify the MaaS ontology with HI-CI-MI coupling

- Classes: HI = {COM, EXP}, CI = {TSP, MO, CRW}, MI = {SA}
- COM / EXP has HI, TSP / MO / CRW has CI, SA has MI
- Object properties hierarchy: inform, improve, innovate, select, design, offer, demand
- Datatype properties: HI-CI {cost, com}, HI-MI {cost, time}, CI-HI {time}, CI-MI {cost}, MI-HI {time}, MI-CI {cost}

### Generate ideas for new services

- Based on HI, CI, MI coupling
- Based on xl and (yl & zl) coupling
- Based on coupling (xl & yl) and coupling (xl & zl)



**Question to ChatGTP-4:** if HI=human intelligence, CI=collective intelligence, and MI=machine intelligence, give me an example of a non existing (HI & CI) & MI in a new service of Mobility as a Service

- **ChatGTP-4:** In the context of Mobility as a Service (MaaS), a non-existing example of HI (human intelligence) combined with CI (collective intelligence) and MI (machine intelligence) could be an "Intelligent Crowdsourced Commute Optimization Platform" (IC-COP). This platform would utilize human insights, machine learning algorithms, and data from various sources to create optimal travel routes for individual users. IC-COP would work as follows:
  1. Human Intelligence (HI): Users of the platform would share their daily commuting preferences, experiences, and suggestions for alternative routes and modes of transportation. This information would be used to generate data points for the platform to analyze and learn from.
  2. Collective Intelligence (CI): The platform would aggregate the commuting data shared by users and analyze it to identify patterns and trends in user behavior, preferences, and travel times. This analysis would help the platform make better-informed decisions on the best routes and transportation modes for users.
  3. Machine Intelligence (MI): The platform would use machine learning algorithms to continuously learn from the data points generated by HI and CI. These algorithms would analyze the data and adapt to changing conditions in real-time, generating personalized travel plans for each user based on their preferences and the current state of the transportation network.
- As a result, IC-COP would create an ever-evolving, data-driven platform that offers optimal commute options by combining the strengths of human intelligence, collective intelligence, and machine intelligence. However, this service does not currently exist in the Mobility as a Service industry.



# (2) Binary coupling & optimisation of MaaS processes and services

**The classic dichotomy in city planning, state vs. market,** is translated in MaaS as dichotomy between monolithic vs distributed systems.

Fedeli, P. M. B. V. (2012) *Urban Planning between State and Market: a possible alliance?*

Alexander, E. R. (2008). *Between state and market: A third way of planning. International Planning Studies, 13(2), 119-132.*

## **MaaS as open distributed ecosystem:** Optimisation through Agent Based Modelling

- Interactions among TSPs, emerging properties
- Assessment of scenarios of fleet change, demand measures, and business models

### Precondition of ABM

- Medium number of agents
- Heterogeneity of agents
- Local interactions
- Rich environment of interactions
- Time, sequence of actions
- Adaptation of behaviour

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo.* MIT Press.

- **Monolithic MaaS:** Integration based on agency / public authority. All transport modes under one providers and owner
- **Distributed MaaS:** Integration through market exchanges

MaaS objectives, means, and measures should align with this initial condition

## **MaaS as a closed ecosystem:** Optimisation through multicriteria analysis

- Identification of areas of HI-CI-MI coupling
- Estimation of improvements due to coupling, performance data
- Multicriteria analysis (MCA), or multicriteria decision making (MCDM) to identify combination of improvement measures within constraints
- Optimize commuter volume per Transport Mode and travel time withing constraints of investment

# (3) Binary coupling & design MaaS under bounded rationality

*Consider the limitations*

Decisions initiating from HI	Decisions initiating from CI	Decisions initiating from MI
<ul style="list-style-type: none"><li>• Black box of human choices</li><li>• Fast, intuitive, emotional thinking (S1)</li><li>• Intention of attention and selective data capture</li><li>• Limited memory</li><li>• Cognitive lock-in (can't teach an old dog new tricks) <a href="#">Murray, K. B., &amp; Häubl, G. (2007). Explaining cognitive lock-in: The role of skill-based habits of use in consumer choice. <i>Journal of Consumer Research</i>, 34(1), 77-88.</a></li></ul>	<ul style="list-style-type: none"><li>• Diverting agendas of partner organisations</li><li>• Organisations' power and hierarchy distort optimisation</li><li>• Public infrastructure monopoly</li><li>• Lock-in in dominant discourse (unchallenged assumptions, incumbents' discursive agency, and narrative co-potation) <a href="#">Simoens, M. C., Fuenfschilling, L., &amp; Leipold, S. (2022). Discursive dynamics and lock-ins in socio-technical systems: an overview and a way forward. <i>Sustainability Science</i>, 17(5), 1841-1853.</a></li></ul>	<ul style="list-style-type: none"><li>• Variable effectiveness of algorithms</li><li>• Local optima</li><li>• Transparency of algorithm</li><li>• Unrealistic assumptions</li><li>• Biased logic</li><li>• Ceteris paribus</li><li>• Computing time</li><li>• Bias due to training data</li></ul>
<p><i>A system of choices based on the wiring of the brain (unknown) &amp; mobility routines (known)</i></p>	<p><i>A system of choices based on partners' agendas (known and unknown)</i></p>	<p><i>A transparent system based on algorithms and data (from a non-optimal system)</i></p>

## Design HI related couplings

### Final choice always to humans

HI-MI should offer multiple options than the best option. Which is the best option for HI?

See below “**the control problem**”

## Design CI related couplings

### Collective intelligence organizes

the MaaS system. HI and MI are deployed within frameworks set by CI

**Improve CI with user engagement**

**Extend collaborative decision**

**making** among stakeholders in the transportation system

## Design MI related couplings

### MI drives rational choice

- Reveal all possible outcomes
- Set hierarchies with Utility estimations of alternative outcomes

$$L = \begin{pmatrix} o_1 & o_2 & \dots & o_m \\ p_1 & p_2 & \dots & p_m \end{pmatrix}$$

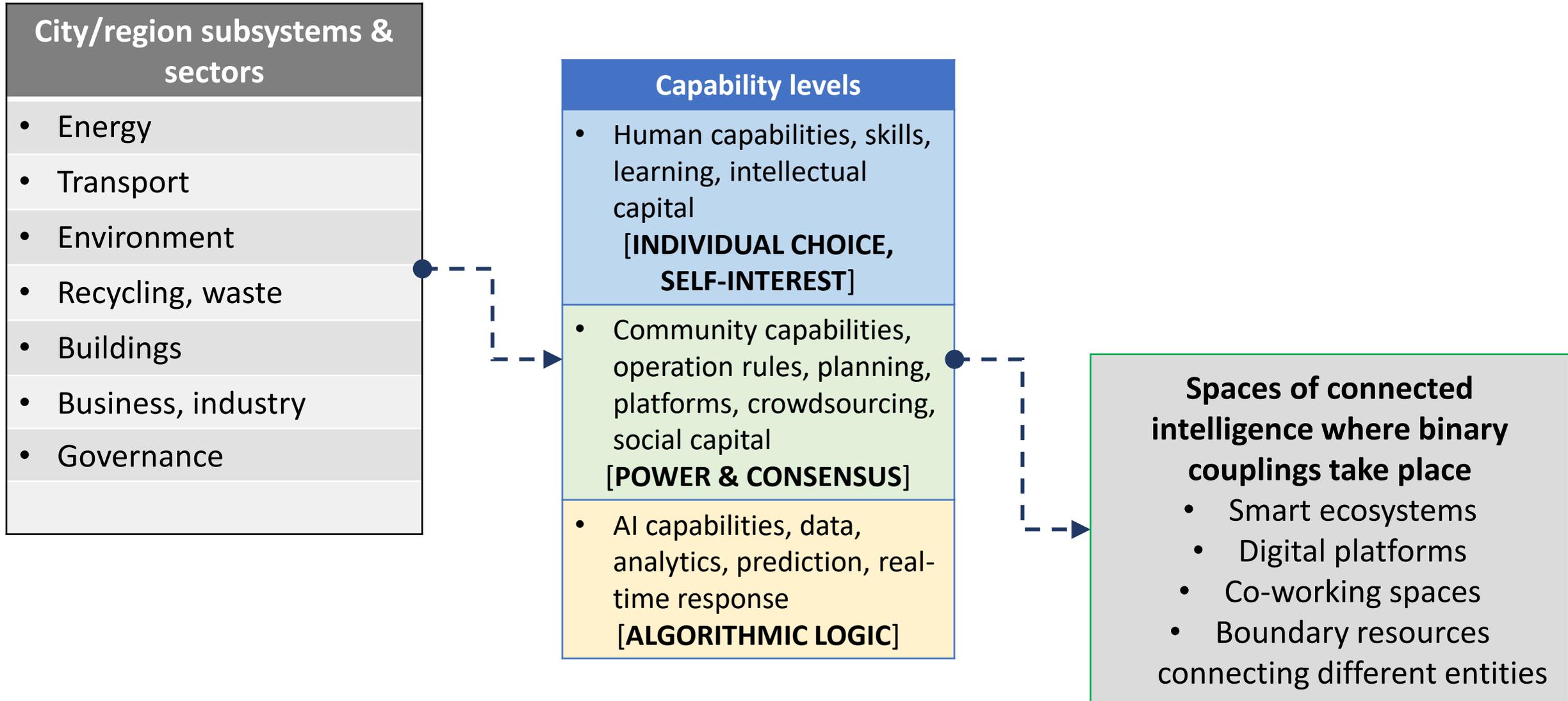
$$\mathbb{E}[U(L)] = p_1U(o_1) + p_2U(o_2) + \dots + p_mU(o_m)$$

Zerilli, J., Knott, A., Maclaurin, J., & Gavaghan, C. (2019) call it

- “**The control problem**”: a tendency of the human within a human–machine control loop to become complacent, over-reliant or unduly diffident when faced with the outputs of a reliable autonomous system
- Except in certain special circumstances, **algorithmic decision tools should not be used in high-stakes or safety-critical decisions** unless the systems concerned are significantly “better than human” in the relevant domain or subdomain of decision-making
- They recommend three strategies to address the control problem, the most promising of which involves a **complementary (and potentially dynamic) coupling** between highly proficient algorithmic tools and human agents working alongside one another.

Zerilli, J., Knott, A., Maclaurin, J., & Gavaghan, C. (2019). Algorithmic decision-making and the control problem. *Minds and Machines*, 29, 555-578.

# A broader lesson: Connected intelligence through spaces where HI-CI-MI couplings occur





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