

Claims

1. An apparatus comprising
equipment located at an intersection of a transportation network, the equipment comprising
5 an input to receive data from a sensor oriented to monitor ground transportation entities at or near the intersection,
a wireless communication device to send to a device of one of the ground transportation entities, a warning about a dangerous situation at or near the intersection,
a processor, and
10 a storage for instructions executable by the processor to
store a machine learning model that can predict behavior of ground transportation entities at or near the intersection at a current time, the machine learning model being based on training data about previous motion and related behavior of ground transportation entities at or near the intersection,
15 apply current motion data received from the sensor about ground transportation entities at or near the intersection to the machine learning model to predict imminent behaviors of the ground transportation entities,
infer an imminent dangerous situation for one or more of the ground transportation entities at or near the intersection from the predicted imminent behaviors, and
20 cause the wireless communication device to send the warning about the dangerous situation to the device of one of the ground transportation entities.
2. The apparatus of claim 1 in which the equipment comprises a roadside equipment.
3. The apparatus of claim 1 comprising a housing for the equipment and in which the sensor is attached to the housing.
- 25 4. The apparatus of claim 1 in which the warning is sent by broadcasting the warning for receipt by any of the ground transportation entities at or near the intersection.

5. The apparatus of claim 1 in which the machine learning model comprises an artificial intelligence model.
6. The apparatus of claim 1 in which the training data and the motion data comprise at least one of speed, location, heading, intent, posture, or direction of look.
- 5 7. The apparatus of claim 1 in which the processor is configured to be capable of generating the machine learning model at the equipment.
8. The apparatus of claim 1 in which the machine learning model is generated at the equipment.
9. The apparatus of claim 1 in which the instructions are executable by the processor to
10 store the training data at the equipment.
10. The apparatus of claim 1 in which the intersection comprises a non-signalized intersection.
11. The apparatus of claim 1 in which the transportation network comprises a road network.
12. The apparatus of claim 1 in which the ground transportation entities comprise vulnerable
15 road users.
13. The apparatus of claim 1 in which the ground transportation entities comprise vehicles.
14. The apparatus of claim 1 in which the imminent dangerous situation comprises a collision or a near miss.
15. The apparatus of claim 1 in which the ground transportation entities comprise pedestrians
20 crossing a road at a crosswalk.
16. The apparatus of claim 1 comprising another communication device to communicate with a central server.
17. The apparatus of claim 1 in which the device of one of the ground transportation entity comprises a mobile communication device.
- 25 18. An apparatus comprising
equipment located in or on a ground transportation entity, the equipment comprising

an input to receive data from sensors in or on the ground transportation entity and oriented to monitor nearby features of a ground transportation network and other information about a context in which the ground transportation entity is traversing the ground transportation network,

- 5 a wireless communication device to receive information about the context,
- a signal processor to apply signal processing to data from the sensor and other information about the context,
- a processor, and
- a storage for instructions executable by the processor to
- 10 store a machine learning model that can predict behavior of an operator of the ground transportation entity and intent and movement of other ground transportation entities in the vicinity, and

 apply the current received data from the sensors and other information about the context to predict behavior of the operator and the intent and movement of other

15 ground transportation entities in the vicinity.

19. The apparatus of claim 18 in which the instructions are executable by the processor to monitor users or occupants of the ground transportation entity.

20. The apparatus of claim 18 in which the other information about the context includes emergency broadcasts, traffic and safety messages road side equipment, and messages about

20 safety, locations, and other motion information from other ground transportation entities.

21. The apparatus of claim 18 in which the sensors comprise cameras, range sensors, vibration sensors, microphones, seating sensors, hydrocarbon sensors, sensors of volatile organic compounds and other toxic materials, and kinematic sensors or combinations of them.

22. The apparatus of claim 18 in which instructions are executable by the processor to filter

25 received alerts at the vehicle by applying the alerts to a machine learning model to predict which alerts are important in the current location, environmental conditions, driver behavior, vehicle health and status, and kinematics.

23. The apparatus of claim 18 in which the wireless communication device sends the warning about the dangerous situation to a sign or other infrastructure presentation device.
24. The apparatus of claim 18 in which the warning includes an instruction or command capable of controlling a specific ground transportation entity.
- 5 25. A method comprising
- store a machine learning model that can predict behavior of ground transportation entities at or near an intersection of a transportation network at a current time, the machine learning model being based on training data about previous motion and related behavior of ground transportation entities at or near the intersection,
- 10 apply current motion data received from a sensor about ground transportation entities at or near the intersection to the machine learning model to predict imminent behaviors of the ground transportation entities,
- infer an imminent dangerous situation for one or more of the ground transportation entities at or near the intersection from the predicted imminent behaviors, and
- 15 cause the wireless communication device to send the warning about the dangerous situation to the device of one of the ground transportation entities.
26. The method of claim 25 in which the warning is sent by broadcasting the warning for receipt by any of the ground transportation entities at or near the intersection.
27. The method of claim 25 in which the machine learning model comprises an artificial
- 20 intelligence model.
28. The method of claim 25 in which the training data and the motion data comprise at least one of speed, location, heading, intent, posture, or direction of look.
29. The method of claim 25 comprising generating the machine learning model at the equipment.
- 25 30. The method of claim 25 comprising storing the training data at the equipment.
31. A method comprising

receiving data from sensors in or on a ground transportation entity and oriented to monitor nearby features of a ground transportation network and other information about a context in which the ground transportation entity is traversing the ground transportation network, receiving information about the context,

5 storing a machine learning model that can predict behavior of an operator of the ground transportation entity and intent and movement of other ground transportation entities in the vicinity, and

applying the current received data from the sensors and other information about the context to predict behavior of the operator and the intent and movement of other ground transportation entities in the vicinity.

32. The method of claim 31 comprising monitoring users or occupants of the ground transportation entity.

33. The method of claim 31 in which the other information about the context includes emergency broadcasts, traffic and safety messages road side equipment, and messages about safety, locations, and other motion information from other ground transportation entities.

34. The method of claim 31 in which the sensors comprise cameras, range sensors, vibration sensors, microphones, seating sensors, hydrocarbon sensors, sensors of volatile organic compounds and other toxic materials, and kinematic sensors or combinations of them.

35. The method of claim 31 comprising filtering received alerts at the vehicle by applying the alerts to a machine learning model to predict which alerts are important in the current location, environmental conditions, driver behavior, vehicle health and status, and kinematics.

36. The method of claim 31 comprising sending the warning about the dangerous situation to a sign or other infrastructure presentation device.

37. The apparatus of claim 31 in which the warning includes an instruction or command capable of controlling a specific ground transportation entity.

38. A method comprising
on board a road vehicle traveling in a ground transportation network:

receiving messages from external sources about location, motion, and state of other ground transportation entities,

receiving data from on board sensors about road and driving conditions and about the locations of static objects and moving ground transportation entities in the vehicle

5 surroundings,

receiving data about quality of driving by a driver of the road vehicle,

receiving basic safety messages from other ground transportation entities and personal safety messages from vulnerable road users,

fusing the received data and messages and applying them to an artificial
10 intelligence model to predict an action of a driver of the road vehicle or of a vulnerable road user or a collision risk for the road vehicle or both.

39. The method of claim 38 comprising on board the road vehicle creating a map of the static objects and moving ground transportation entities in the vicinity of the road vehicle.

40. The method of claim 38 comprising alerting the driver of the road vehicle of a collision
15 risk.

41. The method of claim 38 comprising determining the collision risk based on probabilities of predicted trajectories of nearby other moving ground transportation entities.

42. The method of claim 38 comprising filtering received basic safety messages and personal safety messages to reduce the number of alerts provided to the driver of the road vehicle.

20 43. A method comprising

acquiring motion data for unconnected ground transportation entities moving in a transportation network, and

sending virtual safety messages incorporating information about the motion data for the unconnected ground transportation entities to connected ground transportation entities in the
25 vicinity of the unconnected ground transportation entities.

44. The method of claim 43 in which the virtual safety messages are substitutes for safety messages that would be sent by the unconnected ground transportation entities if they were connected.
45. The method of claim 43 in which the unconnected ground transportation entities
5 comprise vehicles and the virtual safety messages are substitutes for basic safety messages.
46. The method of claim 43 in which the unconnected ground transportation entities comprise vulnerable road users and the virtual safety messages are substitutes for personal safety messages.
47. The method of claim 43 in which the motion data are acquired by infrastructure sensors.
- 10 48. An apparatus comprising
equipment located at an intersection of the transportation network, the equipment comprising
an input to receive data from a sensor oriented to monitor ground transportation entities at or near the intersection,
15 a wireless communication device to send to a device of one of the ground transportation entities, a warning about a dangerous situation at or near the intersection,
a processor, and
a storage for instructions executable by the processor to
store a machine learning model that can predict behavior of ground
20 transportation entities at or near the intersection at a current time, the machine learning model being based on training data about previous motion and related behavior of ground transportation entities at or near the intersection,
apply current motion data received from the sensor about ground transportation entities at or near the intersection to the machine learning model to predict
25 imminent behaviors of the ground transportation entities, including a ground transportation entity the device of which cannot receive a warning from the wireless communication device,

infer an imminent dangerous situation for a ground transportation entity the device of which can receive a warning from the wireless communication device, the imminent dangerous situation being the result of predicted imminent behavior of the ground transportation entity that cannot receive the warning, and

5 send the warning about the dangerous situation to the device of the ground transportation entity that can receive the warning from the wireless communication device.

49. The apparatus of claim 48 in which the equipment comprises a roadside equipment.

50. The apparatus of claim 48 comprising a housing for the equipment and in which the sensor is attached to the housing.

10 51. The apparatus of claim 48 in which the warning is sent by broadcasting the warning for receipt by any of the ground transportation entities at or near the intersection that can receive the warning.

52. The apparatus of claim 48 in which the machine learning model comprises an artificial intelligence model.

15 53. The apparatus of claim 48 in which the intersection comprises a non-signalized intersection.

54. The apparatus of claim 48 in which the intersection comprises a signalized intersection.

55. The apparatus of claim 48 in which the transportation network comprises a road network.

56. The apparatus of claim 48 in which the ground transportation entities comprise
20 vulnerable road users.

57. The apparatus of claim 48 in which the ground transportation entities comprise vehicles.

58. The apparatus of claim 48 in which the imminent dangerous situation comprises a collision.

59. The apparatus of claim 48 in which the ground transportation entity the device of which
25 cannot receive the warning from the wireless communication device comprises a vehicle and the ground transportation entity the device of which can receive the warning from the wireless communication device comprises a pedestrian crossing a road at a crosswalk.

60. The apparatus of claim 48 comprising another communication device to communicate with a central server.
61. The apparatus of claim 48 in which the device of one of the ground transportation entity comprises a mobile communication device.
- 5 62. A method comprising
- using electronic sensors located in a vicinity of an intersection of a ground transportation network to monitor the intersection and approaches to the intersection, the electronic sensors generating motion data about ground transportation entities moving on the approaches or in the intersection, one or more of the ground transportation entities not being capable of sending safety
- 10 messages to other ground transportation entities in the vicinity of the intersection,
- based on the motion data generated by the electronic sensors, sending virtual safety messages to one or more of the ground transportation entities that are capable of receiving the messages, and
- incorporating in the virtual safety messages information about one or more of the ground
- 15 transportation entities that are not capable of sending safety messages, the incorporated information in each of the virtual safety messages comprising at least one of the location, heading, speed, and predicted future trajectory of one of the ground transportation entities that are not capable of sending safety messages.
- 20 63. The method of claim 62 in which the incorporated information comprises a subset of information that would be incorporated in a basic safety message or a personal safety message generated by the ground transportation entity if it were capable of sending basic safety messages or personal safety messages.
64. The method of claim 62 comprising applying the generated motion data to a machine learning model running in equipment located in the vicinity of the intersection to predict a
- 25 trajectory of the ground transportation entity that is not capable of sending safety messages.
65. The method of claim 62 in which at least one of the ground transportation entities comprises a motorized vehicle.

66. The method of claim 62 in which the machine learning model is provided to the equipment located in the vicinity of the intersection by a remote server through the Internet.
67. The method of claim 62 in which the machine learning model is generated at the equipment located in the vicinity of the intersection.
- 5 68. The method of claim 62 comprising training the machine learning model using motion data generated by the sensors located in the vicinity of the intersection.
69. The method of claim 62 comprising sending motion data generated by the sensors located in the vicinity of the intersection to a server for use in training the machine learning model.
70. A method comprising
- 10 using electronic sensors located in a vicinity of a crosswalk that crosses a road to monitor an area in or nearby the crosswalk, the electronic sensors generating motion data about vulnerable roadway users who are in or nearby the pedestrian crosswalk,
- applying the generated motion data to a machine learning model running in equipment located in the vicinity of the crosswalk to predict that one of the vulnerable roadway users is
- 15 about to enter the crosswalk, and
- before the vulnerable roadway user enters the crosswalk, wirelessly transmitting a warning to at least one of: a device associated with the vulnerable roadway user, or a device associated with another ground transportation entity that is approaching the crosswalk on the road.
- 20 71. The method of claim 70 in which the vulnerable roadway user comprises a pedestrian, animal, or cyclist.
72. The method of claim 70 in which the device associated with the vulnerable roadway user comprises a smart watch or other wearable, a smart phone, or another mobile device.
73. The method of claim 70 in which the other ground transportation entity comprises a
- 25 motorized vehicle.
74. The method of claim 70 in which the device associated with the other ground transportation entity comprises a smart phone or another mobile device.

75. The method of claim 70 in which the machine learning model is provided to the equipment located in the vicinity of the crosswalk by a remote server through the Internet.
76. The method of claim 70 in which the machine learning model is generated at the equipment located in the vicinity of the crosswalk.
- 5 77. The method of claim 70 comprising training the machine learning model using motion data generated by the sensors located in the vicinity of the crosswalk.
78. The method of claim 70 comprising sending motion data generated by the sensors located in the vicinity of the crosswalk to a server for use in training the machine learning model.
79. The method of claim 70 comprising segmenting the motion data generated by the sensors
10 located in the vicinity of the crosswalk based on corresponding zones in the vicinity of the crosswalk.
80. The method of claim 70 comprising using the electronic sensors to generate motion related data representing physical properties of the vulnerable road user.
81. The method of claim 70 comprising deriving trajectory information about the vulnerable
15 road user from motion data generated by the sensor.
82. An apparatus comprising
- equipment located at a level crossing of a transportation network, the level crossing comprising an intersection of a road, a pedestrian crossing, and a rail line, the equipment comprising
- 20 inputs to receive data from sensors oriented to monitor road vehicles and pedestrians at or near the level crossing and to receive phase and timing data for signals on the road and on the rail line,
- a wireless communication device to send to a device of one of the ground transportation entities, pedestrians, or rail vehicles on the rail line, a warning about a dangerous
25 situation at or near the level crossing,,
- a processor, and
- a storage for instructions executable by the processor to

store a machine learning model that can predict behavior of ground transportation entities at or near the level crossing at a current time, the machine learning model being based on training data about previous motion and related behavior of road vehicles and pedestrians at or near the intersection,

5 apply current motion data received from the sensors about road vehicles and pedestrians at or near the level crossing to the machine learning model to predict imminent behaviors of the road vehicles and pedestrians,

infer an imminent dangerous situation for a rail vehicle on the rail line at or near the intersection from the predicted imminent behaviors, and

10 cause the wireless communication device to send the warning about the dangerous situation to a device of at least one of the road vehicles, pedestrians, and rail vehicle.

83. The apparatus of claim 82 in which the warning is sent to an on-board equipment of the rail vehicle.

84. The apparatus of claim 82 in which the rail line is on a segregated right of way.

15 85. The apparatus of claim 82 in which the rail line is not on a segregated right of way.

86. The apparatus of claim 82 in which the equipment comprises a roadside equipment.

87. The apparatus of claim 82 in which the warning is sent by broadcasting the warning for receipt by any of the ground transportation entities, pedestrians, or rail vehicles at or near the level crossing.

20 88. The apparatus of claim 82 in which the imminent dangerous situation comprises a collision or a near miss.

89. A method comprising

receiving data from infrastructure sensors representing positions and motions of road vehicles being driven or pedestrians walking in a ground transportation network,

25 receiving data in virtual basic safety messages and virtual personal safety messages about states of the road vehicles and pedestrians,

applying the received data to a machine learning model trained to identify dangerous driving or walking behavior of one of the road vehicles or pedestrians, and

reporting the dangerous driving or walking behavior to authorities.

90. The method of claim 89 comprising

5 identifying the road vehicles based on plate number recognition.

91. The method of claim 89 comprising

identifying the pedestrians based on biometric recognition.

92. The method of claim 89 comprising

identifying the road vehicles or pedestrians based on social networking.

10 93. A method comprising

using electronic sensors located in a vicinity of an intersection of a ground transportation network to monitor the intersection and approaches to the intersection, the electronic sensors generating motion data about ground transportation entities moving on the approaches or in the intersections,

15 defining distinct virtual zones in the intersection and the approaches to the intersection,

segmenting the motion data according to corresponding virtual zones to which the generated motion data relates,

applying the generated motion data for each of the respective segments to a machine learning model running in equipment located in the vicinity of the intersection to predict an

20 imminent dangerous situation in the intersection or one of the approaches involving one or more of the ground transportation entities,

before the imminent dangerous situation becomes an actual dangerous situation, wirelessly transmitting a warning to a device associated with at least one of the involved ground transportation entities.

25 94. The method of claim 93 in which the device associated with each of the ground transportation entities comprises a wearable, a smart phone, or another mobile device.

95. The method of claim 93 in which at least one of the ground transportation entities comprises a motorized vehicle.
96. The method of claim 93 in which the machine learning model is provided to the equipment located in the vicinity of the intersection by a remote server through the Internet.
- 5 97. The method of claim 93 in which the machine learning model is generated at the equipment located in the vicinity of the intersection.
98. The method of claim 93 comprising training the machine learning model using motion data generated by the sensors located in the vicinity of the intersection.
99. The method of claim 93 comprising sending motion data generated by the sensors located
10 in the vicinity of the intersection to a server for use in training the machine learning model.
100. The method of claim 93 comprising using the electronic sensors to monitor an area in or nearby a crosswalk that crosses one of the approaches to the intersection.
101. The method of claim 93 comprising using the electronic sensors to generate motion related data representing physical properties of a vulnerable road user in the vicinity of the
15 crosswalk.
102. The method of claim 93 comprising deriving trajectory information about the vulnerable road user from motion data generated by the sensor.
103. The method of claim 93 in which there is a machine learning model for each of the approaches to the intersection.
- 20 104. The method of claim 93 comprising determining whether to transmit the warning based also on motion data generated by sensors with respect to another nearby intersection.
105. The method of claim 93 comprising determining whether to transmit the warning based also on information received from ground transportation entities moving on the approaches or in the intersection.
- 25 106. The method of claim 93 in which the intersection is signalized and information about the state of the signals is received.

107. The method of claim 93 in which the intersection is not signalized and is controlled by one or more signs.
108. The method of claim 107 in which the defined virtual zones include one or more approaches controlled by the signs.
- 5 109. The method of claim 107 in which the signs comprise a stop sign or a yield sign.
110. The method of claim 107 in which one of the ground transportation entities comprises a rail vehicle.
111. An apparatus comprising
- equipment located at an intersection of a transportation network, the equipment comprising
- 10 inputs to receive data from sensors oriented to monitor ground transportation entities at or near the intersection,
- the data from each of the sensors representing at least one location or motion parameter of at least one of the ground transportation entities
- the data from each of the sensors being expressed in a native format,
- 15 the data received from at least two of the sensors being inconsistent with respect to the location or motion parameters or the native formats or both,
- a processor, and
- a storage for instructions executable by the processor to
- convert the data from each of the sensors into data having a common format
- 20 independent of the native formats of the data of the sensors,
- incorporate the data having the common format into a global unified representation of the ground transportation entities being monitored at or near the intersection, the global unified representation including the location, speed, and heading of each of the ground transportation entities,
- 25 determine relationships of locations and motions of two of the ground transportation entities using the global unified representation,

predict a dangerous situation involving the two ground transportation entities, and
send a message to at least one of the two ground transportation entities alerting it
to the dangerous situation.

112. The apparatus of claim 111 in which the sensors comprise at least two of: radar, lidar, and
5 a camera.

113. The apparatus of claim 111 in which the data received from one of the sensors comprises
image data of a field of view at successive moments.

114. The apparatus of claim 111 in which the data received from one of the sensors comprises
points of reflection in 3D space.

10 115. The apparatus of claim 111 in which the data received from one of the sensors comprises
distance from the sensor and speed.

116. The apparatus of claim 111 in which the global unified representation represents
locations of the ground transportation entities in a common reference frame.

117. The apparatus of claim 111 comprising at least two sensors from which the data is
15 received, the two sensors being mounted in fixed positions at or near the intersection and having
at least partially non-overlapping fields of view.

118. The apparatus of claim 117 in which one of the sensors comprises radar and converting
the data includes determining locations of ground transportation entities from a known location
of the radar and distances from the radar to the ground transportation entities.

20 119. The apparatus of claim 117 in which one of the sensors comprises a camera and
converting the data includes determining locations of ground transportation entities from a
known location, direction of view, and tilt of the camera and the locations of the ground
transportation entities within an image frame of the camera.

120. A method comprising
25 receiving data from sensors oriented to monitor ground transportation entities at or near
an intersection of a ground transportation network,

the data from each of the sensors representing at least one location or motion parameter of at least one of the ground transportation entities

the data from each of the sensors being expressed in a native format,

5 the data received from at least two of the sensors being inconsistent with respect to the location or motion parameters or the native formats or both,

converting the data from each of the sensors into data having a common format independent of the native formats of the data of the sensors,

10 incorporating the data having the common format into a global unified representation of the ground transportation entities being monitored at or near the intersection, the global unified representation including the location, speed, and heading of each of the ground transportation entities,

determining relationships of locations and motions of two of the ground transportation entities using the global unified representation,

15 predicting a dangerous situation involving the two ground transportation entities, and sending a message to at least one of the two ground transportation entities alerting it to the dangerous situation.

121. The method of claim 120 in which the sensors comprise at least two of: radar, lidar, and a camera.

20 122. The method of claim 120 in which the data received from one of the sensors comprises image data of a field of view at successive moments.

123. The method of claim 120 in which the data received from one of the sensors comprises points of reflection in 3D space.

124. The method of claim 120 in which the data received from one of the sensors comprises distance from the sensor and speed.

25 125. The method of claim 120 in which the global unified representation represents locations of the ground transportation entities in a common reference frame.

126. The method of claim 120 in which the data is received from at least two sensors from the two sensors being mounted in fixed positions at or near the intersection and having at least partially non-overlapping fields of view.

127. The method of claim 126 in which one of the sensors comprises radar and the method
5 comprises converting the data includes determining locations of ground transportation entities from a known location of the radar and distances from the radar to the ground transportation entities.

128. The method of claim 126 in which one of the sensors comprises a camera and the method
comprises converting the data includes determining locations of ground transportation entities
10 from a known location, direction of view, and tilt of the camera and the locations of the ground transportation entities within an image frame of the camera.