TMC & 511 System Integration Guide

National Event Feeds & Auto-Notification System

DOT Corridor Communicator Integration Architecture

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Overview

Purpose

This document describes how to integrate the DOT Corridor Communicator with Traffic Management Centers (TMCs) and 511 traveler information systems to:

- **Aggregate national event feeds** from multiple sources
- **Distribute corridor-specific messages** to TMCs and 511 systems
- **Trigger auto-notifications** for impacted corridor traffic
- **Enable bi-directional data exchange** between systems
- **Provide real-time alerts** to travelers and fleet operators

Benefits

✅ **Real-time Traffic Intelligence** - Aggregated view of corridor conditions across states ✅ **Automated Alerting** - Instant notifications when incidents affect your corridors ✅ **Multi-State Coordination** - Share events seamlessly between neighboring states ✅ **Traveler Information** - Push critical updates to 511 systems automatically ✅ **Fleet Management** - Enable commercial vehicle operators to receive corridor alerts ✅ **Grant Competitiveness** - Demonstrate advanced traffic management capabilities

Key Standards

- **TMDD** (Traffic Management Data Dictionary) - Event data exchange
- **CAP** (Common Alerting Protocol) - Emergency alerts
- **EDXL-DE** (Emergency Data Exchange Language) - Event distribution
- **SAE J2354** - Advanced Traveler Information Systems (ATIS)
- **NTCIP 1218** - Transportation sensor systems
- **WZDx** (Work Zone Data Exchange) - Construction information

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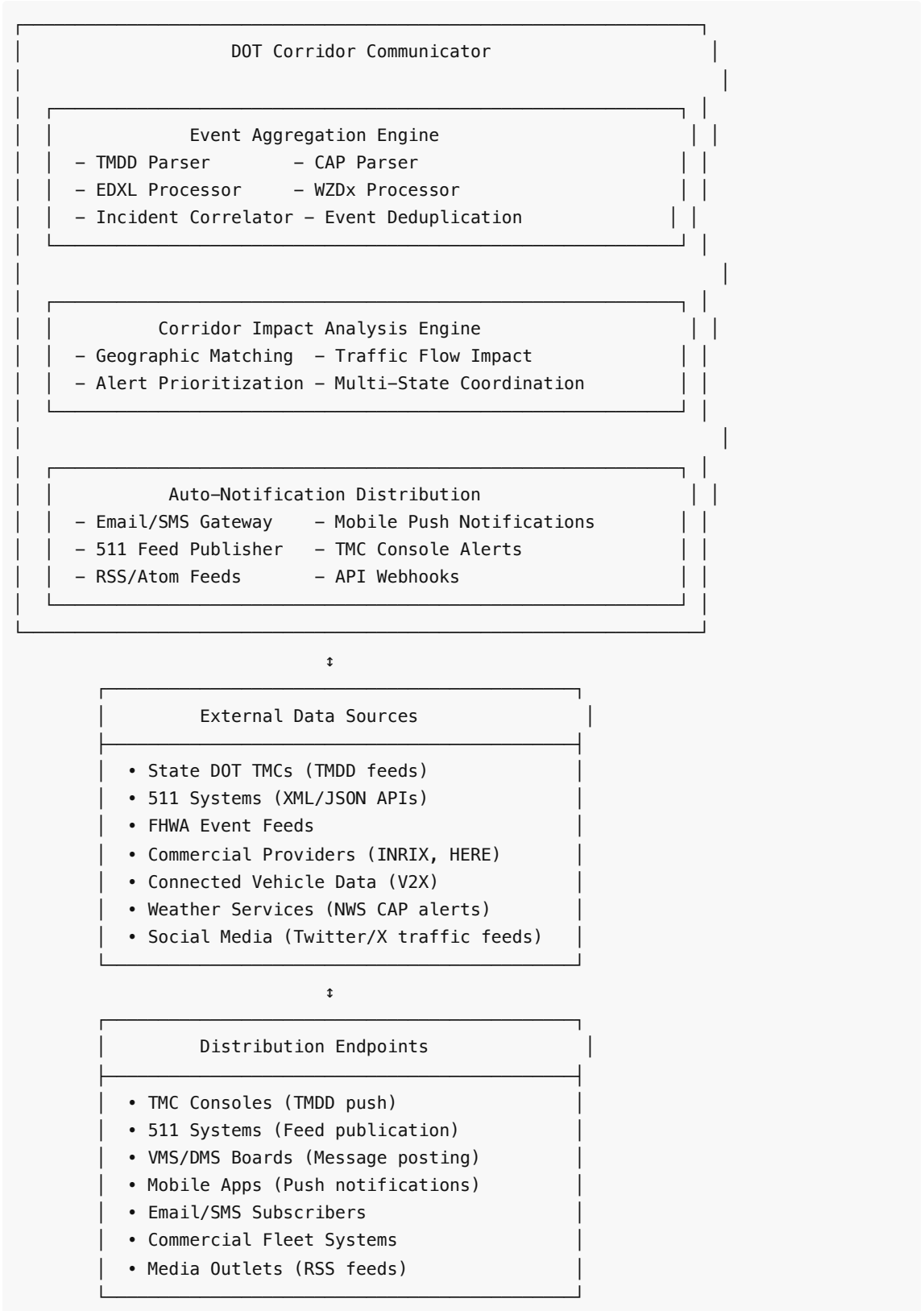
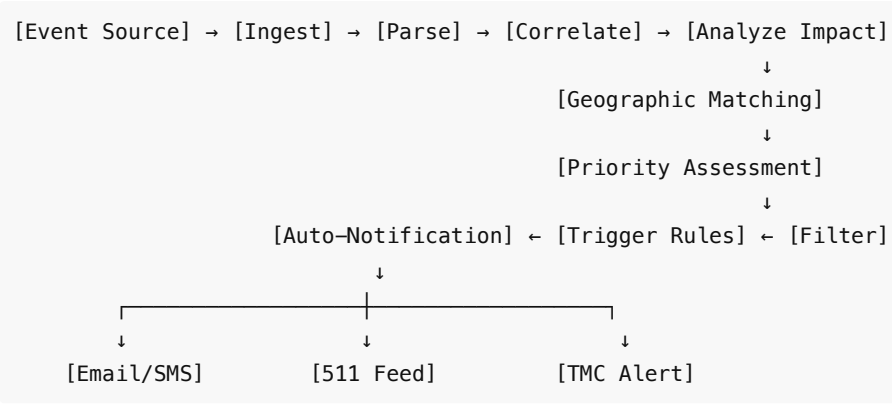
System Architecture

High-Level Architecture



Data Flow



Integration Standards

1. TMDD (Traffic Management Data Dictionary)

Version: TMDD v3.1 (current standard) **Format**: XML **Use**: Incident/event data exchange between TMCs

Key Message Types:

Event Reporting:

```xml
<tmdd:eventReport>
  <event-id>IA-I80-2025-001</event-id>
  <event-type>crash</event-type>
  <severity>major</severity>
  <location>
    <link-id>I-80</link-id>
    <direction>eastbound</direction>
    <milepost>100.5</milepost>
  </location>
  <impact>
    <lanes-blocked>2</lanes-blocked>
    <expected-duration>90</expected-duration>
    <queue-length>3.2</queue-length>
  </impact>
  <timestamp>2025-12-27T10:15:00Z</timestamp>
</tmdd:eventReport>
```

Equipment Status:

```xml
<tmdd:equipmentStatus>
  <equipment-id>VMS-I80-MM100</equipment-id>
  <equipment-type>dynamic-message-sign</equipment-type>
  <status>operational</status>
  <current-message>CRASH AHEAD - RIGHT LANES BLOCKED</current-message>
</tmdd:equipmentStatus>
```

Benefits:

- ✅ Standard used by all major TMC vendors (Delcan, TransSuite, ATMS.now)
- ✅ Comprehensive event taxonomy
- ✅ Built-in geographic referencing
- ✅ Impact assessment fields

2. CAP (Common Alerting Protocol)

Version: CAP v1.2 (OASIS standard) **Format**: XML **Use**: Emergency alerts, weather warnings, public safety

CAP Alert Structure:

```
<alert xmlns="urn:oasis:names:tc:emergency:cap:1.2">
  <identifier>IA-DOT-I80-ALERT-2025-001</identifier>
  <sender>iowa.dot@iowa.gov</sender>
  <sent>2025-12-27T10:15:00-06:00</sent>
  <status>Actual</status>
  <msgType>Alert</msgType>
  <scope>Public</scope>

  <info>
    <category>Transport</category>
    <event>Major Traffic Incident</event>
    <urgency>Expected</urgency>
    <severity>Severe</severity>
    <certainty>Observed</certainty>
    <headline>Major Crash on I-80 EB at MM 100</headline>
    <description>
      Multi-vehicle crash blocking right 2 lanes. Expect delays of 30+ minutes.
      Alternate route: US-6 or I-35 to I-80.
    </description>
    <instruction>Use alternate routes. Reduce speed and watch for emergency
vehicles.</instruction>

    <area>
      <areaDesc>I-80 Eastbound MM 98-105, Polk County, Iowa</areaDesc>
      <polygon>41.59,-93.65 41.59,-93.55 41.57,-93.55 41.57,-93.65
41.59,-93.65</polygon>
    </area>
  </info>
</alert>
```

Benefits:

- ✅ FEMA IPAWS (Integrated Public Alert & Warning System) compatible
- ✅ Wireless Emergency Alerts (WEA) ready
- ✅ Geographic targeting (polygon/circle)
- ✅ Multi-language support

3. EDXL-DE (Emergency Data Exchange Language - Distribution Element)

Version: EDXL-DE v1.0 **Format**: XML **Use**: Routing and packaging of emergency information

EDXL Wrapper:

```xml
<EDXLDistribution xmlns="urn:oasis:names:tc:emergency:EDXL:DE:1.0">
  <distributionID>IA-DOT-DIST-2025-001</distributionID>
  <senderID>iowa.dot@iowa.gov</senderID>
  <dateTimeSent>2025-12-27T10:15:00-06:00</dateTimeSent>
  <distributionStatus>Actual</distributionStatus>
  <distributionType>Report</distributionType>

  <targetArea>
    <circle>41.59,-93.62 10</circle> <!-- 10 mile radius -->
  </targetArea>

  <contentObject>
    <contentDescription>Traffic Incident Alert</contentDescription>
    <xmlContent>
      <!-- CAP or TMDD message here -->
    </xmlContent>
  </contentObject>
</EDXLDistribution>
```

Benefits:

- ✅ Message routing to specific recipients
- ✅ Multi-message bundling
- ✅ Digital signatures for authenticity
- ✅ Distribution tracking

4. WZDx (Work Zone Data Exchange)

Version: WZDx v4.2 **Format**: GeoJSON **Use**: Construction/maintenance zone information

WZDx Feed:

```json
{
  "feed_info": {
    "publisher": "Iowa DOT",
    "version": "4.2",
    "update_frequency": 300,
    "update_date": "2025-12-27T10:15:00Z"
  },
  "type": "FeatureCollection",
  "features": [{
    "type": "Feature",
    "properties": {
      "core_details": {
        "event_type": "work-zone",
        "road_names": ["Interstate 80"],
        "direction": "eastbound",
        "beginning_milepost": 100.0,
        "ending_milepost": 105.0,
        "start_date": "2025-06-01T06:00:00Z",
```

```
        "end_date": "2025-09-30T18:00:00Z"
      },
      "restrictions": [{
        "type": "reduced-width",
        "value": 11,
        "unit": "feet"
      }],
      "types_of_work": [{
        "type_name": "surface-work",
        "is_architectural_change": false
      }]
    },
    "geometry": {
      "type": "LineString",
      "coordinates": [
        [-93.625, 41.586],
        [-93.600, 41.588],
        [-93.575, 41.590]
      ]
    }
  }]
}
```

Benefits:

- ✅ Standard adopted by major navigation apps (Google, Apple, Waze)
- ✅ Real-time updates
- ✅ Lane-level detail
- ✅ Equipment restrictions (height, width, weight)

TMC Integration

Architecture

```
DOT Corridor Communicator ↔ TMC System
        ↓                          ↓
   [REST API]                [TMDD Feed]
        ↓                          ↓
   [WebSocket]               [NTCIP 1218]
        ↓                          ↓
   [Message Bus]             [Database]
```

Integration Methods

Method 1: TMDD XML Feed (Pull)

TMC pulls events from Corridor Communicator

Endpoint:

```
GET /api/tmc/events/tmdd
```

Query Parameters:

- `corridor` - Filter by corridor (e.g., I-80)
- `severity` - Filter by severity (minor, major, critical)
- `event_type` - Filter by type (crash, hazard, weather, etc.)
- `since` - Events since timestamp (ISO 8601)
- `bbox` - Bounding box (minLon,minLat,maxLon,maxLat)

Response:

```
<?xml version="1.0" encoding="UTF-8"?>
<tmdd:eventFeed xmlns:tmdd="http://www.tmdd.org/303/messages">
  <feed-metadata>
    <publisher>DOT Corridor Communicator</publisher>
    <update-frequency>60</update-frequency>
    <last-updated>2025-12-27T10:15:00Z</last-updated>
  </feed-metadata>

  <events>
    <event>
      <event-id>IA-I80-2025-001</event-id>
      <event-type>crash</event-type>
      <severity>major</severity>
      <!-- Full TMDD event details -->
    </event>
  </events>
</tmdd:eventFeed>
```

Update Frequency: 30-60 seconds recommended

Method 2: Real-Time WebSocket (Push)

Corridor Communicator pushes events to TMC

Connection:

```
const tmcSocket = new WebSocket('wss://api.corridor.gov/tmc/stream');

tmcSocket.on('connect', () => {
  // Subscribe to specific corridors
  tmcSocket.send(JSON.stringify({
    action: 'subscribe',
    corridors: ['I-80', 'I-35', 'I-29'],
    event_types: ['crash', 'hazard', 'weather'],
    min_severity: 'major'
  }));
});

tmcSocket.on('event', (data) => {
  // Process incoming event
  const event = JSON.parse(data);
  displayOnTMCConsole(event);
```

```
  updateTrafficMap(event);

  if (event.severity === 'critical') {
    triggerAudibleAlert();
  }
});
```

Message Format:

```
{
  "message_type": "event_update",
  "event_id": "IA-I80-2025-001",
  "timestamp": "2025-12-27T10:15:00Z",
  "event_type": "crash",
  "severity": "major",
  "location": {
    "corridor": "I-80",
    "direction": "eastbound",
    "milepost": 100.5,
    "coordinates": {
      "latitude": 41.5868,
      "longitude": -93.6250
    }
  },
  "impact": {
    "lanes_blocked": 2,
    "total_lanes": 3,
    "queue_length_miles": 3.2,
    "expected_duration_minutes": 90,
    "delay_minutes": 35
  },
  "description": "Multi-vehicle crash involving semi-truck",
  "responders": ["Iowa State Patrol", "DOT FIRST Team"],
  "cameras": ["CAM-I80-MM100-EB"],
  "vms_boards": ["VMS-I80-MM98-EB", "VMS-I80-MM95-EB"]
}
```

Benefits:

- ✅ Instant notifications (< 1 second latency)
- ✅ Reduced server load (no polling)
- ✅ Bi-directional communication
- ✅ Connection status monitoring

Method 3: NTCIP 1218 Integration (Equipment Control)

Direct control of roadside equipment

Use Cases:

- Post messages to VMS/DMS boards
- Activate warning signs
- Control ramp meters

- Adjust traffic signals

Example - Post VMS Message:

```
// Via Corridor Communicator API
POST /api/tmc/vms/post-message

{
  "equipment_id": "VMS-I80-MM95-EB",
  "message": {
    "pages": [
      {
        "text": "CRASH AHEAD",
        "display_time": 3
      },
      {
        "text": "RIGHT LANES BLOCKED",
        "display_time": 3
      },
      {
        "text": "USE CAUTION",
        "display_time": 2
      }
    ],
    "priority": "high",
    "duration": 3600,
    "triggered_by": "event:IA-I80-2025-001"
  }
}
```

Corridor Communicator translates to NTCIP 1218:

```
SET dmsMessageMultiString.1.1.0 = "[cr3][jl3][fo3]CRASH AHEAD[cr3][jl3][fo3]RIGHT
LANES BLOCKED[cr3][jl3][fo3]USE CAUTION"
SET dmsMessagePriority.1.1.0 = 255
SET dmsActivateMessage.1.1.0 = 1
```

TMC Console Integration

Display Event on TMC Map:

```
// Corridor Communicator provides map-ready data
GET /api/tmc/events/map-layer

// Returns GeoJSON for direct display
{
  "type": "FeatureCollection",
  "features": [{
    "type": "Feature",
    "geometry": {
      "type": "Point",
      "coordinates": [-93.6250, 41.5868]
```

```
    },
    "properties": {
      "event_id": "IA-I80-2025-001",
      "event_type": "crash",
      "severity": "major",
      "icon": "crash-major",
      "popup_html": "<strong>Major Crash</strong><br>I-80 EB @ MM 100.5<br>2 lanes
blocked<br>35 min delay",
      "style": {
        "color": "#FF0000",
        "size": "large",
        "blink": true
      }
    }
  }]
}
```

---

511 System Integration

Overview

511 systems provide traveler information via:

- **Phone** (dial 511)
- **Web** (511ia.org, 511ne.org, etc.)
- **Mobile Apps** (iOS/Android)
- **Social Media** (Twitter/X, Facebook)
- **Email/SMS Alerts**

Integration Architecture

```
Corridor Communicator → 511 System
         ↓                    ↓
    [Event Feed]         [IVR System]
         ↓                    ↓
    [CAP Alerts]         [Web Display]
         ↓                    ↓
    [RSS Feeds]          [Mobile Apps]
         ↓                    ↓
   [API Webhooks]        [Alert Subscriptions]
```

Method 1: XML Event Feed

511 System polls Corridor Communicator

Endpoint:

```
GET /api/511/events/xml
```

Response (SAE J2354 compliant):

```xml
<?xml version="1.0" encoding="UTF-8"?>
<traffic-data xmlns="http://www.sae.org/j2354">
  <metadata>
    <provider>Iowa DOT Corridor Communicator</provider>
    <timestamp>2025-12-27T10:15:00Z</timestamp>
    <coverage-area>
      <state>IA</state>
      <corridors>I-80, I-35, I-29, US-30</corridors>
    </coverage-area>
  </metadata>

  <incidents>
    <incident>
      <id>IA-I80-2025-001</id>
      <type>crash</type>
      <severity>major</severity>
      <reported-time>2025-12-27T10:05:00Z</reported-time>
      <location>
        <route>I-80</route>
        <direction>eastbound</direction>
        <cross-street>Exit 125 (Altoona)</cross-street>
        <county>Polk</county>
        <latitude>41.5868</latitude>
        <longitude>-93.6250</longitude>
      </location>
      <impact>
        <affected-lanes>right 2 lanes</affected-lanes>
        <delay>35 minutes</delay>
        <queue>3.2 miles</queue>
      </impact>
      <description>Multi-vehicle crash. Emergency crews on scene.</description>
      <advice>Use alternate route: US-6 or I-35 to I-80 west of Des Moines.</advice>
    </incident>
  </incidents>

  <road-conditions>
    <segment>
      <route>I-80</route>
      <direction>both</direction>
      <from-milepost>100</from-milepost>
      <to-milepost>105</to-milepost>
      <condition>wet</condition>
      <visibility>reduced</visibility>
      <temperature>34</temperature>
      <advisory>Patchy fog. Use caution.</advisory>
    </segment>
  </road-conditions>
</traffic-data>
```

Method 2: JSON REST API

Modern 511 systems prefer JSON

Endpoint:

```
GET /api/511/events/json?format=v2
```

Response:


```
{
  "metadata": {
    "version": "2.0",
    "provider": "Iowa DOT Corridor Communicator",
    "timestamp": "2025-12-27T10:15:00Z",
    "update_frequency": 60,
    "coverage": {
      "state": "IA",
      "corridors": ["I-80", "I-35", "I-29", "US-30"]
    }
  },
  "incidents": [{
    "id": "IA-I80-2025-001",
    "type": "crash",
    "severity": "major",
    "status": "active",
    "reported_at": "2025-12-27T10:05:00Z",
    "updated_at": "2025-12-27T10:15:00Z",
    "location": {
      "corridor": "I-80",
      "direction": "eastbound",
      "milepost": 100.5,
      "cross_street": "Exit 125 (Altoona)",
      "county": "Polk",
      "coordinates": {
        "latitude": 41.5868,
        "longitude": -93.6250
      }
    },
    "impact": {
      "lanes_blocked": "right 2 lanes",
      "lanes_open": "left lane, shoulder",
      "delay_minutes": 35,
      "queue_miles": 3.2,
      "expected_clearance": "2025-12-27T11:45:00Z"
    },
    "description": "Multi-vehicle crash involving semi-truck. Emergency crews on
scene.",
    "traveler_advice": "Use alternate route: US-6 or I-35 to I-80 west of Des
Moines.",
    "cameras": [{
      "id": "CAM-I80-MM100-EB",
      "url": "https://lb.511ia.org/ialb/cameras/routeselect.jsf?
view=state&camera=100"
```

```
    }],
    "related_alerts": ["WEATHER-IA-2025-045"]
  }],
  "road_conditions": [{
    "corridor": "I-80",
    "direction": "both",
    "from_milepost": 100,
    "to_milepost": 105,
    "surface_condition": "wet",
    "visibility": "reduced",
    "temperature_f": 34,
    "weather": "light rain, patchy fog",
    "advisory": "Use caution. Reduce speed in fog."
  }],
  "construction": [{
    "id": "WZ-I80-2025-SUMMER",
    "corridor": "I-80",
    "direction": "eastbound",
    "from_milepost": 110,
    "to_milepost": 115,
    "start_date": "2025-06-01",
    "end_date": "2025-09-30",
    "restrictions": "right lane closed, reduced speed 55 mph",
    "work_type": "pavement resurfacing"
  }]
}
```

Method 3: CAP Alert Distribution

Push alerts to 511 for immediate traveler notification

When to Send CAP:

- Major incidents (severity ≥ major)
- Road closures
- Weather emergencies
- Amber alerts related to highways

Endpoint:

```
POST /api/511/alerts/cap
```

Payload:

```
<alert xmlns="urn:oasis:names:tc:emergency:cap:1.2">
  <identifier>IA-DOT-I80-ALERT-2025-001</identifier>
  <sender>iowa.corridor@iowa.gov</sender>
  <sent>2025-12-27T10:15:00-06:00</sent>
  <status>Actual</status>
  <msgType>Alert</msgType>
  <scope>Public</scope>
```

```
  <info>
    <category>Transport</category>
    <event>Major Traffic Incident</event>
    <urgency>Expected</urgency>
    <severity>Severe</severity>
    <certainty>Observed</certainty>
    <headline>Major Crash I-80 EB at MM 100 - Expect Delays</headline>
    <description>
      Multi-vehicle crash blocking right 2 lanes on I-80 eastbound at
      milepost 100.5 near Altoona. Emergency crews on scene. Expect
      delays of 30-40 minutes. Queue extends back 3+ miles.
    </description>
    <instruction>
      Use alternate routes. Consider US-6 or I-35 to bypass area.
      Reduce speed and watch for emergency vehicles.
    </instruction>
    <contact>Iowa DOT TMC: 515-239-1101</contact>

    <area>
      <areaDesc>I-80 Eastbound MM 98-105, Polk County, Iowa</areaDesc>
      <polygon>
        41.59,-93.65 41.59,-93.55 41.57,-93.55 41.57,-93.65 41.59,-93.65
      </polygon>
    </area>

    <parameter>
      <valueName>EventType</valueName>
      <value>TrafficIncident</value>
    </parameter>
    <parameter>
      <valueName>Corridor</valueName>
      <value>I-80</value>
    </parameter>
    <parameter>
      <valueName>Milepost</valueName>
      <value>100.5</value>
    </parameter>
  </info>
</alert>
```

511 System Actions:

- Post to website homepage
- Send to mobile app subscribers
- Update IVR (phone) system
- Tweet from @511Iowa account
- Email/SMS alert subscribers

Method 4: Subscription-Based Webhooks

511 subscribes to specific event types

Setup:

```
POST /api/511/subscriptions

{
  "subscriber_id": "511-iowa",
  "webhook_url": "https://api.511ia.org/webhooks/corridor-events",
  "webhook_secret": "shared-secret-key",
  "filters": {
    "corridors": ["I-80", "I-35", "I-29"],
    "event_types": ["crash", "road-closed", "weather"],
    "min_severity": "major",
    "counties": ["Polk", "Dallas", "Warren"]
  },
  "delivery_method": "webhook",
  "retry_policy": {
    "max_attempts": 3,
    "backoff": "exponential"
  }
}
```

When event matches, Corridor Communicator POSTs:

```
POST https://api.511ia.org/webhooks/corridor-events

Headers:
  X-Corridor-Signature: sha256=hash-of-body-with-secret
  Content-Type: application/json

Body:
{
  "subscription_id": "sub-511-iowa-001",
  "event_id": "IA-I80-2025-001",
  "event_type": "crash",
  "timestamp": "2025-12-27T10:15:00Z",
  "data": {
    /* Full event details */
  }
}
```

511 System Acknowledges:

```
HTTP/1.1 200 OK
{
  "received": true,
  "event_id": "IA-I80-2025-001",
  "actions_taken": [
    "posted_to_website",
    "sent_to_mobile_apps",
    "updated_ivr"
  ]
}
```

National Event Feed Aggregation

Multi-Source Integration

```
National Event Sources:
├── State DOT TMCs (50 states)
│   ├── TMDD XML Feeds
│   ├── REST APIs
│   └── WebSocket Streams
├── 511 Systems (40+ systems)
│   ├── XML Feeds
│   └── JSON APIs
├── Federal Systems
│   ├── FHWA Real-Time Data
│   ├── NWS Weather Alerts (CAP)
│   └── USGS Earthquake Alerts
├── Commercial Providers
│   ├── INRIX (incidents, speeds)
│   ├── HERE (traffic flow)
│   └── Waze (crowdsourced)
└── Social Media
    ├── Twitter/X (#traffic)
    └── DOT Social Feeds
```

Data Ingestion Pipeline

```
// Event ingestion from multiple sources
class NationalEventAggregator {
  constructor() {
    this.sources = [];
    this.eventQueue = new Queue('national-events');
    this.deduplicator = new EventDeduplicator();
  }

  // Add data source
  addSource(source) {
    const ingestor = {
      id: source.id,
      type: source.type, // 'tmdd', 'cap', 'wzdx', 'json'
      url: source.url,
      poll_interval: source.poll_interval || 60000,
      parser: this.getParser(source.type)
    };

    // Start polling
    setInterval(async () => {
      try {
        const data = await fetch(source.url);
        const events = ingestor.parser(data);
```

```
      for (const event of events) {
        await this.ingestEvent(event, source.id);
      }
    } catch (error) {
      console.error(`Failed to fetch from ${source.id}:`, error);
    }
  }, ingestor.poll_interval);

  this.sources.push(ingestor);
}

// Ingest and process event
async ingestEvent(rawEvent, sourceId) {
  // Normalize to common format
  const normalized = this.normalizeEvent(rawEvent, sourceId);

  // Deduplicate (same event from multiple sources)
  const isDuplicate = await this.deduplicator.check(normalized);
  if (isDuplicate) {
    console.log(`Duplicate event filtered: ${normalized.id}`);
    return;
  }

  // Enrich with additional data
  const enriched = await this.enrichEvent(normalized);

  // Store in database
  await db.run(`
    INSERT INTO national_events
    (event_id, source_id, event_type, severity, corridor,
     latitude, longitude, data, ingested_at)
    VALUES (?, ?, ?, ?, ?, ?, ?, ?, ?)
  `, [
    enriched.id,
    sourceId,
    enriched.type,
    enriched.severity,
    enriched.corridor,
    enriched.location.latitude,
    enriched.location.longitude,
    JSON.stringify(enriched),
    new Date()
  ]);

  // Analyze corridor impact
  await this.analyzeCorridorImpact(enriched);
}

// Normalize different formats to common schema
normalizeEvent(rawEvent, sourceId) {
  const parsers = {
    'tmdd': this.parseTMDD,
```

```
    'cap': this.parseCAP,
    'wzdx': this.parseWZDx,
    'inrix': this.parseINRIX
  };

  const sourceType = this.sources.find(s => s.id === sourceId).type;
  return parsers[sourceType](rawEvent);
}

// Enrich event with corridor context
async enrichEvent(event) {
  // Add corridor information
  if (!event.corridor) {
    event.corridor = await this.geocodeToCorridor(
      event.location.latitude,
      event.location.longitude
    );
  }

  // Add milepost if missing
  if (!event.milepost && event.corridor) {
    event.milepost = await this.calculateMilepost(
      event.corridor,
      event.location.latitude,
      event.location.longitude
    );
  }

  // Add nearby cameras
  event.cameras = await this.findNearbyCameras(
    event.location.latitude,
    event.location.longitude,
    5 // 5 mile radius
  );

  // Add weather data
  event.weather = await this.getWeatherAtLocation(
    event.location.latitude,
    event.location.longitude
  );

  return event;
}

// Analyze impact on corridors
async analyzeCorridorImpact(event) {
  // Get all corridors within impact radius
  const impactedCorridors = await this.getCorridorsInRadius(
    event.location.latitude,
    event.location.longitude,
    event.impact.radius || 10 // miles
  );
```

```
    for (const corridor of impactedCorridors) {
      // Calculate impact score
      const impactScore = this.calculateImpactScore(event, corridor);

      if (impactScore >= NOTIFICATION_THRESHOLD) {
        // Trigger auto-notifications
        await this.triggerNotifications(event, corridor, impactScore);
      }
    }
  }
}
```

Event Deduplication

Challenge: Same incident reported by multiple sources

Solution: Spatial-temporal correlation

```
class EventDeduplicator {
  async check(event) {
    // Find events in same area within time window
    const similar = await db.all(`
      SELECT * FROM national_events
      WHERE event_type = ?
        AND corridor = ?
        AND ABS(latitude - ?) < 0.01  -- ~0.6 miles
        AND ABS(longitude - ?) < 0.01
        AND ingested_at > datetime('now', '-30 minutes')
    `, [
      event.type,
      event.corridor,
      event.location.latitude,
      event.location.longitude
    ]);

    if (similar.length === 0) {
      return false; // Not a duplicate
    }

    // Merge with existing event (take best data from each source)
    const existing = similar[0];
    const merged = this.mergeEvents(existing, event);

    await db.run(`
      UPDATE national_events
      SET data = ?, sources = ?
      WHERE event_id = ?
    `, [
      JSON.stringify(merged),
      JSON.stringify([...existing.sources, event.source]),
      existing.event_id
```

```
    ]);

    return true; // Is a duplicate
  }

  mergeEvents(existing, incoming) {
    return {
      ...existing,
      // Take most recent timestamp
      timestamp: Math.max(existing.timestamp, incoming.timestamp),
      // Take highest severity
      severity: this.maxSeverity(existing.severity, incoming.severity),
      // Combine descriptions
      description: `${existing.description}\n\nUpdate: ${incoming.description}`,
      // Merge impact data (take maximum values)
      impact: {
        lanes_blocked: Math.max(
          existing.impact.lanes_blocked,
          incoming.impact.lanes_blocked
        ),
        delay_minutes: Math.max(
          existing.impact.delay_minutes,
          incoming.impact.delay_minutes
        )
      },
      // Track all sources
      sources: [...new Set([...existing.sources, incoming.source])]
    };
  }
}
```

Auto-Notification Triggers

Trigger Rules Engine

```
class NotificationTriggerEngine {
  constructor() {
    this.rules = [];
    this.loadRules();
  }

  loadRules() {
    // Rule 1: Major incidents on priority corridors
    this.rules.push({
      name: 'Major Incident - Priority Corridors',
      condition: (event, corridor) => {
        return event.severity === 'major' &&
               corridor.priority === 'high' &&
               event.type === 'crash';
      },
```

```
      actions: [
        { type: 'email', recipients: 'tmc-operators' },
        { type: 'sms', recipients: 'on-call-supervisors' },
        { type: 'push', app: 'tmc-mobile' },
        { type: 'vms', message: 'CRASH AHEAD - USE CAUTION' }
      ],
      priority: 'high'
    });

    // Rule 2: Road closures
    this.rules.push({
      name: 'Road Closure Alert',
      condition: (event, corridor) => {
        return event.type === 'road-closed' ||
               (event.impact && event.impact.lanes_blocked >=
event.impact.total_lanes);
      },
      actions: [
        { type: 'email', recipients: 'all-staff' },
        { type: 'sms', recipients: 'supervisors' },
        { type: '511-alert', priority: 'immediate' },
        { type: 'social-media', platforms: ['twitter', 'facebook'] },
        { type: 'vms', message: 'ROAD CLOSED - USE ALT ROUTE' }
      ],
      priority: 'critical'
    });

    // Rule 3: Multi-state corridor events
    this.rules.push({
      name: 'Multi-State Coordination',
      condition: (event, corridor) => {
        return corridor.multi_state === true &&
               event.severity >= 'moderate';
      },
      actions: [
        { type: 'webhook', url: 'https://api.neighboring-state.gov/events' },
        { type: 'email', recipients: 'regional-coordinators' }
      ],
      priority: 'medium'
    });

    // Rule 4: Weather emergencies
    this.rules.push({
      name: 'Severe Weather Alert',
      condition: (event, corridor) => {
        return event.type === 'weather' &&
               (event.subtype === 'blizzard' ||
                event.subtype === 'ice-storm' ||
                event.visibility < 0.25);
      },
      actions: [
        { type: 'email', recipients: 'all-staff' },
```

```
        { type: 'sms', recipients: 'snow-plow-operators' },
        { type: '511-alert', priority: 'immediate' },
        { type: 'cap-alert', scope: 'public' },
        { type: 'vms', message: 'SEVERE WEATHER - REDUCE SPEED' }
      ],
      priority: 'critical'
    });

    // Rule 5: Construction zone incidents
    this.rules.push({
      name: 'Work Zone Incident',
      condition: (event, corridor) => {
        return this.isInWorkZone(event, corridor) &&
               event.type === 'crash';
      },
      actions: [
        { type: 'email', recipients: 'work-zone-supervisors' },
        { type: 'sms', recipients: 'contractor-on-site' },
        { type: 'vms', message: 'INCIDENT IN WORK ZONE' }
      ],
      priority: 'high'
    });

    // Rule 6: Hazmat spills
    this.rules.push({
      name: 'Hazardous Materials Alert',
      condition: (event, corridor) => {
        return event.type === 'hazmat' ||
               (event.description &&
event.description.toLowerCase().includes('spill'));
      },
      actions: [
        { type: 'email', recipients: 'emergency-coordinators' },
        { type: 'sms', recipients: 'hazmat-team' },
        { type: 'phone-call', numbers: 'emergency-contacts' },
        { type: 'cap-alert', scope: 'public', urgency: 'immediate' },
        { type: '511-alert', priority: 'critical' },
        { type: 'vms', message: 'HAZMAT INCIDENT - AREA CLOSED' }
      ],
      priority: 'critical'
    });

    // Rule 7: Recurring congestion (analytics-based)
    this.rules.push({
      name: 'Unexpected Congestion',
      condition: (event, corridor) => {
        return event.type === 'congestion' &&
               event.speed < corridor.typical_speed * 0.5 &&
               !this.isRushHour();
      },
      actions: [
        { type: 'email', recipients: 'traffic-analysts' },
```

```
      { type: 'dashboard-alert', display: 'anomaly-detection' }
    ],
    priority: 'low'
  });
}

async evaluateEvent(event, corridor) {
  const triggeredRules = [];

  for (const rule of this.rules) {
    if (rule.condition(event, corridor)) {
      triggeredRules.push(rule);
      await this.executeActions(rule.actions, event, corridor);

      // Log trigger
      await db.run(`
        INSERT INTO notification_triggers
        (event_id, rule_name, priority, triggered_at)
        VALUES (?, ?, ?, ?)
      `, [event.id, rule.name, rule.priority, new Date()]);
    }
  }

  return triggeredRules;
}

async executeActions(actions, event, corridor) {
  for (const action of actions) {
    try {
      await this.performAction(action, event, corridor);
    } catch (error) {
      console.error(`Failed to execute action ${action.type}:`, error);
      // Continue with other actions
    }
  }
}

async performAction(action, event, corridor) {
  const handlers = {
    'email': this.sendEmail,
    'sms': this.sendSMS,
    'push': this.sendPushNotification,
    'vms': this.postVMSMessage,
    '511-alert': this.send511Alert,
    'cap-alert': this.sendCAPAlert,
    'webhook': this.callWebhook,
    'social-media': this.postSocialMedia,
    'phone-call': this.initiatePhoneCall,
    'dashboard-alert': this.showDashboardAlert
  };

  const handler = handlers[action.type];
```

```
    if (handler) {
      await handler.call(this, action, event, corridor);
    }
  }
}
```

Notification Templates

Email Template:

```
<!DOCTYPE html>
<html>
<head>
  <style>
    .alert-critical { background: #fee; border-left: 4px solid #c00; }
    .alert-high { background: #ffeaa7; border-left: 4px solid #f90; }
    .alert-medium { background: #dfe6e9; border-left: 4px solid #2980b9; }
  </style>
</head>
<body>
  <div class="alert-{{severity}}">
    <h2>{{event_type}} Alert - {{corridor}}</h2>
    <p><strong>Location:</strong> {{corridor}} {{direction}} @ MM {{milepost}}</p>
    <p><strong>Time:</strong> {{timestamp}}</p>
    <p><strong>Severity:</strong> {{severity}}</p>
    <p><strong>Impact:</strong> {{lanes_blocked}} lanes blocked, {{delay}} minute
delay</p>
    <p><strong>Description:</strong> {{description}}</p>

    {{#if cameras}}
    <p><strong>Cameras:</strong></p>
    <ul>
      {{#each cameras}}
      <li><a href="{{url}}">{{name}}</a></li>
      {{/each}}
    </ul>
    {{/if}}

    <p><a href="{{dashboard_url}}">View on TMC Dashboard</a></p>
  </div>
</body>
</html>
```

SMS Template:

```
🚨 {{severity|upper}} ALERT
{{corridor}} {{direction}} MM {{milepost}}
{{event_type}}: {{description|truncate:100}}
{{lanes_blocked}} lanes blocked
Delay: {{delay}} min
More: {{short_url}}
```

Push Notification:

```
{
  "title": "🚨 {{severity}} Alert: {{corridor}}",
  "body": "{{event_type}} @ MM {{milepost}}. {{lanes_blocked}} lanes blocked.
{{delay}} min delay.",
  "data": {
    "event_id": "{{event_id}}",
    "corridor": "{{corridor}}",
    "latitude": {{latitude}},
    "longitude": {{longitude}}
  },
  "priority": "high",
  "sound": "alert_critical.mp3",
  "action": {
    "type": "open_map",
    "coordinates": [{{latitude}}, {{longitude}}]
  }
}
```

Implementation Guide

Backend Setup

Step 1: Install Dependencies

```
npm install --save \
  xml2js \          # Parse TMDD/CAP/EDXL XML
  fast-xml-parser \ # Faster XML parsing
  ws \              # WebSocket server
  axios \           # HTTP requests
  nodemailer \      # Email notifications
  twilio \          # SMS notifications
  node-pushnotifications \ # Mobile push
  turf \            # Geospatial calculations
  cron \            # Scheduled tasks
  bull \            # Job queue for processing
  ioredis           # Redis for caching/queues
```

Step 2: Database Schema

```
-- National events table
CREATE TABLE national_events (
  id SERIAL PRIMARY KEY,
  event_id VARCHAR(100) UNIQUE NOT NULL,
  source_id VARCHAR(100) NOT NULL,
  event_type VARCHAR(50) NOT NULL,
  severity VARCHAR(20),
  status VARCHAR(20) DEFAULT 'active',
```

```
  corridor VARCHAR(50),
  direction VARCHAR(20),
  milepost DECIMAL(6,2),
  latitude DECIMAL(10,6),
  longitude DECIMAL(10,6),
  description TEXT,
  impact_data JSONB,
  raw_data JSONB,
  sources TEXT[], -- Array of source IDs
  ingested_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP,
  updated_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP,
  cleared_at TIMESTAMP,
  INDEX idx_corridor (corridor),
  INDEX idx_location (latitude, longitude),
  INDEX idx_timestamp (ingested_at),
  INDEX idx_status (status)
);

-- Data sources configuration
CREATE TABLE event_sources (
  id SERIAL PRIMARY KEY,
  source_id VARCHAR(100) UNIQUE NOT NULL,
  name VARCHAR(200),
  type VARCHAR(50), -- 'tmdd', 'cap', 'wzdx', 'json'
  url TEXT,
  poll_interval INTEGER DEFAULT 60, -- seconds
  authentication JSONB,
  filters JSONB,
  enabled BOOLEAN DEFAULT true,
  last_poll TIMESTAMP,
  last_success TIMESTAMP,
  error_count INTEGER DEFAULT 0,
  created_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP
);

-- Notification subscriptions
CREATE TABLE notification_subscriptions (
  id SERIAL PRIMARY KEY,
  subscriber_id VARCHAR(100) NOT NULL,
  subscription_type VARCHAR(50), -- 'email', 'sms', 'webhook', 'push'
  delivery_target TEXT NOT NULL, -- email, phone, URL, device token
  filters JSONB, -- Corridors, event types, severity
  enabled BOOLEAN DEFAULT true,
  created_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP,
  INDEX idx_subscriber (subscriber_id),
  INDEX idx_type (subscription_type)
);

-- Notification log
CREATE TABLE notification_log (
  id SERIAL PRIMARY KEY,
  event_id VARCHAR(100) NOT NULL,
```

```
  subscription_id INTEGER REFERENCES notification_subscriptions(id),
  notification_type VARCHAR(50),
  delivery_status VARCHAR(20), -- 'sent', 'failed', 'pending'
  delivery_attempts INTEGER DEFAULT 0,
  error_message TEXT,
  sent_at TIMESTAMP,
  delivered_at TIMESTAMP,
  INDEX idx_event (event_id),
  INDEX idx_status (delivery_status)
);

-- TMC/511 integration endpoints
CREATE TABLE integration_endpoints (
  id SERIAL PRIMARY KEY,
  endpoint_id VARCHAR(100) UNIQUE NOT NULL,
  system_type VARCHAR(50), -- 'tmc', '511', 'vms', 'fleet'
  name VARCHAR(200),
  organization VARCHAR(200),
  endpoint_url TEXT,
  webhook_url TEXT,
  api_key_hash TEXT,
  subscription_filters JSONB,
  enabled BOOLEAN DEFAULT true,
  last_delivery TIMESTAMP,
  delivery_success_count INTEGER DEFAULT 0,
  delivery_failure_count INTEGER DEFAULT 0,
  created_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP
);
```

Step 3: Create API Endpoints

Add to `backend_proxy_server.js`:

```
const xml2js = require('xml2js');
const WebSocket = require('ws');
const turf = require('@turf/turf');

// ============================================================================
// TMC INTEGRATION ENDPOINTS
// ============================================================================

// TMDD XML Feed - TMC pulls events
app.get('/api/tmc/events/tmdd', async (req, res) => {
  try {
    const { corridor, severity, event_type, since, bbox } = req.query;

    let query = `
      SELECT * FROM national_events
      WHERE status = 'active'
    `;
    const params = [];
```

```
    if (corridor) {
      query += ` AND corridor = ?`;
      params.push(corridor);
    }

    if (severity) {
      query += ` AND severity = ?`;
      params.push(severity);
    }

    if (event_type) {
      query += ` AND event_type = ?`;
      params.push(event_type);
    }

    if (since) {
      query += ` AND updated_at >= ?`;
      params.push(since);
    }

    if (bbox) {
      const [minLon, minLat, maxLon, maxLat] = bbox.split(',').map(parseFloat);
      query += ` AND latitude BETWEEN ? AND ? AND longitude BETWEEN ? AND ?`;
      params.push(minLat, maxLat, minLon, maxLon);
    }

    query += ` ORDER BY ingested_at DESC LIMIT 500`;

    const events = db.db.prepare(query).all(...params);

    // Build TMDD XML
    const tmddXml = buildTMDDFeed(events);

    res.set('Content-Type', 'application/xml');
    res.send(tmddXml);

  } catch (error) {
    console.error('Error generating TMDD feed:', error);
    res.status(500).json({ error: 'Failed to generate TMDD feed' });
  }
});

// WebSocket stream for real-time events
const wss = new WebSocket.Server({ noServer: true });

wss.on('connection', (ws) => {
  console.log('TMC WebSocket client connected');

  ws.subscriptions = {
    corridors: [],
    event_types: [],
    min_severity: null
```

```
  };

  ws.on('message', (message) => {
    try {
      const data = JSON.parse(message);

      if (data.action === 'subscribe') {
        ws.subscriptions = {
          corridors: data.corridors || [],
          event_types: data.event_types || [],
          min_severity: data.min_severity || null
        };

        ws.send(JSON.stringify({
          status: 'subscribed',
          subscriptions: ws.subscriptions
        }));
      }
    } catch (error) {
      console.error('WebSocket message error:', error);
    }
  });

  ws.on('close', () => {
    console.log('TMC WebSocket client disconnected');
  });
});

// Upgrade HTTP to WebSocket
app.server.on('upgrade', (request, socket, head) => {
  if (request.url === '/api/tmc/stream') {
    wss.handleUpgrade(request, socket, head, (ws) => {
      wss.emit('connection', ws, request);
    });
  }
});

// Broadcast event to WebSocket clients
function broadcastEventToTMC(event) {
  wss.clients.forEach((client) => {
    if (client.readyState === WebSocket.OPEN) {
      const subs = client.subscriptions;

      // Check if event matches client subscriptions
      const corridorMatch = subs.corridors.length === 0 ||
                            subs.corridors.includes(event.corridor);
      const typeMatch = subs.event_types.length === 0 ||
                        subs.event_types.includes(event.event_type);
      const severityMatch = !subs.min_severity ||
                            compareSeverity(event.severity, subs.min_severity) >= 0;

      if (corridorMatch && typeMatch && severityMatch) {
```

```
        client.send(JSON.stringify({
          message_type: 'event_update',
          ...event
        }));
      }
    }
  });
}

// Post message to VMS board (NTCIP 1218)
app.post('/api/tmc/vms/post-message', async (req, res) => {
  try {
    const { equipment_id, message } = req.body;

    // Get VMS equipment details
    const vms = db.db.prepare(`
      SELECT * FROM its_equipment
      WHERE equipment_id = ? AND equipment_type = 'vms'
    `).get(equipment_id);

    if (!vms) {
      return res.status(404).json({ error: 'VMS not found' });
    }

    // Convert message to NTCIP 1218 MULTI string
    const multiString = buildNTCIPMessage(message.pages);

    // Send to VMS controller (requires NTCIP library)
    // This is a placeholder - actual implementation depends on VMS vendor
    const result = await sendNTCIPCommand(vms, {
      oid: 'dmsMessageMultiString.1.1.0',
      value: multiString,
      priority: message.priority === 'high' ? 255 : 128,
      duration: message.duration || 3600
    });

    // Log the message posting
    await db.run(`
      INSERT INTO vms_message_log
      (equipment_id, message_text, priority, duration, triggered_by, posted_at)
      VALUES (?, ?, ?, ?, ?, ?)
    `, [
      equipment_id,
      JSON.stringify(message),
      message.priority,
      message.duration,
      message.triggered_by,
      new Date()
    ]);

    res.json({ success: true, result });
```

```
  } catch (error) {
    console.error('Error posting VMS message:', error);
    res.status(500).json({ error: 'Failed to post VMS message' });
  }
});

// Get events as GeoJSON map layer
app.get('/api/tmc/events/map-layer', async (req, res) => {
  try {
    const { corridor, severity } = req.query;

    let query = `SELECT * FROM national_events WHERE status = 'active'`;
    const params = [];

    if (corridor) {
      query += ` AND corridor = ?`;
      params.push(corridor);
    }

    if (severity) {
      query += ` AND severity = ?`;
      params.push(severity);
    }

    const events = db.db.prepare(query).all(...params);

    // Convert to GeoJSON
    const geojson = {
      type: 'FeatureCollection',
      features: events.map(event => ({
        type: 'Feature',
        geometry: {
          type: 'Point',
          coordinates: [event.longitude, event.latitude]
        },
        properties: {
          event_id: event.event_id,
          event_type: event.event_type,
          severity: event.severity,
          corridor: event.corridor,
          milepost: event.milepost,
          description: event.description,
          icon: getEventIcon(event.event_type, event.severity),
          popup_html: buildPopupHTML(event),
          style: getEventStyle(event.severity)
        }
      }))
    };

    res.json(geojson);

  } catch (error) {
```

```
    console.error('Error generating map layer:', error);
    res.status(500).json({ error: 'Failed to generate map layer' });
  }
});

// ============================================================================
// 511 SYSTEM INTEGRATION ENDPOINTS
// ============================================================================

// XML Event Feed (SAE J2354)
app.get('/api/511/events/xml', async (req, res) => {
  try {
    const { state, corridor } = req.query;

    let query = `SELECT * FROM national_events WHERE status = 'active'`;
    const params = [];

    if (corridor) {
      query += ` AND corridor = ?`;
      params.push(corridor);
    }

    const events = db.db.prepare(query).all(...params);

    // Build SAE J2354 XML
    const xmlFeed = build511XMLFeed(events, state);

    res.set('Content-Type', 'application/xml');
    res.send(xmlFeed);

  } catch (error) {
    console.error('Error generating 511 XML feed:', error);
    res.status(500).json({ error: 'Failed to generate 511 feed' });
  }
});

// JSON Event Feed
app.get('/api/511/events/json', async (req, res) => {
  try {
    const { corridor, format = 'v2' } = req.query;

    let query = `SELECT * FROM national_events WHERE status = 'active'`;
    const params = [];

    if (corridor) {
      query += ` AND corridor = ?`;
      params.push(corridor);
    }

    const events = db.db.prepare(query).all(...params);

    // Get related data
```

```
    const incidents = events.filter(e => e.event_type === 'crash' || e.event_type
=== 'hazard');
    const roadConditions = events.filter(e => e.event_type === 'weather');
    const construction = db.db.prepare(`
      SELECT * FROM work_zones WHERE status = 'active'
    `).all();

    const feed = {
      metadata: {
        version: format,
        provider: 'DOT Corridor Communicator',
        timestamp: new Date().toISOString(),
        update_frequency: 60,
        coverage: {
          corridors: [...new Set(events.map(e => e.corridor))]
        }
      },
      incidents: incidents.map(e => format511Incident(e)),
      road_conditions: roadConditions.map(e => format511RoadCondition(e)),
      construction: construction.map(wz => format511Construction(wz))
    };

    res.json(feed);

  } catch (error) {
    console.error('Error generating 511 JSON feed:', error);
    res.status(500).json({ error: 'Failed to generate 511 feed' });
  }
});

// CAP Alert Distribution
app.post('/api/511/alerts/cap', async (req, res) => {
  try {
    const { event_id } = req.body;

    const event = db.db.prepare(`
      SELECT * FROM national_events WHERE event_id = ?
    `).get(event_id);

    if (!event) {
      return res.status(404).json({ error: 'Event not found' });
    }

    // Only send CAP for major/critical events
    if (event.severity !== 'major' && event.severity !== 'critical') {
      return res.status(400).json({ error: 'Event severity too low for CAP alert'
});
    }

    // Build CAP alert
    const capAlert = buildCAPAlert(event);
```

```
    // Distribute to subscribed 511 systems
    const endpoints = db.db.prepare(`
      SELECT * FROM integration_endpoints
      WHERE system_type = '511'
        AND enabled = true
        AND subscription_filters->>'cap_alerts' = 'true'
    `).all();

    const results = [];
    for (const endpoint of endpoints) {
      try {
        const response = await axios.post(endpoint.webhook_url, capAlert, {
          headers: {
            'Content-Type': 'application/xml',
            'X-Signature': generateSignature(capAlert, endpoint.api_key_hash)
          }
        });

        results.push({
          endpoint: endpoint.name,
          status: 'delivered',
          response: response.data
        });

      } catch (error) {
        results.push({
          endpoint: endpoint.name,
          status: 'failed',
          error: error.message
        });
      }
    }

    res.json({ success: true, alert_id: event.event_id, deliveries: results });

  } catch (error) {
    console.error('Error distributing CAP alert:', error);
    res.status(500).json({ error: 'Failed to distribute CAP alert' });
  }
});

// Webhook Subscriptions
app.post('/api/511/subscriptions', async (req, res) => {
  try {
    const { subscriber_id, webhook_url, webhook_secret, filters, delivery_method,
retry_policy } = req.body;

    // Create endpoint subscription
    const result = await db.run(`
      INSERT INTO integration_endpoints
      (endpoint_id, system_type, webhook_url, api_key_hash, subscription_filters)
      VALUES (?, ?, ?, ?, ?)
```

```
    `, [
      `sub-511-${subscriber_id}-${Date.now()}`,
      '511',
      webhook_url,
      hashSecret(webhook_secret),
      JSON.stringify(filters)
    ]);

    res.json({
      success: true,
      subscription_id: result.lastID,
      message: 'Subscription created successfully'
    });

  } catch (error) {
    console.error('Error creating subscription:', error);
    res.status(500).json({ error: 'Failed to create subscription' });
  }
});

// ============================================================================
// NATIONAL EVENT AGGREGATION ENDPOINTS
// ============================================================================

// Ingest event from external source
app.post('/api/events/ingest', async (req, res) => {
  try {
    const { source_id, format, data } = req.body;

    // Verify source is authorized
    const source = db.db.prepare(`
      SELECT * FROM event_sources WHERE source_id = ? AND enabled = true
    `).get(source_id);

    if (!source) {
      return res.status(401).json({ error: 'Unauthorized source' });
    }

    // Parse event based on format
    let events = [];
    switch (format) {
      case 'tmdd':
        events = parseTMDD(data);
        break;
      case 'cap':
        events = parseCAP(data);
        break;
      case 'wzdx':
        events = parseWZDx(data);
        break;
      case 'json':
        events = [data];
```

```
        break;
      default:
        return res.status(400).json({ error: 'Unsupported format' });
    }

    // Process each event
    const ingested = [];
    for (const rawEvent of events) {
      const normalized = normalizeEvent(rawEvent, source_id);
      const enriched = await enrichEvent(normalized);

      // Check for duplicates
      const isDuplicate = await checkDuplicate(enriched);
      if (!isDuplicate) {
        await storeEvent(enriched);
        await analyzeCorridorImpact(enriched);
        broadcastEventToTMC(enriched);
        ingested.push(enriched.event_id);
      }
    }

    res.json({
      success: true,
      ingested_count: ingested.length,
      event_ids: ingested
    });

  } catch (error) {
    console.error('Error ingesting events:', error);
    res.status(500).json({ error: 'Failed to ingest events' });
  }
});

// Get national event feed
app.get('/api/events/national', async (req, res) => {
  try {
    const { corridor, state, event_type, severity, limit = 100 } = req.query;

    let query = `SELECT * FROM national_events WHERE status = 'active'`;
    const params = [];

    if (corridor) {
      query += ` AND corridor = ?`;
      params.push(corridor);
    }

    if (event_type) {
      query += ` AND event_type = ?`;
      params.push(event_type);
    }

    if (severity) {
```

```
      query += ` AND severity = ?`;
      params.push(severity);
    }

    query += ` ORDER BY ingested_at DESC LIMIT ?`;
    params.push(parseInt(limit));

    const events = db.db.prepare(query).all(...params);

    res.json({
      success: true,
      count: events.length,
      events: events.map(e => ({
        ...e,
        impact_data: JSON.parse(e.impact_data || '{}'),
        sources: JSON.parse(e.sources || '[]')
      }))
    });

  } catch (error) {
    console.error('Error fetching national events:', error);
    res.status(500).json({ error: 'Failed to fetch events' });
  }
});

// ============================================================================
// AUTO-NOTIFICATION ENDPOINTS
// ============================================================================

// Create notification subscription
app.post('/api/notifications/subscribe', async (req, res) => {
  try {
    const { subscriber_id, subscription_type, delivery_target, filters } = req.body;

    const result = await db.run(`
      INSERT INTO notification_subscriptions
      (subscriber_id, subscription_type, delivery_target, filters)
      VALUES (?, ?, ?, ?)
    `, [
      subscriber_id,
      subscription_type,
      delivery_target,
      JSON.stringify(filters)
    ]);

    res.json({
      success: true,
      subscription_id: result.lastID,
      message: 'Notification subscription created'
    });

  } catch (error) {
```

```
    console.error('Error creating subscription:', error);
    res.status(500).json({ error: 'Failed to create subscription' });
  }
});

// Trigger notifications for event
async function triggerNotifications(event, corridor, impactScore) {
  try {
    // Get matching subscriptions
    const subscriptions = db.db.prepare(`
      SELECT * FROM notification_subscriptions
      WHERE enabled = true
    `).all();

    for (const sub of subscriptions) {
      const filters = JSON.parse(sub.filters || '{}');

      // Check if event matches subscription filters
      const corridorMatch = !filters.corridors ||
filters.corridors.includes(event.corridor);
      const typeMatch = !filters.event_types ||
filters.event_types.includes(event.event_type);
      const severityMatch = !filters.min_severity ||
                            compareSeverity(event.severity, filters.min_severity) >=
0;

      if (corridorMatch && typeMatch && severityMatch) {
        await sendNotification(sub, event);
      }
    }

  } catch (error) {
    console.error('Error triggering notifications:', error);
  }
}

// Send notification
async function sendNotification(subscription, event) {
  try {
    let result;

    switch (subscription.subscription_type) {
      case 'email':
        result = await sendEmailNotification(subscription.delivery_target, event);
        break;
      case 'sms':
        result = await sendSMSNotification(subscription.delivery_target, event);
        break;
      case 'webhook':
        result = await sendWebhookNotification(subscription.delivery_target, event);
        break;
      case 'push':
```

```
        result = await sendPushNotification(subscription.delivery_target, event);
        break;
    }

    // Log notification
    await db.run(`
      INSERT INTO notification_log
      (event_id, subscription_id, notification_type, delivery_status, sent_at)
      VALUES (?, ?, ?, ?, ?)
    `, [
      event.event_id,
      subscription.id,
      subscription.subscription_type,
      result.success ? 'sent' : 'failed',
      new Date()
    ]);

  } catch (error) {
    console.error(`Error sending ${subscription.subscription_type} notification:`,
error);
  }
}

// ============================================================================
// HELPER FUNCTIONS
// ============================================================================

function buildTMDDFeed(events) {
  const builder = new xml2js.Builder({ rootName: 'tmdd:eventFeed' });

  const tmddData = {
    'feed-metadata': {
      publisher: 'DOT Corridor Communicator',
      'update-frequency': 60,
      'last-updated': new Date().toISOString()
    },
    events: {
      event: events.map(e => ({
        'event-id': e.event_id,
        'event-type': e.event_type,
        severity: e.severity,
        location: {
          corridor: e.corridor,
          direction: e.direction,
          milepost: e.milepost,
          latitude: e.latitude,
          longitude: e.longitude
        },
        description: e.description,
        timestamp: e.ingested_at
      }))
    }
```

```
  };

  return builder.buildObject(tmddData);
}

function build511XMLFeed(events, state) {
  const builder = new xml2js.Builder({ rootName: 'traffic-data' });

  const feedData = {
    metadata: {
      provider: `${state} DOT Corridor Communicator`,
      timestamp: new Date().toISOString(),
      'coverage-area': {
        state: state,
        corridors: [...new Set(events.map(e => e.corridor))].join(', ')
      }
    },
    incidents: {
      incident: events.map(e => ({
        id: e.event_id,
        type: e.event_type,
        severity: e.severity,
        'reported-time': e.ingested_at,
        location: {
          route: e.corridor,
          direction: e.direction,
          latitude: e.latitude,
          longitude: e.longitude
        },
        description: e.description
      }))
    }
  };

  return builder.buildObject(feedData);
}

function buildCAPAlert(event) {
  const builder = new xml2js.Builder({ rootName: 'alert' });

  const capData = {
    $: { xmlns: 'urn:oasis:names:tc:emergency:cap:1.2' },
    identifier: `CAP-${event.event_id}`,
    sender: 'corridor.communicator@dot.gov',
    sent: new Date().toISOString(),
    status: 'Actual',
    msgType: 'Alert',
    scope: 'Public',
    info: {
      category: 'Transport',
      event: `${event.event_type} Alert`,
      urgency: event.severity === 'critical' ? 'Immediate' : 'Expected',
```

```
      severity: event.severity === 'critical' ? 'Severe' : 'Moderate',
      certainty: 'Observed',
      headline: `${event.event_type} on ${event.corridor}`,
      description: event.description,
      area: {
        areaDesc: `${event.corridor} ${event.direction} @ MM ${event.milepost}`,
        circle: `${event.latitude},${event.longitude} 5`
      }
    }
  };

  return builder.buildObject(capData);
}

function format511Incident(event) {
  const impactData = JSON.parse(event.impact_data || '{}');

  return {
    id: event.event_id,
    type: event.event_type,
    severity: event.severity,
    status: event.status,
    reported_at: event.ingested_at,
    updated_at: event.updated_at,
    location: {
      corridor: event.corridor,
      direction: event.direction,
      milepost: event.milepost,
      coordinates: {
        latitude: event.latitude,
        longitude: event.longitude
      }
    },
    impact: impactData,
    description: event.description
  };
}

function normalizeEvent(rawEvent, sourceId) {
  // Normalize different event formats to common schema
  return {
    event_id: rawEvent.id || `EVT-${Date.now()}`,
    source_id: sourceId,
    event_type: rawEvent.type || rawEvent.event_type,
    severity: rawEvent.severity || 'moderate',
    corridor: rawEvent.corridor || rawEvent.route,
    direction: rawEvent.direction,
    milepost: rawEvent.milepost,
    location: {
      latitude: rawEvent.latitude || rawEvent.location?.latitude,
      longitude: rawEvent.longitude || rawEvent.location?.longitude
    },
```

```
    description: rawEvent.description,
    impact: rawEvent.impact || {},
    timestamp: rawEvent.timestamp || new Date()
  };
}

async function enrichEvent(event) {
  // Add corridor information if missing
  if (!event.corridor && event.location) {
    event.corridor = await geocodeToCorridor(
      event.location.latitude,
      event.location.longitude
    );
  }

  // Add nearby cameras
  const cameras = db.db.prepare(`
    SELECT * FROM its_equipment
    WHERE equipment_type = 'camera'
      AND ABS(latitude - ?) < 0.05
      AND ABS(longitude - ?) < 0.05
    LIMIT 5
  `).all(event.location.latitude, event.location.longitude);

  event.cameras = cameras.map(c => ({
    id: c.equipment_id,
    name: c.name,
    url: c.stream_url
  }));

  return event;
}

async function checkDuplicate(event) {
  const similar = db.db.prepare(`
    SELECT * FROM national_events
    WHERE event_type = ?
      AND corridor = ?
      AND ABS(latitude - ?) < 0.01
      AND ABS(longitude - ?) < 0.01
      AND ingested_at > datetime('now', '-30 minutes')
  `).get(
    event.event_type,
    event.corridor,
    event.location.latitude,
    event.location.longitude
  );

  return similar !== undefined;
}

async function storeEvent(event) {
```

```
  await db.run(`
    INSERT INTO national_events
    (event_id, source_id, event_type, severity, corridor, direction, milepost,
     latitude, longitude, description, impact_data, sources)
    VALUES (?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?)
  `, [
    event.event_id,
    event.source_id,
    event.event_type,
    event.severity,
    event.corridor,
    event.direction,
    event.milepost,
    event.location.latitude,
    event.location.longitude,
    event.description,
    JSON.stringify(event.impact),
    JSON.stringify([event.source_id])
  ]);
}

async function analyzeCorridorImpact(event) {
  // Get corridors within impact radius
  const corridors = db.db.prepare(`
    SELECT DISTINCT corridor FROM its_equipment
    WHERE ABS(latitude - ?) < 0.1
      AND ABS(longitude - ?) < 0.1
  `).all(event.location.latitude, event.location.longitude);

  for (const corridor of corridors) {
    const impactScore = calculateImpactScore(event, corridor);

    if (impactScore >= 50) {
      await triggerNotifications(event, corridor.corridor, impactScore);
    }
  }
}

function calculateImpactScore(event, corridor) {
  let score = 0;

  // Severity weight
  const severityWeights = { minor: 20, moderate: 40, major: 70, critical: 100 };
  score += severityWeights[event.severity] || 0;

  // Event type weight
  const typeWeights = { crash: 30, 'road-closed': 50, weather: 20, hazmat: 50 };
  score += typeWeights[event.event_type] || 0;

  // Normalize to 0-100
  return Math.min(100, score);
}
```

```
function compareSeverity(severity1, severity2) {
  const levels = { minor: 1, moderate: 2, major: 3, critical: 4 };
  return (levels[severity1] || 0) - (levels[severity2] || 0);
}

function getEventIcon(eventType, severity) {
  const icons = {
    crash: severity === 'critical' ? 'crash-critical' : 'crash-major',
    weather: 'weather-alert',
    'road-closed': 'road-closed',
    hazmat: 'hazmat-warning',
    construction: 'construction-zone'
  };
  return icons[eventType] || 'event-generic';
}

function getEventStyle(severity) {
  const styles = {
    critical: { color: '#FF0000', size: 'large', blink: true },
    major: { color: '#FF6600', size: 'medium', blink: false },
    moderate: { color: '#FFAA00', size: 'small', blink: false },
    minor: { color: '#FFFF00', size: 'small', blink: false }
  };
  return styles[severity] || styles.moderate;
}

function buildPopupHTML(event) {
  return `
    <strong>${event.event_type.toUpperCase()}</strong><br>
    ${event.corridor} ${event.direction} @ MM ${event.milepost}<br>
    <em>${event.description}</em>
  `;
}
```

Step 4: Event Processing Worker

Create `workers/event-processor.js`:

```
const cron = require('node-cron');
const axios = require('axios');

class EventProcessor {
  constructor(db) {
    this.db = db;
    this.sources = [];
    this.init();
  }

  async init() {
    // Load configured event sources
    this.sources = this.db.prepare(`
```

```
    SELECT * FROM event_sources WHERE enabled = true
  `).all();

  // Start polling each source
  for (const source of this.sources) {
    this.startPolling(source);
  }

  // Cleanup old events (every hour)
  cron.schedule('0 * * * *', () => {
    this.cleanupOldEvents();
  });
}

startPolling(source) {
  const interval = source.poll_interval * 1000;

  setInterval(async () => {
    try {
      console.log(`Polling ${source.name}...`);

      const response = await axios.get(source.url, {
        headers: this.buildAuthHeaders(source),
        timeout: 30000
      });

      const events = this.parseEvents(response.data, source.type);
      console.log(`Found ${events.length} events from ${source.name}`);

      for (const event of events) {
        await this.processEvent(event, source.source_id);
      }

      // Update last poll time
      await this.db.run(`
        UPDATE event_sources
        SET last_poll = ?, last_success = ?, error_count = 0
        WHERE source_id = ?
      `, [new Date(), new Date(), source.source_id]);

    } catch (error) {
      console.error(`Error polling ${source.name}:`, error.message);

      // Increment error count
      await this.db.run(`
        UPDATE event_sources
        SET last_poll = ?, error_count = error_count + 1
        WHERE source_id = ?
      `, [new Date(), source.source_id]);
    }
  }, interval);
}
```

```
  parseEvents(data, sourceType) {
    switch (sourceType) {
      case 'tmdd':
        return this.parseTMDD(data);
      case 'cap':
        return this.parseCAP(data);
      case 'wzdx':
        return this.parseWZDx(data);
      case 'json':
        return Array.isArray(data) ? data : [data];
      default:
        return [];
    }
  }

  async processEvent(rawEvent, sourceId) {
    // Normalize, deduplicate, enrich, store
    // (Use functions from backend_proxy_server.js)
  }

  async cleanupOldEvents() {
    // Delete events older than 7 days
    await this.db.run(`
      DELETE FROM national_events
      WHERE status = 'cleared'
        AND cleared_at < datetime('now', '-7 days')
    `);

    console.log('Cleaned up old events');
  }

  buildAuthHeaders(source) {
    const auth = JSON.parse(source.authentication || '{}');
    const headers = {};

    if (auth.type === 'api_key') {
      headers['X-API-Key'] = auth.key;
    } else if (auth.type === 'bearer') {
      headers['Authorization'] = `Bearer ${auth.token}`;
    }

    return headers;
  }
}

module.exports = EventProcessor;
```

API Reference

TMC Integration

GET /api/tmc/events/tmdd

Retrieve events in TMDD XML format.

Query Parameters:

- `corridor` - Filter by corridor (e.g., I-80)
- `severity` - Filter by severity (minor, moderate, major, critical)
- `event_type` - Filter by type (crash, weather, construction, etc.)
- `since` - Events since ISO timestamp
- `bbox` - Bounding box (minLon,minLat,maxLon,maxLat)

Response: TMDD XML feed

WebSocket /api/tmc/stream

Real-time event stream via WebSocket.

Subscribe Message:

```
{
  "action": "subscribe",
  "corridors": ["I-80", "I-35"],
  "event_types": ["crash", "weather"],
  "min_severity": "major"
}
```

Event Message:

```
{
  "message_type": "event_update",
  "event_id": "IA-I80-2025-001",
  "event_type": "crash",
  "severity": "major",
  "location": { ... },
  "impact": { ... }
}
```

POST /api/tmc/vms/post-message

Post message to VMS board.

Request:

```
{
  "equipment_id": "VMS-I80-MM95-EB",
  "message": {
    "pages": [
      { "text": "CRASH AHEAD", "display_time": 3 },
      { "text": "USE CAUTION", "display_time": 2 }
    ],
```

```
    "priority": "high",
    "duration": 3600,
    "triggered_by": "event:IA-I80-2025-001"
  }
}
```

Response:

```
{
  "success": true,
  "result": { ... }
}
```

---

511 System Integration

GET /api/511/events/xml

SAE J2354 compliant XML feed.

Query Parameters:

- `state` - Filter by state
- `corridor` - Filter by corridor

Response: SAE J2354 XML

GET /api/511/events/json

JSON event feed.

Query Parameters:

- `corridor` - Filter by corridor
- `format` - Version (v1, v2)

Response:

```
{
  "metadata": { ... },
  "incidents": [ ... ],
  "road_conditions": [ ... ],
  "construction": [ ... ]
}
```

POST /api/511/alerts/cap

Distribute CAP alert to 511 systems.

Request:

```
{
  "event_id": "IA-I80-2025-001"
```

```
}
```

Response:

```
{
  "success": true,
  "alert_id": "CAP-IA-I80-2025-001",
  "deliveries": [
    { "endpoint": "511 Iowa", "status": "delivered" }
  ]
}
```

POST /api/511/subscriptions

Create webhook subscription.

Request:

```
{
  "subscriber_id": "511-iowa",
  "webhook_url": "https://api.511ia.org/webhooks/events",
  "webhook_secret": "shared-secret",
  "filters": {
    "corridors": ["I-80"],
    "event_types": ["crash", "road-closed"],
    "min_severity": "major"
  }
}
```

Response:

```
{
  "success": true,
  "subscription_id": 123
}
```

National Event Aggregation

POST /api/events/ingest

Ingest events from external sources.

Request:

```
{
  "source_id": "iowa-tmc",
  "format": "tmdd",
  "data": "<tmdd:event>...</tmdd:event>"
}
```

Response:

```
{
  "success": true,
  "ingested_count": 5,
  "event_ids": ["EVT-001", "EVT-002", ...]
}
```

GET /api/events/national

Get aggregated national events.

Query Parameters:

- `corridor` - Filter by corridor
- `state` - Filter by state
- `event_type` - Filter by type
- `severity` - Filter by severity
- `limit` - Max results (default 100)

Response:

```
{
  "success": true,
  "count": 42,
  "events": [ ... ]
}
```

Auto-Notifications

POST /api/notifications/subscribe

Subscribe to event notifications.

Request:

```
{
  "subscriber_id": "user-123",
  "subscription_type": "email",
  "delivery_target": "recipient@yourdot.gov",
  "filters": {
    "corridors": ["I-80"],
    "min_severity": "major"
  }
}
```

Response:

```
{
  "success": true,
```

```
  "subscription_id": 456
}
```

Use Cases & Examples

Use Case 1: Multi-State Corridor Event Sharing

Scenario: Iowa DOT wants to share I-80 incidents with Nebraska DOT in real-time.

Implementation:

```
// Iowa DOT publishes events via TMDD feed
// Nebraska DOT subscribes to Iowa events

// 1. Nebraska configures event source
await axios.post('https://corridor.nebraska.gov/api/admin/sources', {
  source_id: 'iowa-i80',
  name: 'Iowa DOT I-80 Events',
  type: 'tmdd',
  url: 'https://corridor.iowa.gov/api/tmc/events/tmdd?corridor=I-80',
  poll_interval: 60,
  authentication: {
    type: 'api_key',
    key: 'shared-api-key'
  },
  enabled: true
});

// 2. Events automatically flow Iowa → Nebraska
// Iowa incident detected at MM 5 (near IA/NE border)
const iowaEvent = {
  event_id: 'IA-I80-2025-001',
  event_type: 'crash',
  corridor: 'I-80',
  milepost: 5,
  severity: 'major'
};

// 3. Nebraska ingests and enriches with local data
// 4. Nebraska TMC displays on map
// 5. Nebraska posts VMS message: "CRASH IN IOWA - DELAYS EXPECTED"
```

Benefits:

- Travelers get advance warning before crossing state line
- Nebraska can adjust signal timing to accommodate diverted traffic
- Coordinated incident response between states

Use Case 2: 511 System Auto-Update

Scenario: When major incident occurs, automatically push to state 511 system.

Implementation:

```
// 1. Configure 511 webhook subscription
await axios.post('https://corridor.iowa.gov/api/511/subscriptions', {
  subscriber_id: '511-iowa',
  webhook_url: 'https://api.511ia.org/webhooks/corridor-events',
  webhook_secret: 'shared-secret-key',
  filters: {
    corridors: ['I-80', 'I-35', 'I-29'],
    event_types: ['crash', 'road-closed', 'weather'],
    min_severity: 'major'
  }
});

// 2. Major crash occurs on I-80
const event = {
  event_id: 'IA-I80-2025-001',
  event_type: 'crash',
  severity: 'major',
  corridor: 'I-80',
  milepost: 100.5
};

// 3. Corridor Communicator triggers notification
// POST to https://api.511ia.org/webhooks/corridor-events
{
  "subscription_id": "sub-511-iowa-001",
  "event_id": "IA-I80-2025-001",
  "event_type": "crash",
  "data": { /* full event details */ }
}

// 4. 511 System automatically:
// - Updates website homepage
// - Sends mobile app push notifications
// - Updates IVR (phone) system messages
// - Tweets from @511Iowa
// - Emails/SMS subscribers in affected area
```

Result: Travelers receive alerts within seconds of incident detection

---

Use Case 3: National Freight Corridor Monitoring

Scenario: Track incidents across I-80 freight corridor (CA to NJ) and alert fleet operators.

Implementation:

```
// 1. Aggregate events from all I-80 states
const i80States = ['CA', 'NV', 'UT', 'WY', 'NE', 'IA', 'IL', 'IN', 'OH', 'PA',
'NJ'];
```

```
for (const state of i80States) {
  // Configure event sources
  await configureEventSource({
    source_id: `${state.toLowerCase()}-i80`,
    url: `https://corridor.${state.toLowerCase()}.gov/api/tmc/events/tmdd?
corridor=I-80`,
    type: 'tmdd',
    poll_interval: 60
  });
}

// 2. Fleet operator subscribes to I-80 alerts
await axios.post('https://corridor.national.gov/api/notifications/subscribe', {
  subscriber_id: 'fleet-operator-123',
  subscription_type: 'webhook',
  delivery_target: 'https://api.fleet-company.com/corridor-alerts',
  filters: {
    corridors: ['I-80'],
    event_types: ['crash', 'road-closed', 'weather', 'construction'],
    min_severity: 'moderate'
  }
});

// 3. When Nebraska crash occurs, fleet gets immediate webhook
// Fleet system automatically:
// - Alerts drivers currently on I-80 in Nebraska
// - Reroutes trucks not yet in affected area
// - Updates ETAs for deliveries
// - Notifies customers of potential delays
```

Benefits:

- National visibility of corridor conditions
- Proactive route optimization
- Reduced delays and fuel costs
- Improved customer service

Use Case 4: Weather Event Coordination

Scenario: Blizzard warning issued for I-80 across multiple states.

Implementation:

```
// 1. National Weather Service issues CAP alert
const capAlert = `
<alert xmlns="urn:oasis:names:tc:emergency:cap:1.2">
  <info>
    <event>Blizzard Warning</event>
    <severity>Severe</severity>
    <area>
      <polygon>41.5,-104.0 41.5,-95.0 40.5,-95.0 40.5,-104.0 41.5,-104.0</polygon>
    </area>
```

```
  </info>
</alert>
`;

// 2. Corridor Communicator ingests CAP alert
await axios.post('https://corridor.national.gov/api/events/ingest', {
  source_id: 'nws',
  format: 'cap',
  data: capAlert
});

// 3. System determines I-80 impact across WY, NE, IA
const impactedStates = calculateImpact(capAlert.polygon, 'I-80');
// Result: ['WY', 'NE', 'IA']

// 4. Trigger coordinated response
for (const state of impactedStates) {
  // Post VMS messages
  await postVMSMessages(state, 'I-80', 'BLIZZARD WARNING - TRAVEL NOT ADVISED');

  // Send CAP alerts to 511 systems
  await send511Alert(state, event);

  // Notify TMC operators
  await notifyTMC(state, event);

  // Alert snow plow coordinators
  await notifySnowPlows(state, event);
}

// 5. Multi-state coordination call initiated
await notifyEmergencyCoordinators({
  event: 'Multi-State Blizzard',
  states: ['WY', 'NE', 'IA'],
  priority: 'critical'
});
```

Result: Coordinated response across state lines, consistent traveler messaging, proactive resource deployment

---

Security & Authentication

API Authentication Methods

1. API Key Authentication

For TMC/511 System Integration:

```
// Generate API key for external system
const apiKey = crypto.randomBytes(32).toString('hex');
const apiKeyHash = crypto.createHash('sha256').update(apiKey).digest('hex');
```

```
// Store in database
await db.run(`
  INSERT INTO integration_endpoints
  (endpoint_id, system_type, api_key_hash)
  VALUES (?, ?, ?)
`, ['nebraska-tmc', 'tmc', apiKeyHash]);

// External system includes API key in requests
const response = await axios.get('https://corridor.iowa.gov/api/tmc/events/tmdd', {
  headers: {
    'X-API-Key': apiKey
  }
});
```

Validation:

```
app.use('/api/tmc/*', (req, res, next) => {
  const providedKey = req.headers['x-api-key'];
  if (!providedKey) {
    return res.status(401).json({ error: 'API key required' });
  }

  const keyHash = crypto.createHash('sha256').update(providedKey).digest('hex');

  const endpoint = db.db.prepare(`
    SELECT * FROM integration_endpoints
    WHERE api_key_hash = ? AND enabled = true
  `).get(keyHash);

  if (!endpoint) {
    return res.status(401).json({ error: 'Invalid API key' });
  }

  req.endpoint = endpoint;
  next();
});
```

2. OAuth 2.0 (For 511 Mobile Apps)

```
const { AuthorizationCode } = require('simple-oauth2');

const oauth2 = new AuthorizationCode({
  client: {
    id: process.env.OAUTH_CLIENT_ID,
    secret: process.env.OAUTH_CLIENT_SECRET
  },
  auth: {
    tokenHost: 'https://auth.corridor.gov',
    tokenPath: '/oauth/token',
```

```
    authorizePath: '/oauth/authorize'
  }
});

// Token endpoint
app.post('/oauth/token', async (req, res) => {
  try {
    const result = await oauth2.getToken({
      code: req.body.code,
      redirect_uri: req.body.redirect_uri
    });

    res.json(result.token);
  } catch (error) {
    res.status(401).json({ error: 'Authentication failed' });
  }
});

// Protected endpoint
app.get('/api/511/events/json', authenticateOAuth, (req, res) => {
  // Return events
});
```

3. Webhook Signature Verification

Prevent tampering with webhook payloads:

```
function generateSignature(payload, secret) {
  const hmac = crypto.createHmac('sha256', secret);
  hmac.update(JSON.stringify(payload));
  return `sha256=${hmac.digest('hex')}`;
}

function verifySignature(payload, signature, secret) {
  const expectedSignature = generateSignature(payload, secret);
  return crypto.timingSafeEqual(
    Buffer.from(signature),
    Buffer.from(expectedSignature)
  );
}

// Send webhook with signature
const payload = { event_id: 'IA-I80-2025-001', ... };
const signature = generateSignature(payload, webhookSecret);

await axios.post(webhookUrl, payload, {
  headers: {
    'X-Corridor-Signature': signature,
    'Content-Type': 'application/json'
  }
});
```

```
// Receive and verify webhook
app.post('/webhooks/corridor-events', (req, res) => {
  const signature = req.headers['x-corridor-signature'];
  const payload = req.body;

  if (!verifySignature(payload, signature, webhookSecret)) {
    return res.status(401).json({ error: 'Invalid signature' });
  }

  // Process webhook
  processEvent(payload);
  res.json({ received: true });
});
```

IP Whitelisting

Restrict access to known TMC IP addresses:

```
const allowedIPs = [
  '192.168.1.0/24',     // Iowa DOT TMC
  '10.0.0.0/8',         // Nebraska DOT Network
  '172.16.0.0/12'       // Internal systems
];

function isIPAllowed(ip) {
  // Use ip-range-check library
  return allowedIPs.some(range => ipRangeCheck(ip, range));
}

app.use('/api/tmc/*', (req, res, next) => {
  const clientIP = req.ip || req.connection.remoteAddress;

  if (!isIPAllowed(clientIP)) {
    console.warn(`Blocked request from unauthorized IP: ${clientIP}`);
    return res.status(403).json({ error: 'Access denied' });
  }

  next();
});
```

Rate Limiting

Prevent abuse and ensure fair usage:

```
const rateLimit = require('express-rate-limit');

// TMC feed endpoints - higher limits
const tmcLimiter = rateLimit({
  windowMs: 1 * 60 * 1000, // 1 minute
  max: 120, // 120 requests per minute (1 every 500ms)
  message: 'Too many requests from this IP'
```

```
});

// 511 public endpoints - standard limits
const publicLimiter = rateLimit({
  windowMs: 1 * 60 * 1000,
  max: 60, // 60 requests per minute
  message: 'Rate limit exceeded'
});

app.use('/api/tmc/*', tmcLimiter);
app.use('/api/511/*', publicLimiter);
```

Encryption

TLS/SSL Required:

```
// Force HTTPS in production
if (process.env.NODE_ENV === 'production') {
  app.use((req, res, next) => {
    if (!req.secure) {
      return res.redirect(`https://${req.headers.host}${req.url}`);
    }
    next();
  });
}

// HSTS Header
app.use((req, res, next) => {
  res.setHeader('Strict-Transport-Security', 'max-age=31536000; includeSubDomains');
  next();
});
```

Monitoring & Alerting

System Health Monitoring

Monitor event ingestion pipeline:

```
const prometheus = require('prom-client');

// Metrics
const eventsIngested = new prometheus.Counter({
  name: 'events_ingested_total',
  help: 'Total number of events ingested',
  labelNames: ['source_id', 'event_type']
});

const eventProcessingDuration = new prometheus.Histogram({
  name: 'event_processing_duration_seconds',
  help: 'Event processing duration in seconds'
```

```
});

const notificationsSent = new prometheus.Counter({
  name: 'notifications_sent_total',
  help: 'Total notifications sent',
  labelNames: ['type', 'status']
});

const sourceErrors = new prometheus.Counter({
  name: 'source_errors_total',
  help: 'Total errors by source',
  labelNames: ['source_id']
});

// Instrument code
async function processEvent(event, sourceId) {
  const timer = eventProcessingDuration.startTimer();

  try {
    // Process event
    await storeEvent(event);
    eventsIngested.inc({ source_id: sourceId, event_type: event.type });
  } catch (error) {
    sourceErrors.inc({ source_id: sourceId });
    throw error;
  } finally {
    timer();
  }
}

async function sendNotification(type, target, event) {
  try {
    await deliverNotification(type, target, event);
    notificationsSent.inc({ type, status: 'success' });
  } catch (error) {
    notificationsSent.inc({ type, status: 'failed' });
    throw error;
  }
}

// Metrics endpoint
app.get('/metrics', async (req, res) => {
  res.set('Content-Type', prometheus.register.contentType);
  res.end(await prometheus.register.metrics());
});
```

Uptime Monitoring

Monitor external data sources:

```
const cron = require('node-cron');

// Check source health every 5 minutes
cron.schedule('*/5 * * * *', async () => {
  const sources = db.db.prepare(`
    SELECT * FROM event_sources WHERE enabled = true
  `).all();

  for (const source of sources) {
    try {
      const response = await axios.get(source.url, {
        timeout: 10000,
        headers: buildAuthHeaders(source)
      });

      // Update last success
      await db.run(`
        UPDATE event_sources
        SET last_success = ?, error_count = 0
        WHERE source_id = ?
      `, [new Date(), source.source_id]);

    } catch (error) {
      console.error(`Health check failed for ${source.name}:`, error.message);

      // Increment error count
      await db.run(`
        UPDATE event_sources
        SET error_count = error_count + 1
        WHERE source_id = ?
      `, [source.source_id]);

      // Alert if source down for extended period
      const errorCount = db.db.prepare(`
        SELECT error_count FROM event_sources WHERE source_id = ?
      `).get(source.source_id).error_count;

      if (errorCount >= 6) { // 30 minutes of failures
        await sendAlert({
          severity: 'critical',
          message: `Event source "${source.name}" has been down for 30+ minutes`,
          source_id: source.source_id
        });
      }
    }
  }
});
```

Logging

Comprehensive logging for troubleshooting:

```
const winston = require('winston');

const logger = winston.createLogger({
  level: 'info',
  format: winston.format.combine(
    winston.format.timestamp(),
    winston.format.json()
  ),
  transports: [
    new winston.transports.File({ filename: 'logs/error.log', level: 'error' }),
    new winston.transports.File({ filename: 'logs/combined.log' }),
    new winston.transports.Console({
      format: winston.format.simple()
    })
  ]
});

// Log event ingestion
logger.info('Event ingested', {
  event_id: event.event_id,
  source_id: source.source_id,
  event_type: event.event_type,
  severity: event.severity,
  corridor: event.corridor
});

// Log notifications
logger.info('Notification sent', {
  event_id: event.event_id,
  subscription_id: subscription.id,
  type: subscription.subscription_type,
  target: subscription.delivery_target,
  status: 'success'
});

// Log errors
logger.error('Event processing failed', {
  event_id: event.event_id,
  error: error.message,
  stack: error.stack
});
```

Dashboard

Real-time monitoring dashboard:

```
// WebSocket for live dashboard updates
const dashboardWSS = new WebSocket.Server({ port: 8081 });

dashboardWSS.on('connection', (ws) => {
  // Send current stats on connect
```

```
  ws.send(JSON.stringify({
    type: 'stats',
    data: getCurrentStats()
  }));
});

// Broadcast stats every 10 seconds
setInterval(() => {
  const stats = getCurrentStats();

  dashboardWSS.clients.forEach((client) => {
    if (client.readyState === WebSocket.OPEN) {
      client.send(JSON.stringify({
        type: 'stats',
        data: stats
      }));
    }
  });
}, 10000);

function getCurrentStats() {
  const activeEvents = db.db.prepare(`
    SELECT COUNT(*) as count FROM national_events WHERE status = 'active'
  `).get().count;

  const eventsByType = db.db.prepare(`
    SELECT event_type, COUNT(*) as count
    FROM national_events
    WHERE status = 'active'
    GROUP BY event_type
  `).all();

  const notificationsLast Hour = db.db.prepare(`
    SELECT COUNT(*) as count FROM notification_log
    WHERE sent_at > datetime('now', '-1 hour')
  `).get().count;

  return {
    active_events: activeEvents,
    events_by_type: eventsByType,
    notifications_sent_hour: notificationsLastHour,
    sources_active: getActiveSourceCount(),
    timestamp: new Date()
  };
}
```

Conclusion

This TMC & 511 System Integration Guide provides a comprehensive framework for connecting the DOT Corridor Communicator with Traffic Management Centers and 511 traveler information systems nationwide.

Key Capabilities Enabled

✅ **National Event Visibility** - Aggregate incidents from all 50 states ✅ **Real-Time Coordination** - Instant event sharing between TMCs ✅ **Traveler Information** - Automatic updates to 511 systems ✅ **Auto-Notifications** - Rule-based alerts to affected stakeholders ✅ **Multi-State Corridors** - Seamless coordination across state lines ✅ **Standards-Based** - TMDD, CAP, EDXL-DE, WZDx compliant

Implementation Checklist

Phase 1: Foundation (Weeks 1-2)

- [ ] Set up database schema
- [ ] Install dependencies
- [ ] Configure authentication
- [ ] Implement core API endpoints

Phase 2: TMC Integration (Weeks 3-4)

- [ ] TMDD XML feed endpoint
- [ ] WebSocket streaming
- [ ] VMS message posting
- [ ] Map layer GeoJSON

Phase 3: 511 Integration (Weeks 5-6)

- [ ] XML/JSON event feeds
- [ ] CAP alert distribution
- [ ] Webhook subscriptions
- [ ] IVR system integration

Phase 4: National Aggregation (Weeks 7-8)

- [ ] Event source configuration
- [ ] Polling workers
- [ ] Deduplication logic
- [ ] Event enrichment

Phase 5: Auto-Notifications (Weeks 9-10)

- [ ] Trigger rules engine
- [ ] Email/SMS delivery
- [ ] Push notifications
- [ ] Notification logging

Phase 6: Monitoring & Production (Weeks 11-12)

- [ ] Metrics & monitoring
- [ ] Health checks
- [ ] Logging infrastructure
- [ ] Load testing
- [ ] Security audit
- [ ] Documentation

- [ ] Training

Resources

Standards Documentation:

- TMDD: https://www.standards.its.dot.gov/Catalog/TMDD
- CAP: https://docs.oasis-open.org/emergency/cap/v1.2/
- EDXL-DE: https://www.oasis-open.org/committees/emergency/
- WZDx: https://github.com/usdot-jpo-ode/wzdx
- SAE J2354: https://www.sae.org/standards/content/j2354/

Related Documentation:

- JSTAN Integration Guide: `docs/JSTAN_INTEGRATION_GUIDE.md`
- JSTAN Quick Reference: `JSTAN_QUICK_REFERENCE.md`
- Grant Proposal Analyzer: `GRANT_PROPOSAL_ANALYZER_DOCUMENTATION.md`
- Connected Corridors Grants: `CONNECTED_CORRIDORS_GRANTS_INTEGRATION.md`

Support & Questions:

- For technical issues: Contact your system administrator
- Documentation: Available in the app under "📚 Docs"
- AASHTO JSTAN Committee: jstan@aashto.org

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