0-6803-01-P3

CRITICAL EMERGING TECHNOLOGIES (PRELIMINARY ANALYSIS)

Authors:
Jia Li
Andrea Hall
Kristie Chin
C. M. Walton

TxDOT Project 0-6803-01: Texas Technology Task Force (TTTF)

MARCH 2015; PUBLISHED NOVEMBER 2015

Performing Organization:	**Sponsoring Organization:**
Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, Texas 78701	Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080
Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.	

1. Introduction

This report builds on a preceding report titled *Emerging Transportation Technology Portfolio* (0-6803-01-P2), and like the preceding report is completed for the Texas Technology Task Force (TTTF). The prior report outlines a full portfolio, describing emerging technologies with transportation applications that industry experts have deemed transformative in nature.

The portfolio is the product of Step 1 in a three-step process for researching and identifying some of the most critical technologies for Texas to pursue. This report builds on Step 1 and focuses on the application of a proposed framework by the Task Force research team. Observations from the applied framework (provided in Section 3) are intended to serve as preliminary results, highlighting the most critical of technologies from the full portfolio.

Since transportation systems are complex and embody varying goals and barriers across various modes and user groups, a multidimensional evaluation framework is needed to understand how technologies could impact the system across multiple dimensions. At a minimum, assessing the performance of transportation systems requires consideration of the safety, mobility, and environmental dimensions, among others. Further, measurable and quantifiable indicators are needed along each dimension. The remainder of this report focuses on outlining a framework that allows for the analysis of a technology across multiple dimensions and present results from step 2.

2. Portfolio Development and Management

The three-step technology portfolio development and management process is described in Sections 2.1 through 2.3.

2.1. Step 1—Technology Identification: In this step, subgroup interviews with the Task Force members and literature surveys were conducted in parallel. The interview questions and direction of the literature survey were periodically updated based on each other's inputs. The output of this step was the full, initial technology portfolio. A summary of technologies in the portfolio is provided below (see 0-6803-01-P2, *Emerging Transportation Technology Portfolio*, for full descriptions of technologies).

> ***Autonomous Vehicles,*** which may include specific applications in the following areas: autonomous freight technology, platoons, and pilots; personal autonomous vehicles including neighborhood/low speed and non-neighborhood vehicles; commercial uses (taxis); and autonomous parking in urban cores. For the evaluation process, these are broken into two categories: levels one and two automation and levels three and four automation.
>
> ***Connected Vehicles (CV).*** For the ranking process, these technologies are broken into two categories: vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). This includes current and prospective applications, trials and, pilots; V2I implementation/ wrong-way driver detection; and studies of human behavior and driver interfaces with CV applications.

Electric Vehicles and Systems, including smart highways, solar highways, or roadway energy storage and transmission; battery technology; distributed nuclear energy; alternative fuels, inductive charging, or wireless energy transfer; DC fast charging systems, and smart grids.

Unmanned Aerial Vehicles (UAV), including surveillance applications and logistics.

Information and communication technologies, including ***cloud computing*** with big data, distribution, and analysis (automotive cloud), and super-fast computing for V2I, and ***crowdsourcing,*** including smartphone applications and surveillance or emergency management examples and applications.

Infrastructure and construction technologies, including infrastructure enhancements, such as fiber optics and ITS technologies, and construction techniques and equipment, including truss sliding and vacuum consolidation.

Materials, including self-healing pavements and nanotechnologies.

Additive manufacturing for vehicles and infrastructure (***3D printing***).

Service-based technologies, which are divided into ***location-based services*** (including ridesharing and social networking applications for transportation) and ***transportation subscription services*** (including shared vehicle fleets).

These technologies are carried forward into Step 2, described in the next section.

2.2. Step 2—Technology Assessment: Upon the completion of expert interviews described in Step 1, an initial technology list was generated, which became the initial technology portfolio. Step 2 was designed to assess individual technologies, providing a basis for comprehensive evaluation when selecting preliminary critical technologies for further inspection. The assessment focuses on four primary dimensions:

- **Strategic Goal Alignment:** Ability to meet or further national and state transportation goals, which mainly pertain to safety, congestion, and the environment.
- **Deployment Barriers:** Presence of barriers to adoption and implementation, which include the regulatory, cost-efficiency, and safety aspects.
- **Mode-Specific System Enhancement**: Ability of technology to improve transportation in different modes, encompassing highway traffic, bicycle/pedestrian, freight, transit, aviation, port, etc.
- **User Group Enhancement:** Ability of a technology to enhance or improve transportation user group experience. User groups will closely align with trip purpose and mode combinations. For example, passenger vehicle travel for home-based work trips may use technologies differently than passenger vehicle trips for leisure travel, or interregional freight travel may receive different benefits from a particular technology than intraregional freight travel will.

For each evaluation, each research team member was asked to rank technologies in a matrix of technologies across columns against each evaluation dimension (rows) on a scale from zero to five. Each integer on the ordinal scale corresponded to each individual's belief about how each dimension represents each technology, with lower values indicating less relevance in a dimension and higher values indicating more relevance. For example, when considering the benefits that lower levels of vehicle automation could have on travel, a rank of zero would indicate no benefit and a rank of five would indicate a monumental impact on travel. A full summary of the assessments along these four dimensions and corresponding factors considered are listed in Tables 1a–d. After individual rankings, results from each team member are to be combined to form one final set of evaluation matrices to reflect the consensus of the team.

The final combined rankings will be used to inform a trade-offs analysis to compare technologies along common dimensions. The final evaluation in this step (radar chart) allows for the assessment and comparison of technologies along various dimensions so that a final set of critical technologies may be chosen for further analysis in subsequent steps. The area that each technology covers (area score) on the radar chart is calculated help identify critical technologies. A diagram of this full ranking and combining process is shown in Figure 1.

Table 1a: Factors in ranking considerations for goals evaluation

Proposal Goal	Factor Consideration
Economic development	• Quantity and quality of jobs directly created in Texas
Safety	• Crash frequency reduction • Crash severity reduction
Congestion	• Decreased hours of congested travel • Improved traffic flows during congestion • Improved travel time reliability
Connect Texas communities	• Enhanced access to goods and services • Increased Texas gross state product • Public relations and dissemination of information to Texas communities
Best-in-class agency	• Agency able to deploy resources more efficiently
Infrastructure condition	• Direct improvement to infrastructure condition • Indirect improvement to infrastructure condition
System reliability	• Improved system efficiency
Environmental sustainability	• Reduced fuel and energy consumption • Reduced air pollutant emissions, to meet EPA standards
Reduce project delivery	• Reduced project delivery delays due to shortened time during construction

Table 1b: Factors in ranking considerations for barriers evaluation

Proposal Issues & Concern	Factor Consideration
Institutional	• Internal public transportation agencies changes • Potential new agency positions and duties • Technology standardization and coordination • Cross-agency and private institution collaboration
Infrastructure	• Extent of new infrastructure required • Existing infrastructure repurposed
Regulatory	• Legislative regulatory changes (may be helpful or necessary) Administrative regulatory changes (may be helpful or necessary)
Policy	• Public agency direction and support
Cost, public	• Direct public agency costs
Safety	• New crashes or incidents otherwise avoidable • Increased crash or incident severity • Electronic security vulnerabilities
Energy	• Energy consumption of new technology greater than potential savings
Public concerns	• Disparate impacts across income groups • Privacy concerns Neighborhood concerns • Other non-safety or energy concerns
Cost, private	• Consumer technology purchase costs • Corporate technology development costs
Time (develop & deploy)	• Timeframe required to complete phase after entering
Technology	• Technical barriers technology development

Table 1c: Factors in ranking considerations for modal enhancement evaluation

Mode	Factor Consideration
Surface transportation **Transit** **Freight** **Ports, waterways** **Air/aviation**	• Increased safety • Increased mobility • Decreased cost on system • Operations and maintenance benefits

Table 1d: Factors in ranking considerations for user group enhancement evaluation

Mode	Factor Consideration
Freight (interregional) **Freight (intraregional)** **Personal (commute)** **Personal (recreational)** **Emergency** **School/students**	• Increased safety • Increased mobility • Decreased cost on system • Operations and maintenance benefits

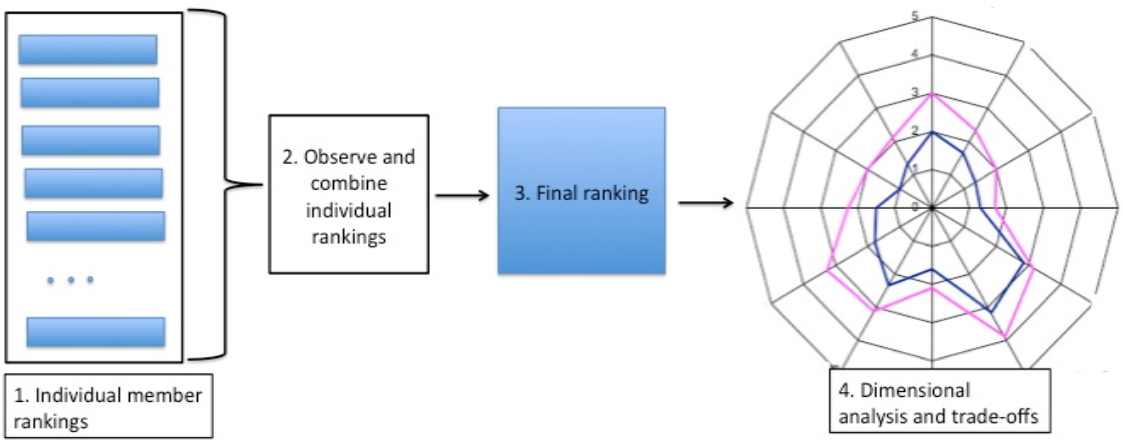


Figure 1: Overview of technology assessment

Step 2.3. Step 3—Portfolio Assessment: This third and final step, which will be carried out during the next stage with the help of the TTTF, will more rigorously assess the technologies and build on Step 2. Due to resource limitations, agencies need to strategically allocate the available resources to technologies under consideration. As a final step, a comprehensive portfolio assessment framework will be used to gain a deeper, more technical understanding of the technologies. The key difference between this step and the previous ones lies in a more comprehensive perspective—based on the current and forecast attributes of individual technologies, we consider the technology life cycle; short- and long-term institutional, technological, and economic uncertainties; and the synergy of technologies. To be specific, we will examine these facets:

- **Technology Life Cycle:** This analysis will provide a better understanding of the development phases and trajectory of technologies, and highlight opportunities for synergy. Life cycle curves will be used to visualize the evolution phases of technologies.
- **Scenario Generation:** The team will forecast possible technology adoption scenarios for the analysis of portfolio benefits in terms of safety, congestion, and environmental issues.
- **Technology Synergy:** This analysis will formally investigate the synergy effect that can be realized by pairing technologies. The possibility of synergy and potential benefits will be analyzed together.
- **Performance Metrics:** Different portfolios will be compared to select and prioritize individual technologies within the portfolio. Three sub-steps will be taken:
    - Convene the Task Force and use a Delphi-like process to further rank the technology portfolio and obtain feedback from TTTF members.
    - Combine input from individual Task Force members to support development of the critical list.
    - Select technologies based on highest rankings among technology-dimension intersections weighed against Task Force member input.

The above steps constitute a tentative evaluation framework to apply to the technologies in the portfolio and is intended to be illustrative, as it will be refined continuously based on Task Force guidance.

3. Observations from Application of Step Two: Technology Evaluation

Figure 2 presents the ranking matrices, while Figure 3 displays the results of the combined rankings.

Observations on strategic goal alignment

For each of the technologies on the radar chart, the total area was calculated such that technologies that align more closely with goals would have larger coverage areas. The total area (area score) is shown in the final row of each matrix. The technologies with the highest area score were ***V2I technologies*** (47.7), ***cloud computing*** (48.4), ***crowd sourcing*** (40.3), ***location-based services*** (32.9), and ***transportation subscription services*** (40.0), **(**perhaps ***automation levels three and four*** (32.2) could be included). Electric systems technologies show the lowest alignment with goals overall, although they ranked the highest in the environmental sustainability dimension.

Observations on deployment barriers

To minimize barriers for transformative technologies, those with low area scores are highlighted in Figure 2's result depictions. The lowest scores were for ***automation levels one and two*** (10.3), ***crowd sourcing*** (14.5), ***materials*** (18.7), ***transportation subscription services*** (19.8), and ***V2V technologies*** (19.1). Note that crowd sourcing, transportation subscription services, and location-based services showed high goal alignment and simultaneously low barrier to implementation. In addition, technologies that are less transformational and unlike any existing technology have higher barriers to overcome, whereas technologies with marginal enhancements over existing ones face lowers barriers to adoption and diffusion.

Observations on mode-specific system enhancements

Results from the modal enhancement analysis show that ***automation of all levels***, CVs (***V2V and V2I***), and ***cloud computing*** provide the most benefit across modes with area scores as follows: automation levels one and two (31.5), automation levels three and four (37.5), V2I (31.5), V2V (37.5), cloud computing (34.3). For surface transportation, location-based services and transportation subscription services would also greatly enhance travel. For transit, the same is true. For freight, automation and CVs showed the most enhancements along with the diffusion of 3D printing, which could have great impact on freight travel. For ports and waterways, the greatest enhancements could come from automation levels three and four, V2I technologies, cloud computing, and infrastructure and construction enhancements. Finally, the single largest impact on air and aviation likely arises from the use of UAVs/drones.

Observations on user group enhancements

Results of the user group enhancement rankings show that all levels of ***automation, CVs, cloud computing, crowd sourcing, and location-based services*** have the greatest ability to enhance travel across user groups with area scores as follows: automation levels one and two (36.8), automation levels three and four (49.5), V2I (33.6), V2V (46.0), cloud computing (31.1), crowd sourcing (34.6), and location-based services (31.8).

Overall, the most critical technologies in terms of alignment with goals, minimized barriers to adoption and diffusion and enhancements across modes and users were those that fall into ***autonomous vehicles***, ***connected vehicles, information and communication***, and ***service-based technologies***.

Ratings 0-5: 0 = Does not address goal, 5 = Disruptively beneficial solution

		Autonomous Vehicles		Connected Vehicles				Information and Communication						
Goals		A1/A2	A3/A4	V2I	V2V	Elec. Sys	UAVs	Cloud Comp.	Croud Sourcing	Infrastra. & Const. Enhance	Materials	3D Printing	Location Based Services	Transp. Subscription services
Texas Goals	Safety	5	5	5	5	1	2	4	4	3	4	3	3	3
	Congestion	2	4	4	4	1	3	4	5	3	2	3	4	5
	Connect TX communities	2	4	3	4	1	3	5	4	2	1	3	5	5
	Best in class agency	3	4	5	3	2	3	5	4	3	4	3	4	4
Other National Goals	Infrastructure condition	3	2	5	2	2	5	4	4	5	5	3	2	2
	System reliability	3	3	4	4	1	4	4	4	4	4	3	3	4
	Environmental sustain.	3	3	4	3	5	3	4	3	3	4	3	3	4
	Reduce proj. delivery	2	2	3	2	2	3	3	2	3	2	4	3	3
Area Score		22.3	32.2	47.7	31.8	9.5	30.4	48.4	40.3	30.4	30.4	27.6	32.9	40.0

Ratings 0-5: 0 = No Barrier, 5 = Barrier likely insurmountable in

	Autonomous Vehicles		Connected Vehicles				Information and Communication						
Barriers	A1/A2	A3/A4	V2I	V2V	Elec. Sys	UAVs	Cloud Comp.	Croud Sourcing	Infrastra. & Const. Enhance	Materials	3D Printing	Location Based Services	Transp. Subscription services
Institutional	1	4	3	2	2	4	2	2	3	2	3	3	3
Infrastructure	1	4	3	2	3	2	3	1	3	3	2	2	2
Regulatory	2	4	2	3	2	5	3	3	1	1	4	4	3
Policy	2	4	3	2	2	4	3	3	3	2	3	4	4
Cost, public	4	2	3	2	4	1	3	2	4	4	4	2	2
Safety	2	4	3	4	2	4	2	2	1	2	2	2	2
Energy	1	1	2	1	3	1	1	1	3	1	1	1	1
Public concern	1	4	3	4	2	5	3	3	2	2	2	2	2
Time (develop and deploy)	1	4	2	3	3	3	2	2	3	4	3	2	2
Technology	1	4	1	2	4	2	2	2	2	3	3	2	2
Area Score	10.3	42.4	24.4	19.1	23.0	31.5	21.2	14.5	21.6	18.7	25.1	21.9	19.8

Ratings 0-5: 0 = No benefit to mode, 5 = Greatly benefits travel/operations on mode

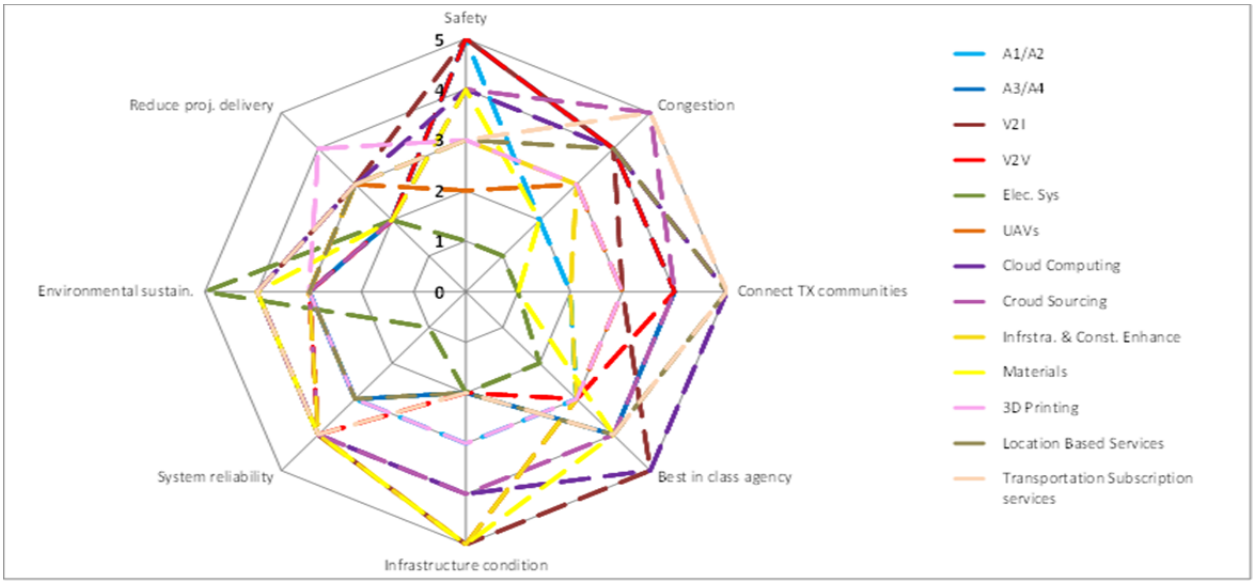
	Autonomous Vehicles		Connected Vehicles				Information and Communication						
Modal Enhancements	A1/A2	A3/A4	V2I	V2V	Elec. Sys	UAVs	Cloud Computing	Croud Sourcing	Infrstra. & Const. Enhance	Materials	3D Printing	Location Based Services	Transportation Subscription services
Surface Transportation	5	5	5	5	3	3	5	5	4	5	3	5	5
Transit	5	5	5	5	5	2	5	4	4	2	2	4	4
Freight	5	5	5	5	3	4	4	4	4	4	5	3	1
Ports, Marine, Waterways	3	4	3	4	1	2	4	2	4	3	3	1	2
Air/Aviation	3	4	3	4	2	5	4	1	4	2	2	1	2
Area Score	31.5	37.5	31.5	37.5	14.5	16.6	34.3	18.0	28.3	16.3	15.2	14.5	14.1

Ratings 0-5: 0 = No benefit to user group, 5 = Greatly benefits travel/operations for user group

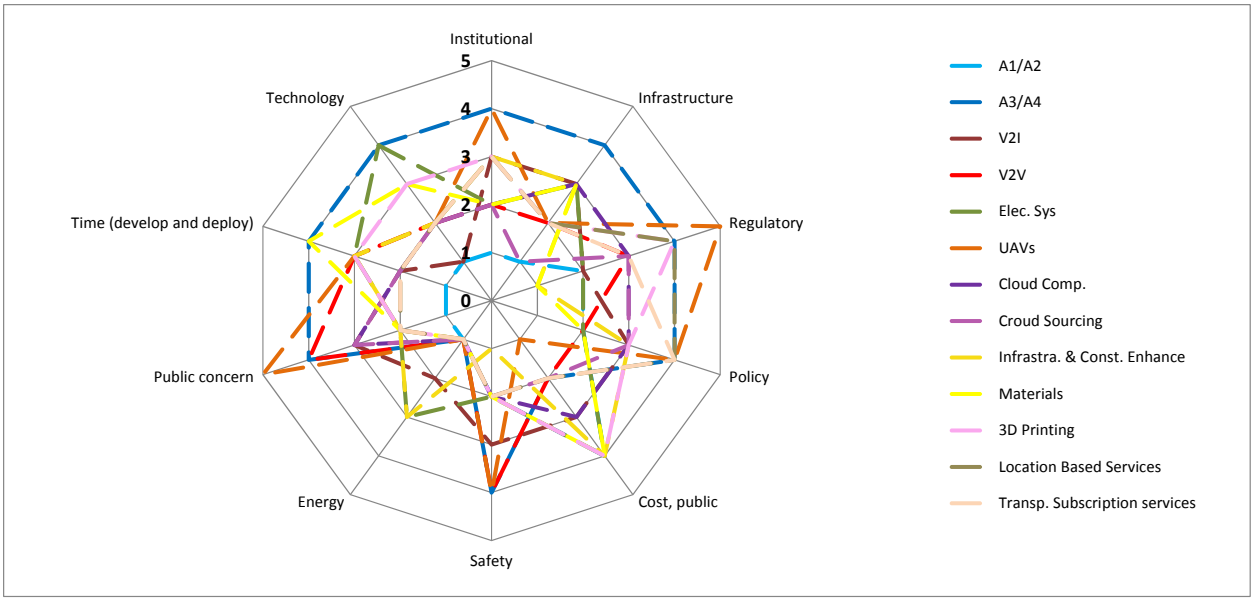
	Autonomous Vehicles		Connected Vehicles				Information and Communication						
User Group Enhancements	A1/A2	A3/A4	V2I	V2V	Elec. Sys	UAVs	Cloud Computing	Croud Sourcing	Infrstra. & Const. Enhance	Materials	3D Printing	Location Based Services	Transportation Subscription services
Freight (interregional)	4	5	4	5	2	4	4	3	3	3	3	3	2
Freight (intraregional)	4	5	4	5	2	2	4	3	3	3	4	4	3
Personal (commute)	4	4	4	5	4	1	4	5	4	4	3	5	5
Personal (Recreational)	4	5	4	5	3	2	4	5	4	4	2	5	5
Emergency	4	5	5	5	2	4	4	5	3	3	2	3	2
School/students	5	5	3	3	3	2	3	3	2	2	2	3	4
Area Score	36.8	49.5	33.6	46.0	14.8	12.7	31.1	34.6	21.6	21.6	15.6	31.8	25.5

Figure 2: Ranking matrices

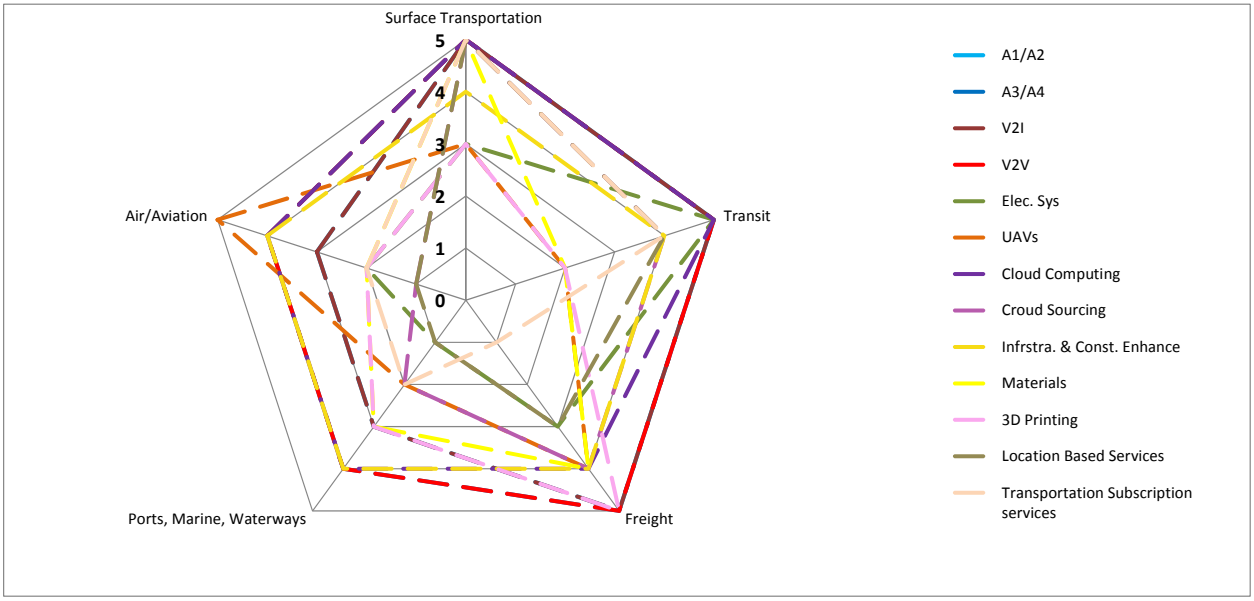
a. Goals



b. Barriers



c. Modal Enhancements



d. User Group Enhancements

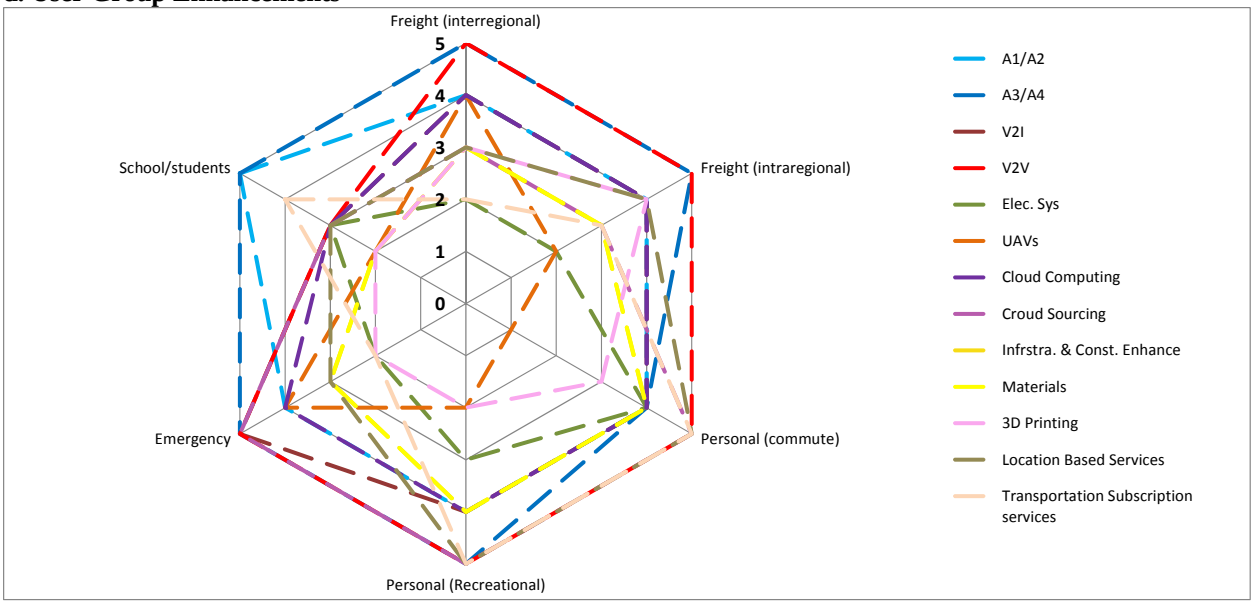


Figure 3a-d: Results of the combined rankings as radar charts