A Survey of Models and Algorithms for Intelligent Transportation and Traffic Management

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I. Topics for Further Investigation

In this survey we provide a comprehensive and unified review of the core research areas we deem are the most important for promoting the advancement of ITS. These areas include freeway traffic modelling, air traffic management, sensing and perception, traffic analysis and optimization, smart public transportation, shared mobility, demand responsive transportation and first and last-mile solutions, human-machine interface algorithms and communication algorithms. As a conclusion to this survey we provide a list of topics that should be further investigated in order to advance the development of Intelligent Transportation Systems. These topics are divided based on the identified core research areas we considered above. Advancing research in these fields shall play a crucial role in the development of intelligent and smart transportation solutions and enable its deployment for the benefit of humanity.

1. Ground Traffic Management (Freeway and Urban) Algorithms
   - Vehicle routing problems using time varying graphs.
   - Evolution game theory.
   - Feedback dynamic traffic assignment.
   - Shortest paths on graphs.
   - Social vehicle route selection and Stackelberg algorithms.
   - Trajectory planning.
   - Speed planning.
   - Collision avoidance.
   - Multi-vehicle interaction
     - Resource allocation problems involving a wide range of possible approaches:
       * Linear and non-linear programming.
       * Conflict-region algorithms.
       * Centralized and decentralized. synchronization protocols.
       * Graph coloring.
       * Mimetic and machine-learning based optimization, transfer learning and prediction.
2. Air Traffic Management Algorithms
   - Dynamic routing problems on time varying graphs for air space sharing and dynamic air space allocation.
   - Collision avoidance for unstructured air space using conflict detection and resolution algorithms.
   - Scheduling and sequencing algorithms for vertiports traffic management for Urban Air Mobility.
   - Optimal control and model predictive control.
   - Reachability analysis allowing for safe platooning.
   - Path planning using optimization approaches such as mixed integer optimization for incorporation of logical constraints in trajectory design and non linear programming for generation of flyable paths.
   - Reinforcement learning for path planning.
   - $4D$ trajectory theory.
3. Perception, Data fusion, Processing and Aggregation Techniques
   - Map generation and fusion.
   - 3D object localization.
   - Fusion algorithms of data from heterogeneous data sources for road network traffic representation.
   - Cooperative vehicles

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  - Vehicular communication.
  - Cooperative localization.
  - Motion coordination.
  - Sensor management of autonomous vehicles.
  - Message dissemination protocols and infrastructure assisted coordination.
  - Cooperative navigation using distributed consensus.
  - Model predictive, $\mathcal{H}_\infty$ and sliding mode controls.
  - Platoon coordination, virtual platoons, platoon and string stability theory.
  - Speed harmonization algorithms and optimal control based speed harmonization.
4. Traffic Simulation and Prediction Models
   - short- and long-term traffic prediction algorithms based on statistical and time series analysis, auto-correlation functions, neural networks, pattern recognition and machine learning approaches.
   - Microscopic car-following models.
   - Particle-hopping models.
   - Gas-kinetic theoretical models.
   - Macroscopic fluid models.
   - Human-driving modeling using differential equations and acceleration correction algorithms.
   - Detailed vehicle dynamics modeling.
5. Smart Public Transportation
   - Adaptive route planning and scheduling for public transportation.
   - Train re-routing algorithms that incorporate future predictions.
   - Algorithms for demand responsive passenger balancing.
   - Prediction of occupancy and saturation in public transportation using automatic passenger information collection systems.
   - Algorithms for schedule synchronization for intermodal transportation.
6. Shared mobility, Demand Responsive Transportation and First and Last-mile Solutions
   - Algorithms for Ride-sharing and Carpooling such as matching and assignment problems on graphs, scheduling algorithms, combinatorial optimization approaches and algorithms for solving dynamic and stochastic shared mobility problems.
   - Algorithms for management of fleets of autonomous vehicles for first and last-mile transportation services.
   - Algorithms for combined human and parcel transportation.
   - Parking guidance and management systems algorithms- Data sharing algorithms for combined parking routing and traffic prediction, Markov chains and queuing theory for future occupancy of parking spots and machine learning approaches.
   - optimal sensor placement for parking applications.
   - Dynamic re-balancing based on predictions.
   - Optimal trading schemes and distributed decision making.
7. Human-machine Interface Algorithms
   - Algorithms for safe hand off and take over requests for partially autonomous vehicles
   - Maneuver recognition using statistical modeling and machine learning classification algorithms such as Bayesian models, hidden Markov models and decision trees.
   - Distraction detection and analysis.
   - Verification and Validation Methods for Human-Machine Interface
8. Communication Algorithms
   - DSRC based V2X communication
     - Congestion control algorithms.
     - Transmission control rate algorithms.
     - Spectrum resource allocation algorithms.
     - Prioritization algorithms for limiting rebroadcasting issues.
     - Error correction algorithms for information lost due network collisions.
     - Decentralized misbehaviour detection algorithms.
     - Security algorithms for VANET protection.
     - Low latency cryptographic algorithms.
   - Cellular based V2X communication
     - LTE based V2X communication
       * Centralized and distributed resource allocation algorithms
         · graph matching

        - semi-Markov decision processes
        - optimization algorithms
        - reinforcement learning.
      - Multi-link Synchronization Priority Algorithms
      - Low latency and robust Multimedia Broadcast Multicast Algorithms
      - Security algorithms concerning authentication, V2X one-to-many communication, vehicular UE privacy and authorization and accountability algorithms.
  - 5G based vehicular communication
      - Cooperative transmission algorithms for heterogeneous and small cell networks, handover and mobility prediction algorithms, cell association optimization.
      - Massive MIMO (multiple-input and multiple-output) communication algorithms including diverse modulation algorithms, 3D MIMO, full dimensional MIMO, graph based and machine-learning approaches.
      - Millimeter wave communication algorithms: directional transmission, beamforming and contextual online learning.
      - Vehicular cloud and fog computing algorithms including data mining, vehicular mobility prediction and fog resource allocation algorithms.
      - Mobile edge computing algorithms such as machine-learning based content pre-fetching and graph based content distribution.
      - Dynamic spectrum sharing algorithms.
- Heterogeneous DSRC and Cellular based V2X Communication Algorithms