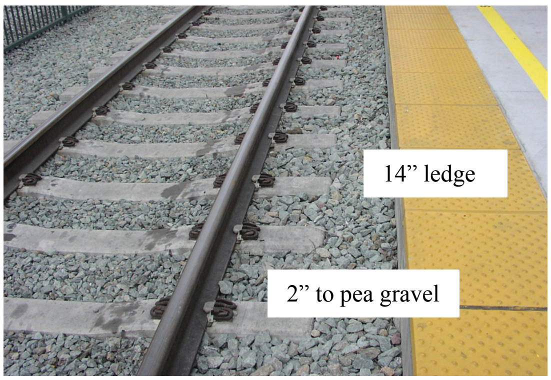
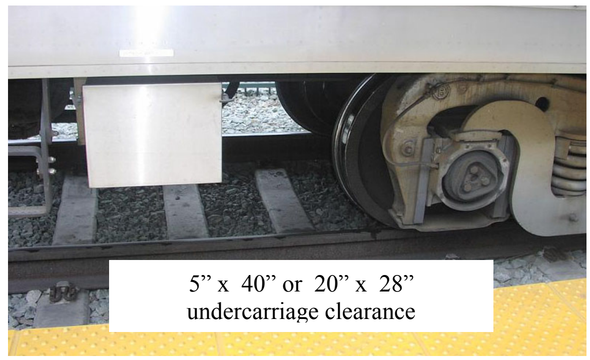
Roadways and Terrain

Roadways and terrain consist of paved streets and highways, railroad and subway tracks, bridges and tunnels, and all surrounding areas that a robotic device must traverse to access the vehicle thoroughfare. A robotic device can negotiate paved roads in good condition quite easily. Railroad tracks in open country are similarly unchallenging in the area along the track. Crossing the rail, however, will be difficult for a robotic device. Climbing the rail will be a challenge, and if the surrounding terrain is gravel or loose dirt, this will be a challenge too. To function in these conditions, a robotic device will have to meet certain wheel or continuous-tread requirements. Common rail sizes range from 132 to 136 lbs/yard, depending on whether they are 7 1/2- or 8-inches high. Gravel, dirt, sand, grass, and low brush get trapped in robotic device wheel and tread mechanisms; this requires that the device undercarriage and drive system design include either guards or a compliant drive train.





Unusual terrain features such as potholes and lowered track beds require that a device be able to straddle holes and drive off ledges. With vehicles on roadways or tracks, a clearance dimension also becomes critical. Shown above is a typical reduced-access railway situation in which the reduced access is caused by the vehicle. It will be difficult to find a robotic device that can negotiate high dividers, median barriers, and other extremely impenetrable roadway obstacles. The device will have to navigate around them.

Disaster situations on roadways include bridge collapses, smoke- or chemical-agent-filled tunnels or subways, weather- or bomb-damaged roads, and so forth. Unlike buildings, where floor-based fixtures might support a collapse and allow some vertical clearance, the extreme mass of roadway structures will overload such supports. In roadway collapses, the vehicles themselves are the supports that determine the clearances, and, as seen in the earthquake-damaged Cypress Street section of I-880 (Oakland, CA) shown below, will be reduced to an impenetrable height. No set standard can be suggested for such occurrences. The robotic device with the smallest physical dimensions that performs to all other requirements will fare best in a disaster.

By permission of ABS Consulting

Damaged Cypress Street section of I-880

Weather Conditions

By permission of Larry McNaughton

Weather conditions can challenge robotic device functioning ability. For the device to be mobile in snow and water and operable and storable in certain temperature ranges, certain requirements have to be met in the traction and motor power of the device's drive system; the robustness of electronic, electrical, and mechanical components with respect to temperature; and water-sealing capabilities. Military requirements are used in the sample requirements specification.

Optical Navigation Environments

Optical navigation refers to the robotic device operator's ability to operate the device remotely without seeing it or the terrain directly, relying only on the optical system on the robot. Optical navigation environments include lighting conditions, visibility (e.g., smoke or fog), and optical properties of targets (e.g., infrared, diffuse, or transparent). The demands of these environments must be met not only by a device's lighting and camera system, but also by other features. These include the use of multiple views, adequate picture quality in video presented to the operator, and the capability of commanding the optical system to simulate the operator actually being at the robot's location with the ability to look around. This feature is called "situational awareness" and is the single most important feature for ease and safety in controlling the robotic device. Some minimum robotic device requirements for transit environments include path flood lighting, end-effector lighting, and a steerable spotlight. Camera requirements include a forward-looking path camera, an overhead-steerable camera, and an arm-mounted camera for monitoring the end effector or viewing areas only accessible by the extended arm. The device's video presentation must allow the operator to view all the images with minimal confusion. The ability to zoom in/out is also a requirement for at least one camera. The system should also have auto focus, auto iris (mechanical or electronic), and image stabilization. For disasters with a smoke-filled environment, an infrared lighting and camera system is required.

Radio Environments

How well a robotic device can be operated remotely depends on the radio environment in which it is used. Interfering radio transmission from other sources is of little concern for the use of robotic devices in transit environments. However, closed metal structures, such as bus and train bodies, impair radio transmission and will limit the range of tele-operation. A radio link range for open terrain is determined by accessibility to the target and a safe operating distance in hazardous situations. An alternative to a poor radio link is an optical-fiber tether from the operator station to the robotic device. Two considerations—vehicle or structure length and a safe operating distance—will dictate how long the tether will have to be. Tethered operation of robotic devices is generally less desirable because cable kinking during deployment can lead to potential entanglements and possible fiber breakage.

Hazardous Environments

Hazardous environments typically include nuclear, biological, or chemical (NBC) threats. These hazards present several electrical and mechanical challenges for the robotic device. The main concern is whether it will able to operate in the presence of high radiation and corrosive chemicals. Nuclear radiation primarily affects the electronics of the device, including the video system. Biological hazards do not affect the device, but require it to be decontaminated, usually with a bleach solution. Chemical hazards, such as an acid spill, present the threat of corrosion. Robotic devices used in these kinds of hazardous environments need to meet requirement specifications for liquid-sealing ability and corrosion resistance of materials.

Other Requirements

The critical performance requirements for robotic device use in various parts of the transit environment have been reviewed above. There are, however, other requirements that must be met for robotic devices to operate successfully in the transit environment. These requirements are the following:

- Weight—The human carrying weight of the entire robotic system and individual components.
- Endurance—The length of the mission, usually a function of battery life.
- Speed—Robotic device ground speed, which determines time to target.
- Audio—The ability to listen and talk via the robotic device.
- Load—Amount of payload weight the robotic device and manipulator arm can carry.
- Set-up and turnaround times—Time to prepare to deploy and to refurbish for another mission.
- Reliability—Mean time between failure (MTBF) for mission hours.
- Maintainability—Mean time to repair (MTTR) and availability of spare parts and support.
- Usability—Ease of use, intuitive operation, and training.
- Industry compatibility—Conformance to industry standards, off-the-shelf components, common communication protocols, and ability to link to industry sensors and payloads.
- Survivability—Robustness of the design for shock, vibration, impact, and watertight seals.
- Cost—Within the typical budget of a law enforcement or civic agency.

Requirements Specification

As seen in the section "Environments," transit vehicles, structures, operating arena, and other related environmental conditions dictate requirement specifications for robotic devices used in transit applications. Table 1 presents a compilation of the requirements discussed in "Environments" with specifications determined by worst-case environmental demands. The source of the specification is given, and the objective of the requirement is listed for reference. This compilation, appropriately tailored, can serve as a requirements specification for a robotic device. Some requirements are not specific to the transit environment, so military standards or typical industrial-product specifications have been used to complete the specification. Two of these specifications are the Naval Sea System Command (NAVSEA) "Man Transportable Robotic System" (MTRS) solicitation and the National Institute of Justice (NIJ) "Bomb Disposal/Law Enforcement Robot Design Guidelines."

TRANSIT ENVIRONMENT ROBOT SYSTEM REQUIREMENTS

Table 1

REQUIREMENT	SPECIFICATION	OBJECTIVE	SOURCE
Size Length Width Height	Limited by Turn Circle, below 16 in. max. 12 in. max.	Stair to corridor transition Corridor width Under seat, disaster debris	Train corridor transition Bus corridor Bus seats
Weight	150 lbs max.	Carried by two people	Typ. human factors spec.
Speed	2 mph min.	On scene in 15 min	Typical access distance
Stair Climb Solid Gap	8 in. x 8 in. 12 in. x 8 in.	Building, vehicle stairway Curb to vehicle empty span	Bus & train steps Train step
Inscribed Turn Circle Severe Typical	 16 in. 36 in	Stair to corridor transition	Bus entrance Train upper deck
Slope Climb Traverse	60 deg. 45 deg.	Embankments	Train Station
Snow	4 in. deep min.	Roadside terrain	MTRS spec.
Hurtle	8 in.	Railroad track	Typical track
Curb	14 in.	Railroad platform curb	Train station
Rubble, Debris	4 in. diameter min.	Concrete building collapse	MTRS spec.
Loose Sand	2 in. deep min.	Roadside terrain	MTRS spec.
Gravel	2 in. diameter min.	Railroad track	Train station
High Grass, Brush	6 in. high min.	Roadside terrain	MTRS spec.
Shallow Water & Rain	2 in. deep min.	Pooled rain	MTRS spec.
Range Wireless Wired	½ mi min. ⅛ mi min.	Safe access Inside car, safe access	Train station Vehicle & safety
Endurance	½ mi driving, 1hr mission, ½ mi driving	Drive to/from mission, all functions for 1 hr	MTRS spec. & NIJ guidelines
Payload Weight	50 lbs min.	X-ray sensor payload	Typical sensor
Manipulator Reach Load Grip Dexterity	68 in. from ground 15 lbs 4 in. diameter min. 5 degrees of freedom	Luggage carrier X-ray source Retrieve pipe bomb Reach into overhead	Bus NIJ guidelines MTRS spec. Bus
Set-up Time Deploy Refresh	10 min, no tools 2 min no tools	Quick response time Quick battery change time	MTRS spec. MTRS spec.
Video Cameras Zoom Infrared	Path, steerable, arm 20X Optional	Full situational awareness Detailed viewing Night/smoke vision	Typical & hazardous rail environments
Lights	Path, steerable, arm, infrared	Same as video	Same as video
Audio	Two way, recordable	Survivor location Perpetrator statements	MTRS spec. & NIJ guidelines
Power	Rechargeable battery, 110VAC	Common battery charger	MTRS spec.
Data & Power Jacks	RS232, USB, 12VDC	Sensor & payload data	MTRS spec.
Usability	8 hrs training	Minimize training/practice	NIJ guidelines
Survivability	10 ft drop & tumble on dirt	Dropped, thrown, fall, etc.	Rough deployment
Reliability	100 mission hrs MTBF	Maximize up time	Typ. product standard
Maintenance	30 min MTTR	Minimize maintenance	Typ. product standard