Deliberations from an Expert Workshop on Vehicle Automation, Public Transportation, and Shared Mobility

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As part of TRB’s Road Vehicle Automation Conference (July 15th to 20th, 2013, Stanford University), a two-day expert workshop took place addressing automation, shared-mobility and transit.

Google has reaffirmed its commitment to public Level 4 vehicles in mixed traffic by 2018. While some public-sector transit agencies have already started to think about the impacts of increasing levels of vehicle-automation, many have limited awareness of the mobility opportunities these technologies can offer that may impact structurally on planned investment programs. While, over the last decade, our European counterparts have been planning for these new technologies and implementing many site demonstrations. Automation also offers opportunities for shared-mobility models currently coming on board, such as car share programs. Shared-mobility providers are generally private-sector entities facing a different competitive environment; there are both far-reaching visions of fully-automated taxi-style services and more near-term opportunities for shared-mobility fleets to serve as testbeds for moderate levels of automation.

This paper synopsizes the workshop’s scientific content and outcomes, including identified research needs and plans for a Task Force to advance the required program of research.

Keywords: vehicle automation, shared mobility, carsharing, automated transit, personal rapid transit
1. INTRODUCTION

The automation of road vehicles has been an active and controversial topic for discussion for decades. In July 2013, a group of Transportation Research Board (TRB) Subcommittees: Intelligent Transportation Systems AHB15, Vehicle Highway Automation AHB30, Emerging Technology Law ALO40, Major Activity Center Circulation Systems APO40, Emerging and Innovative Public Transportation and Technologies, APO20, Vehicle User Characteristics, AND10, Cyber Security ABE40(7) and Transportation Energy ADC70 co-sponsored a weeklong workshop at Stanford University, CA to discuss the issues and research needs associated with increasing automation of road vehicles.

The purpose of the workshop was not to reach a consensus on the application of automation and what policies to pursue. Rather, the intention was to establish the state-of-the-art, highlight the research issues, discuss the evidence and identify research needs regarding safety, mobility, and other consequences of vehicle automation.

Over 300 people participated in the conference, with a strong presence of key public-sector, industry, and academic experts on vehicle automation from different parts of the world. The workshop was primarily oriented toward developments in the U.S., but international representation (including multiple keynote speakers) provided valuable perspective on developments abroad.

In addition to the plenary content, ten breakout groups met simultaneously for two afternoons, at which several multidisciplinary challenges of road vehicle automation where discussed. Each breakout was planned by sub-committees of discipline leaders. The main objectives of these in-depth sessions were to establish opportunities and challenges, based on which research needs statements could be developed. The breakout sessions were:

- Automated commercial vehicle operations
- Cybersecurity and resiliency
- Data ownership, access, protection, and discovery
- Energy and environment
- Human factors and human-machine interaction
- Infrastructure and operations
- Liability, risk, and insurance
- Shared mobility and transit
- Testing, certification, and licensing
- V2X communication and architecture

Current evidence suggests that full vehicle automation (where a human driver is not needed at any point during journeys) may be achieved sooner than expected. London’s Heathrow Airport, for instance, has implemented driverless vehicles on guided roadways for small groups of passengers. In the United States, several states, including Nevada, California and Florida have enacted legislation that expressly allows the operation of self-driving vehicles, whether private or operated under certain conditions. Hence the urgent need for a major program of research on the theme of vehicle automation. While, Google has reaffirmed its commitment to public Level 4 vehicles in mixed traffic by 2018.
This paper reports out the highlights of the Shared-Mobility and Transit breakout workshop to the broader research community (including both workshop attendees and other interested professionals).

This article is not an official report of TRB’s Subcommittee on Vehicle Automation, and it does not necessarily represent the views of all of the workshop participants, although it takes these into consideration.

In preparing this paper, presentation media and supplemental notes on the proceedings provided by volunteers were reviewed, highlighting major themes and discussion points that emerged. The article covers the state-of-knowledge about the integration of autonomous vehicles in both public transit services and shared-mobility systems. It concludes with a list of key research needs that emerged from the workshop and from subsequent discussions by the coauthors in the preparation of this article.

Presentations and discussions addressed the following topics:

- Automation and its effect on shared mobility and congestion.
- Integrating automated vehicles with existing and future transit services.
- Risks of automation.
- Automated vehicles for mass transportation: its capabilities, requirements and benefits.
- Legal frameworks applied in other countries.
- Vehicle ownership vs. transit: how will autonomous vehicles affect this ratio.
- Automation and its effect on the mobility of disadvantaged population (e.g., disabled).
- Empty vehicle and parking management.

The rest of this paper is structured as follows. Section 2 presents background to the workshop. Section 3 summarizes the content and interactive discussions. Section 4 outlines the research needs that were identified, and Section 5 concludes the paper with a discussion of next steps.

2. WORKSHOP BACKGROUND

2.1 Background: Automation definition and levels

Automated vehicles can be defined as those in which control operations of the vehicle, such as steering, acceleration, and braking, occurs without direct driver input for at least part of journey. In its most rudimentary form, self-driving requires the driver to remain vigilant and ready to re-assume control of the vehicle with little warning. In such cases, these systems provide only secondary assistance to the driver. More enhanced systems are robust enough to allow the driver to perform other tasks but lack sufficient scope to be able to handle all driving environments; however, they are capable of differentiating those environments so as to always be able to implement a fail-safe maneuver or alert the driver to regain control. Full automation is achieved when the robustness of the automation is sufficiently great that it can handle ‘all’ expected driving environments using fail-safe maneuvers without the assistance of a human driver.

The standard classification of levels of automation is the system developed by the National Highway Traffic Safety Administration (1):

- Level 0: No Automation. The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
• Level 1: Function-specific Automation. Involves one or more specific control functions like electronic stability control or pre-charged brakes.
• Level 2: Combined Function Automation. This level involves automation of at least two primary control functions designed to work in unison (e.g., adaptive cruise control in combination with lane centering).
• Level 3: Limited Self-Driving Automation. Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic but the driver is expected to be available for occasional control. The Google car is an example of limited self-driving automation.
• Level 4: Full Self-Driving Automation. The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. This includes both occupied and unoccupied vehicles.

2.2 Background: Automation, shared-mobility and public transport
Unlike road vehicles, full automation in public transit has been maturing and is found in deployed systems worldwide. Automated train control systems have evolved continuously to the point that fully automated metros are now the rule rather than the exception, within many older lines under conversion as is witnessed in Paris. Although the adoption has been slower in the United States, the trend is still toward fully automated systems as in the most recent metro rail project in Honolulu, HI.

In the United States, automated people movers (APMs) under the purview of The American Society of Civil Engineers (ASCE), is where automated vehicle technology has been explored and developed with many real world applications. The technology can be traced to the various turn of the century Expos and Expeditions such as The World Columbian Exposition, Chicago, II, 1893 where the first moving stand, walk or seated automated technology was deployed. Eugene Hennard at the turn of the century explored their application in the urban fabric showing many spatial conditions for the new technology. Airports have been using various automated technology for many decades, with the first 1971 in Tampa. Many airport APM have switches embedded in the guideway as a rail system. In 1966, a Downtown People Mover Program was advanced by the US Government and many systems were developed. Architects and planners participated in creating new visions of cites implementing the automated technology. Also around the world many systems were also being designed.

The Morgantown Personal Rapid Transit (PRT) is the first fully automated road vehicle system (level 4) that entered production transit service. It was followed by a similar system at DFW airport. These guideways are passive with respect to switching, the vehicle controls the switching. Occurring in the 1970s, this system is often discounted due to its electro-mechanical control systems and exclusive guideway, but has amassed a stellar safety history in comparison with conventional transit. More modern automated road vehicle systems have entered production in recent years, such as the Ultra system at Heathrow terminal 5, and the Masdar system by 2getthere.

3. EMERGENT THEMES
As participant Adriano Alessandri succinctly stated: There are two paths forward with vehicle automation -- one starting from the protected environment of transit and moving toward the unprotected environment of mixed traffic and the other from slowly transforming the vehicle and human vehicle-drivers) within the unprotected environment (2).
As background, most participants were familiar with the general principles of the functionality of automation technology and its current transit applications. Several automated transit systems with small driverless vehicles have recently been coming online for public use: Heathrow airport, Suncheon city, Masdar city and soon in India.

Alain Kornhauser sees opportunity between these two extremes - "Level 4" transit opportunity for high speed driverless vehicles sharing existing roadways with existing road users. Such autonomousTaxis (aTaxis) could provide auto-like service where demand is diffuse in space and time while facilitating casual ride-sharing to serve demand that is happens to be correlated spatially and temporally. This casual ride-sharing substantially improves efficiency and eliminates congestion. Such systems could emerge from smaller precursor exclusive guideway system whose vehicles could emerge onto existing roadways to serve a broader spatial scope of travel demand. Or, they could emerge from a broader, but less intense suburban service using existing roadways to serve more concentrated urban areas by creating exclusive guideways to deliver higher capacity services in the dense core. Each of these could be done by demand responsive management of a fleet consisting of various sized driverless vehicles (3).

Looking at Multi-modal linkages and how these new systems including ride-sharing can interact/intersect was also of concern in these discussions. So, the autonomous taxi could provide shared-ride opportunities that could capture as it served the 32+ million trips that are taken in NJ on a typical weekday. 2+ million of the trips are short and are readily served by walking and biking. 1+ million of the trips can readily use NJ Transit’s rail service for at least a portion of the trips. A large portion of the remaining trips are so diffuse spatially and temporally that shared ridership is not practical and are served individually by the aTaxi system. The remainder, occurring in the denser locations during peak hours, has substantial ride-sharing that would correspondingly decongest these roadways at these times while delivering excellent mobility at reduced energy and environmental consequences.

This break out session explored the synergies and overlaps for road vehicle automation both in the short term – NHTSA Levels 1-3 – and for Level 4, where the consensus of participants was that the largest positive impact on human activity patterns and the built environment is likely to occur, though the technical barriers are daunting.

The presentations and discussions ranged from urban design to insurance, from the human interface at a large public transit agency to the need for last-mile (possibly automated) transit solutions to feed California’s future high speed rail network.

The process and findings of a recent feasibility study for automated transit at Mineta Airport (San Jose, CA) was discussed by both the consultant team and client. The legal infrastructure for European models was explored as they have focused their research and demonstrations much earlier on the transit approach.

The breakout session participants agreed that the greatest impact for road vehicle automation was for the mobility impaired and for general mobility safety. Automation has the ability to transform lives by allowing access to jobs and normal living patterns for those currently challenged by our American transportation system. Automated vehicles will also transform our living environments and the way we move through space in so many positive ways that we want to explore and define this potential. One of the most important focuses to come out of our 2-day discussions was to educate planners to know that this technology exists, what its parameters are and that it is safely functioning for the public now in several locations in the world. So, updating the CUTS (Characteristics of Urban Transportation Systems) manual is one of our top priorities.
3.1 Automated road transport systems in European cities

The CityMobil and CityMobil2 research projects, sponsored by the European Commission, have been developing automated transit vehicles and operating concepts since the 1990s (2). Simulation models have shown that even the capacity gains from vehicle automation would prove inadequate to address the inefficiencies of private car use in the centers of large European urban areas. One prospective model under study in European cities is the provision of taxi-like public transport services on segregated infrastructure in small city centers and the peripheries of large cities with automated road vehicles or dual-mode shared cars. Additionally, public transport corridors with large buses could use platooning concepts to provide adequate people-moving capacity. The motivations in Europe are somewhat different from North America, with private-car automation being seen as less promising (with the exception of safety benefits). The CityMobil2 project is currently developing a legal framework for driverless vehicles in public transportation, which will be considered by the European Commission as a possible directive.

3.2 City of San Jose (CA) Automated Transit Network Feasibility Study

Voters in San Jose mandated feasibility studies for an automated people mover connecting the Mineta Airport terminals to the city’s public transportation networks (Bay Area Rapid Transit, Caltrain and Valley Transportation Authority) (4). One aspect of the vision is that an interconnected system would reinforce Silicon Valley as a center of innovation, encourage sustainable development and stimulate public transit use. At present the feasibility of the Automated Transit Network (ATN) system has been established, but the system is not proceeding towards construction due to the funding not having yet been allocated. On the basis of this study, research needs were identified regarding regulatory and liability issues, pricing, perceptions of personal safety, optimum vehicle size, forecasting techniques, operation in pedestrian zones, methods for implementing the technology in phases, and risk-management.


As with other aspects of vehicle automation (5), automated-mass-transit system designers face much uncertainty regarding acceptable design practices. An approach for addressing this issue is to build on the Automated Transit Systems /Automated People Mover ATS/APM Industry hazard framework as a model to guide safety requirements for automated transit (6). This Industry standard was developed through a collaborative process of system/equipment suppliers, system integrators/operators and safety regulators as an international committee. Further development could be based on application/adaption of IEC Hazards Analysis Table from IEC 62267-2, which requires updating to address the distinct issues related to vehicle automation in transit guideway, controlled environments and open road.

3.4 Automated Vehicles for mass transportation in cities: technological and scientific challenges

French researchers have led development of automated vehicles over many years, under the ‘cybercars’ concept (7). Cybercars are managed by a human operator and are fully integrated complete urban transportation with automated parking, platoon driving and environmental awareness. One of the most recent projects, the 2011 LaRochelle demonstration was an on-demand fully automated shuttle service in mixed-traffic road environments. Based on research undertaken at the INRIA laboratory in France, areas identified requiring further research are in redistribution/fleet management, refueling/electric recharging management, payment and availability. It was suggested that there is a need for more “intelligent” infrastructure: both
dedicated and cooperative with other road management systems. This will require macroscopic and mesoscopic modeling of large systems with specialized simulation and the collection and analysis of large data streams from real databases.

3.5 Innovations to Support High Speed Rail Internationally, California and San Jose

High-Speed Rail (HSR) operates successfully in Asia and Europe, and a network (790 miles; 26 stations) is being rapidly advanced in California (8). The first construction contract was issued December 2012. Due to the urban geography, feeder systems will be necessary if the full benefits of the HSR system are to be realized (emissions reductions, mobility enhancements, etc.) In both San Jose and other Californian communities automated transit networks are seen as a workable solution to the last-mile problem of HSR and under serious consideration by policymakers. Additionally, it is recognized that stronger land use controls will be needed than have traditionally been used to further support the ATN and HSR networks; several communities affected by the CA HSR system are engaged in “pre-clearance” of regulatory processes to adapt their land use profiles.

3.6 Architecture and Vehicle Automation: Shifting Through Networks

Vehicle automation can be seen as part of a wider shift in how infrastructure functions. The Interstate Highway System developed in the 20th century can be characterized as ‘dumb, monovalent, and static,’ based on its lack of intermodality (and resiliency) as compared to the functionality of digital networks. The Interstate network lacks intelligent switching or a means to develop ‘robust parallelism’, a way to interconnect different systems. Historically, however, modal interchanges have existed (e.g. rail terminals) that operate more like switches. The French Aramis project (a failed experiment in the 1970s at an automated people mover) serves as an example of a project where technology was the goal rather than its outcome for transportation. In studies of container freight intermodality, many new developments have taken place in which automated vehicles and transponder-studded landscapes were getting much more traction than Aramis-style projects because they were rehearsing not complex algorithms but simple tasks performed in concert in large vehicle-populations. An emergent trend in architecture convergent with the vehicle-automation agenda is the increasing intelligence of floors—the surface of information and navigation and determinate of architectural morphology (9).

3.7 The Impact of Autonomous Vehicle Technology on Operations at Major Public-Sector Transit Operators

On the one hand, increased highway capacity and decreased parking requirements will remove some of the advantages of transit in dense urban environments, but conversely automated vehicles could serve to replace low-volume bus routes, providing superior service to customers and lower operating costs for the transit agency (10). Automation will also enable safer transit-vehicle operation, potentially resulting in large cost savings due to reduced self-insured losses (or alternatively reduced insurance premiums). Further, partial automation in bus vehicles could lead to greatly reduced headways and thus increased people-moving capacities in environments where capacity is a constraining factor (e.g. the NY/NJ corridor through the Lincoln Tunnel into the New York Port Authority Bus Terminal). It is, however, unclear whether enabling legislation for public-sector transit agencies allows operators the desired freedom to implement some of these operating concepts, particular as they relate to fleets of small vehicles that would provide automated taxi-like services.
3.8 US DOT’s Accessible Transportation Technologies Research Initiative

55 million people in the US (fully 20% of the population) have physical or cognitive disabilities, a number that is projected to rise to 72 million by 2025 (11). Transportation has great impacts on this group as many are reliant on serviced-transportation for key aspects of their daily needs. Expensive para-transit (costing many tens of dollars for public-sector agencies to provide) is typically employed, though despite the expense rarely provides a level of service comparable to that enjoyed by independently-mobile people. The US Federal Department of Transportation (US DOT) is currently undertaking a 5 year joint research effort to improve the mobility of travelers with disabilities, focusing in particular on the efficiencies achievable with increasing levels of vehicle-automation.

3.9 Bridging Uncertainty to Opportunity

The requirement for commercial insurance in shared-mobility systems introduces many complexities, challenges and inefficiencies (12). But the greater situational awareness inherent in automated-vehicle concepts will provide substantial opportunities to better manage the risks of shared-use fleets. Meanwhile, innovation in insurance products is burdensome as permissions are required from dozens of state-level regulators, even in circumstances where insurance providers are willing to engage with new types of mobility providers. The emerging trend is therefore that the technical barriers to new insurance products relevant to automated-vehicles are increasingly being overcome through the use of advanced sensing technologies (including data mining of social media and integrated cross-platform personal-identification systems), whereas the social/legal barriers to providing effective insurance products are becoming more acute.

4. IDENTIFIED RESEARCH NEED THEMES

On the basis of the workshop’s expert presentations and interactive discussions, the following priority topics requiring further research were identified.

• 4.1 Shared Mobility. Working group: Jeral Poskey, Scott Le Vine, Jerry Lutin, Mohammed Yousuf, Dan Fagnant, Guy Fraker, Ramses Madou, Eugene Willard

Automation enables the possibility of sharing ownership of vehicles, querying the capacity of current business models to accept this and how will other services (e.g., transit and para-transit) be affected. In summary, how will this affect demand of all services? Can a shift be expected and in what direction?

• 4.2 Automation in Public Transit – a Holistic View. Working group: Jerome Lutin, Alain Kornhauser, Stan Young, Rod Diridon

From a long-term planning and public infrastructure investment perspective, automation is simply another tool to address long standing needs and missions. From this holistic perspective, it is best to fully understand the mission of public transportation, and then review how automation by assist in meeting that mission, as well as understand its fundamental limits. In other words, it is beneficial to take the perspective of “What are the fundamental public transit needs that automation may address?” In order to answer this, case scenarios should be developed to better understand public transit mission and objectives, its built and institutional infrastructures, opportunities for enhancing service or improving efficiencies, and pitfalls to avoid.
• **4.3 Promise of Auto-valet Parking: a Panacea or Simply Shifting the Problem.**
  Working Group: Shannon Sanders McDonald, Stan Young, Alain Kornhauser, Keller Easterling

  Popular press has speculated on the large potential impact that auto-valet capabilities (a level 3 automation capability) may have to reshape our urban spaces currently so dominated by parking. Little to now objective analysis is currently available to estimate the practical impact in terms of increased space efficiency, reduction in vehicle circulation, and potential to create more walkable developments. A realistic model to evaluate the impact of auto-parking is needed. The main objective is to understand how and the extent to which land use and demand will be impacted by this feature.

• **4.4 Performance Measures for Automated Mobility in Urban Settings.** Working Group: Fawzi Nashashibi, Louis Merlin, Dan Fagnant, Eva Frederich, Scott Le Vine

  The effect of automation cannot be solely measured based on travel time savings. The reality is that not all existing definitions of performance measures can be applied to this new mode of transportation. Research is needed to update the existing measures and develop new ones that may be necessary to successfully and efficiently evaluate autonomous vehicles.

• **4.5 Exclusive Guideway vs Open Road.** Working Group: Laura Stuchinsky, Alain Kornhauser, Louis Merlin, Stan Young, Jeral Poskey

  A frequent polarizing view of automation surrounds the exclusivity of the guideway or road upon which automated vehicles (specifically level 4) may be deployed. Examples of level 4 automation are currently available in transit systems with exclusive right-of-way. Although frequently discounted due to its age and use of mechanical control systems, the Morgantown PRT system is the earliest example of level 4 automation in road vehicles dedicated to transit service on exclusive guideways. Recent deployment at Heathrow and Masdar of require considerable less substantive infrastructure, but still provide operating paths to vehicles that are separated from other vehicular and pedestrian traffic. As technology continues to improve, level 4 automated systems may be deployed in ever less protected environments, perhaps allowing cross vehicular and/or pedestrian traffic, decreasing the cost of completely exclusive guideways. Alternatively, fully functional level 4 automation may allow operations of vehicles on existing public roadways – alleviating the investment in additional dedicated infrastructure to achieve level 4 functionality. No level 4 automation is currently in production on public roadways, though the process of such automation appears closer than before. Research is needed to understand the tradeoffs between investing currently into exclusive infrastructure to enable near term level 4 automation versus continued patience until level 4 is viable on existing roadways.

• **4.6 Automation Impact on Mobility Impaired.** Working Group: Mohammed Yousef, Ron Boenau, Will Ackel, Scott Levine, Shannon McDonald

  Further research is needed to fully develop our understanding the demographic and its subsets for emerging design strategies due to the current reliance on para-transit. Different levels of automation will pose different challenges to the mobility impaired and each of these conditions needs to be explored. Further identification of any trends in the
behavior of mobility impaired patterns of living to contrast their existing mobility options to automated concepts at each level. How full automation can change the economics of transit and travel for the mobility impaired

- **4.7 Legal Framework for Automated Driverless Transit.** Working Group: Adriano Alessandrini, Sam Lott, Alain Kornhauser

A clear legal structure will be needed before approving the use of Levels 3 and 4 automation in public transit systems. Research is needed to evaluate existing and proposed laws and to identify the lessons that can be learned from other countries, as well as what collaboration could be initiated with them.

- **4.8 Integration of Automation and Shared Mobility into the Urban Fabric.** Working Group: Shannon McDonald, Adriano Allessandrini, Louis Merlin, Will Baumgartner, Paul Godsmark, Ron Boenau, Dan Fagnant, Ramses Madou

The successful introduction of automated vehicles to an urban environment will depend on how prepared the environment is to accept automated vehicles. Hence, research is needed to understand the situational benefits and detriments of this technology from a quality of life, architecture and development point of view.

- **4.9 Future Alternative Analysis for MPOs and NEPA Processes.** Working Group: Rod Diridon, Will Baumgardner, Sam Lott, Stephan Parker, Laura Stuchinsky, Stan Young

Automation will affect every part of the transportation industry, from the user to the agencies. In order to prepare for this, official documents, such as Characteristics of Urban Transport Systems (CUTS), need to be updated to identify current capabilities and how they will/can adapt.


The considerable risk involved with incorporating level 3 and 4 automation into vehicles to serve transit is obvious; however, little has been done to fully assess the risk attached to this service. This is mainly due to the lack of a well-defined, and accepted, hazard assessment (HA) framework that is tailored to the uniqueness of autonomous vehicles. A framework for RVA could reduce confusion, foster collaboration in industry & government, advance the timeline to viable products.


An objective data collection process from known automation deployment is needed to provide evidence of existing and potential issues of the different levels of automation. This could also provide a more realistic cost/benefit analysis of existing technology (i.e. Level I and II) and facilitate the evaluation of retrofitting, standards and future planning efforts.

5. **NEXT STEPS**

The proceedings of this workshop highlight the rapid developments in vehicle automation, which present grand challenges and opportunities to both the public transit industry and the shared-mobility sector.
To guide the development and further progress of the required research program, a proposal for a Task Force, co-sponsored by the relevant TRB committees, the American Public Transportation Association, and the Advanced Transit Association is now being formalized.

The mission of the Task Force on Delivering the Potential of Automation in Public Transportation and Shared Mobility will be to deliver the research needs statements that emerged from this Workshop’s discussions, to advance them via appropriate funding mechanisms, and to organize linked events for the TRB Annual Meeting of the in January 2014 and other venues, such as the Advanced Transportation Symposium in October 2013. The Research Need Statements emanating from the concepts developed at this workshop will be presented at the inaugural subcommittee meeting in January 2014. The Task Force will also provide a forum to develop the key institutional relationships related to automated vehicles for public mobility.

REFERENCES


**TABLE**

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Table 1: List of workshop participants