

407 Express Toll Route

October 11, 2013

Problem Statement

The 407 Express Toll Route is a highway that runs east-west just north of Toronto, and was one of the largest road construction projects in the history of Canada. The road uses a highly modern Electronic Toll Collection (ETC) system constructed by Raytheon.

The ETR technology allows motorists to pass through toll routes without stopping or even opening a window. To make this happen, each highway entry and exit point is equipped with a *gantry* (see figure 1).

Processing Registered Vehicles

The most cost-efficient way to pay for highway use is to open an account with the 407 ETR system. Accounts can be personal or linked to a company. In either case, billing information (name and address) is saved with the account. Once an account is created, vehicles can be registered with it. Registered vehicles require a small electronic tag, called a transponder (see figure 2), to be attached to the windshield behind the rear-view mirror. Transponders are leased for a small monthly fee. The registration includes the vehicle details.

The system automatically records the entry and exit of vehicles, and creates a transaction for each trip. This is done in the following way. When the vehicle enters the highway, it passes under the overhead gantry. The hardware devices of a gantry are shown in figure 3.

The locator antennae determine if the vehicle is equipped with a transponder. Next, the read / write antennae read the account number from the transponder and the point of entry, time and date is recorded.

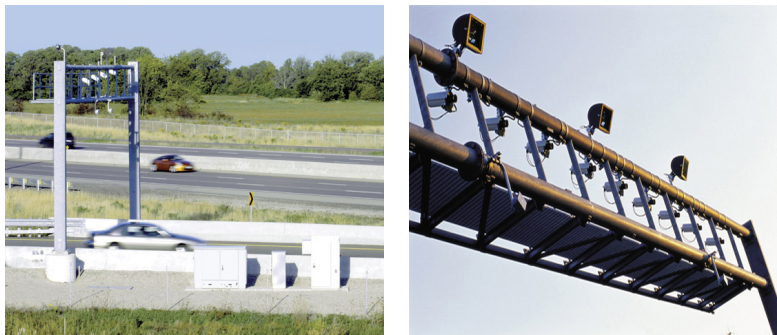


Figure 1: The 407 Entry / Exit Gantries



Figure 2: A Transponder

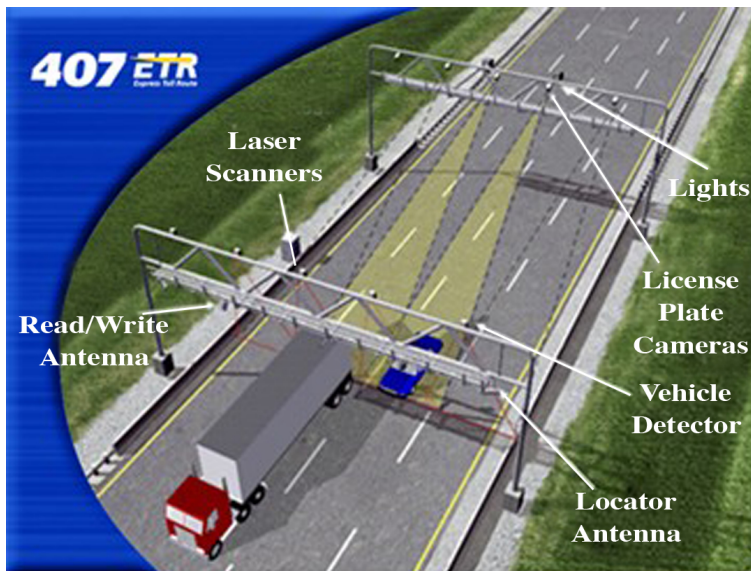


Figure 3: An Entry / Exit Gantry

In addition, as a vehicle passes under the gantries, the system uses laser scanners to determine the class of vehicle (e.g. light vehicle, heavy single unit vehicle, heavy multiple unit vehicle). It does this by measuring the height, width and depth of each approaching vehicle. A check is made to verify that the class of vehicle corresponds to the one registered for this particular transponder.

The same process occurs when the vehicle exits the highway. The entry and exit data are then matched and the transponder account holder is debited. When the route is exited, the transponder gives a green signal followed by four short beeps to indicate a successful completion of the transaction.

Processing Unregistered Vehicles

Transponders are mandatory for heavy vehicles, i.e. vehicles with a gross weight of 5,000 kg. However, light vehicles can use the 407 ETR without registering.

When a motorist without a transponder enters the highway and passes under the two tolling gantries, the system triggers a set of digital cameras to take pictures of the rear number plate of the vehicle from different angles. In order to get good images, a set of lights are turned on before the images are taken. The lights automatically adjust their intensity to ensure the best conditions for taking an image of the number plate. At the same time, the laser scanners are activated to classify the vehicle and tell the toll collection system whether to charge for a passenger or commercial vehicle. The owner of the vehicle is identified by electronic access to government records.

The cameras and lights have been tested to ensure accuracy, even in blizzards and rainstorms. However, if the video correlation and image processing fails to determine the license plate with sufficient probability, a human operator has to look at the pictures to make the call.

Payment

Registered car owners, registered companies, and motorist that used the highway, receive an invoice in the mail at the end of the month containing the monthly rental fee for the registered transponders (\$3 per transponder), if any, and the trips of all of the vehicles registered with their accounts. The price of each trip is calculated based on the time of day, distance traveled and type of vehicle. If the entry or exit time falls within peak hours (6am - 10am, 3pm - 7pm), the toll rate is 16.25 cents/km for light vehicles, 32.5 cents/km for heavy vehicles, and 48.75 cents/km for heavy multiple unit vehicles. Otherwise, the toll rate is 15.5 cents/km for light vehicles, 31 cents/km for heavy vehicles and 46.5 cents/km for heavy multiple unit vehicles.

If a light vehicle uses the highway without a transponder, an additional video toll charge of \$3.50 is applied per trip. Cheating motorists (for instance, motorists using a transponder with an unregistered vehicle, or heavy vehicles taking the highway without a transponder) are fined with \$50.

Registered drivers must sign up for auto-payment by credit card. Unregistered drivers simply pay each month by cheque. Refusal to pay invoices for 3 months results in plate denial, meaning that a debtor cannot renew the license plate of his cars or obtain a new license plate from the government until all tolls and fees have been paid.

Hardware / Software Decisions

The software to be developed has to interface with the hardware devices of the gantry. The development of the software running on the transponders is going to be outsourced to a different company, and hence does not have to be considered for this assignment.

Use Case Model

The use cases of the 407 ETR and their relationships are summarized in figure 4. The individual descriptions of each use case are shown below.

UseHighway Use Case

Use Case: UseHighway

Scope: 407 ETR System

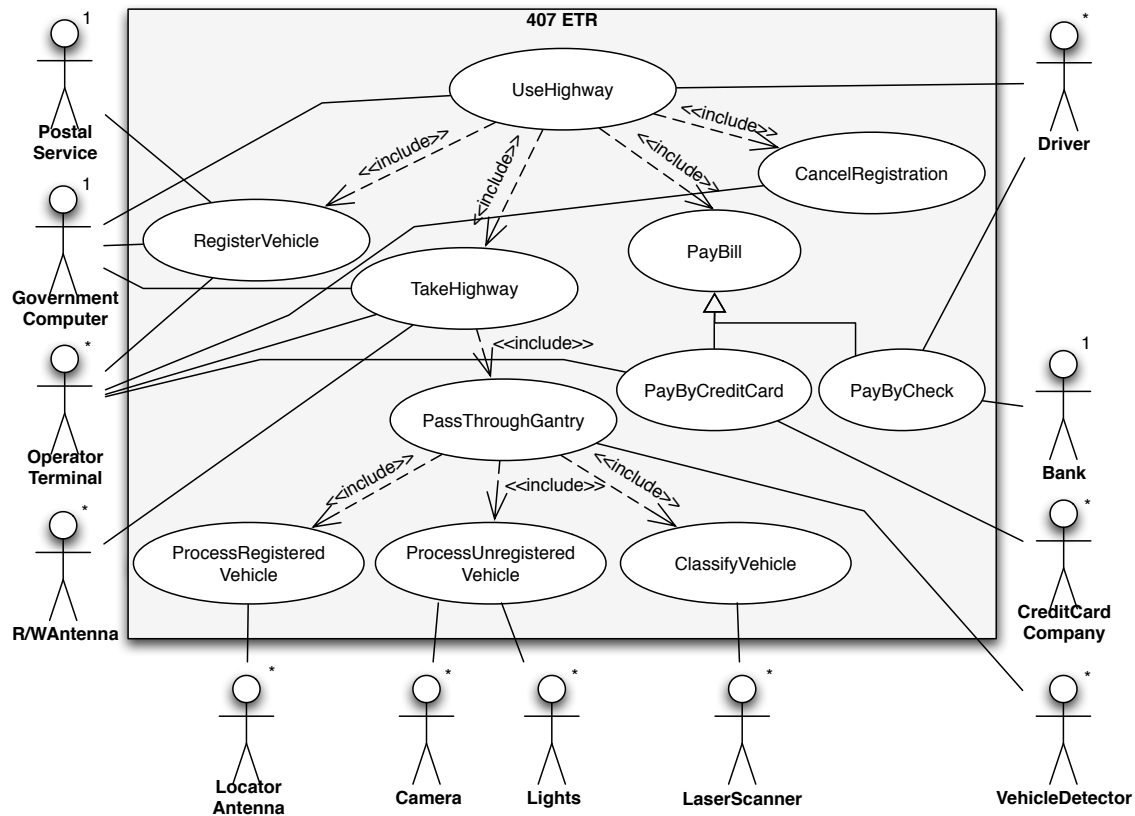


Figure 4: 407 ETR Use Case Diagram

Level: Summary

Intention in Context: The intention of the Driver is to use the 407 ETR highway on a regular basis.

Multiplicity: One Driver can only drive one vehicle at a time on the highway. However, different Drivers can use the highway simultaneously.

Primary Actor: Driver

Secondary Actor: GovernmentComputer

Main Success Scenario:

1. Driver registers vehicle.
Step 2-4 are repeated once a month as long as the vehicle is registered.
2. Driver takes highway.
Step 2 can be repeated any number of times per month.
3. At the end of the month, System sends bill to Driver.
4. Driver pays bill.
5. Driver cancels registration.

Extensions:

- 1a. Driver uses highway without registering vehicle. Use case continues at step 2.
- 4a. Driver does not pay bill for 3 consecutive months.
 - 4a.1. System informs GovernmentComputer of refusal to pay the bill. Use case continues at step 2.

RegisterVehicle Use Case

Use Case: RegisterVehicle

Scope: 407 ETR System

Level: User Goal

Intention in Context: The goal of the Driver is to register a vehicle with the system, which involves opening an account and linking a transponder to it.

Multiplicity: A driver registers his vehicles one at a time. However, the system should be able to handle multiple simultaneous registrations done by different drivers.

Primary Actor: Driver

Secondary Actor: OperatorTerminal, GovernmentComputer, PostalService

Main Success Scenario:

The Driver interacts with the System by calling an Operator.

1. Driver provides System with personal data and vehicle information.
2. System sends vehicle information to GovernmentComputer for verification.
3. GovernmentComputer notifies System that vehicle information is correct.
4. System acknowledges registration to the Driver.
5. System assigns a new transponder to the vehicle, and informs Postal Service to deliver the transponder to the Driver.
6. Driver installs and tests transponder.
7. Driver notifies the System of successful installation of the transponder.

Extensions:

- 3a. Exception{GovernmentComputerUnavailable}. Use case ends in failure.
- 4a. Driver does not have an account with the system yet. System opens a new account for the driver. Use case continues at step 4.
- 6a. Transponder installation and testing fails. Driver notifies System of the problem. Use case continues at step 5.
- 7a. Driver forgets to acknowledge installation and simply starts using the transponder on the highway. Use case ends in success.

TakeHighway Use Case

Use Case: TakeHighway

Scope: 407 ETR System

Level: User Goal

Intention in Context: The intention of the Driver is to drive a vehicle from one location to another by taking the 407 ETR highway.

Multiplicity: One Driver can only drive one vehicle at a time on the highway. However, different Drivers can take the highway simultaneously.

Primary Actor: Driver

Secondary Actor: RWAntenna, GovernmentComputer, OperatorTerminal

Main Success Scenario:

1. Driver enters highway, passing through gantry.
2. Driver exits highway, passing through gantry.
3. System retrieves the driver's vehicle record based on trip information*.
4. System determines the amount owed based on the trip information and adds the transaction to the vehicle's records.
5. System informs Driver by sending a signal to the RWAntenna of successful completion of transaction.

Extensions:

- 3a. Vehicle is unregistered and does not have a record yet.
 - 3a.1. System sends licence plate information to GovernmentComputer.
 - 3a.2. GovernmentComputer sends vehicle information and owner's address to System.
 - 3a.2a. Exception{GovernmentComputerUnavailable}: use case ends in failure.
 - 3a.3. System creates a new vehicle record. Use case continues at step 4.
- 3b. Vehicle is unregistered and licence plate is unrecognizable.
 - 3b.1. System displays pictures on OperatorTerminal.
 - 3b.2. OperatorTerminal sends licence plate information to System. Use case continues at step 3.
 - 3b.2a. Exception{OperatorTerminalFailure}: use case ends in failure.
- 4a. Exit unsuccessful.
 - 4a.1a. If entry was successful, minimum trip charge is added to vehicle's records. Use case ends in success.
 - 4a.1b. If entry was unsuccessful as well, use case ends in failure.
- 4b. Entry unsuccessful.
 - 4b.1a. If exit was successful, minimum trip charge is added to vehicle's records. Use case continues at step 4.
- 5a. Vehicle is not registered. Use case ends in success.

5b. Exception{RWAntennaFailure}: use case ends in success.

***Trip Information Details:** A complete trip information record includes entry and exit time and place, measured and obtained vehicle classification, transponder account or licence plate information or licence plate images.

PassThroughGantry Use Case

Use Case: PassThroughGantry

Scope: 407 ETR System

Level: Sub-Function

Intention in Context: The Driver passes through a entry or exit gantry as part of his trip.

Multiplicity: One Driver can only drive one vehicle at a time through a gantry. However, different Drivers can pass through the same or different gantries simultaneously.

Primary Actor: Driver

Main Success Scenario:

1. System processes registered vehicle.
2. System classifies vehicle.
Steps 1 and 2 can be performed in any order or in parallel.
3. System records entry time and vehicle information for the trip.

Extensions:

- 2a. Processing registered vehicle fails.
 - 2a.1. System processes unregistered vehicle. Use case continues at step 2.
- 4a. Both processing were unsuccessful. Use case ends in failure.
- 4b. Classification was unsuccessful. Use case ends in success.

ProcessRegisteredVehicle Use Case

Use Case: ProcessRegisteredVehicle

Scope: 407 ETR System

Level: Sub-Function

Intention in Context: The System communicates with the transponder to identify the approaching vehicle.

Multiplicity: The System must be able to process multiple registered vehicles simultaneously.

Primary Actor: N/A

Secondary Actor: LocatorAntenna, R/WAntenna

Main Success Scenario:

1. LocatorAntenna notifies System that it detected an approaching vehicle with transponder.
2. System asks R/WAntenna to obtain account information from transponder.
3. RWAntenna informs System of account information.
4. System records account information for the trip.
5. System turns on the Lights.
6. System triggers the Cameras.
7. Cameras send images to System.
8. System determines licence plate information based on images.

Extensions:

- 1a. The approaching vehicle does not have a transponder. Use case ends in failure.
- 1b. Exception{LocatorAntennaFailure}: use case ends in failure.
- (2-3)a. Exception{RWAntennaFailure}: use case ends in failure.
- 3a. R/WAntenna is unable to obtain account information. Use case ends in failure.
- 6a. Exception{LightFailure}: use case continues at step 6.
- 7a. Exception{CameraFailure}: use case ends in success.

ProcessUnregisteredVehicle Use Case

Use Case: ProcessUnregisteredVehicle

Scope: 407 ETR System

Level: Sub-Function

Intention in Context: The System wants to identify the approaching vehicle using the licence plate information.

Multiplicity: The System must be able to process multiple unregistered vehicles simultaneously.

Primary Actor: N/A

Secondary Actors: VehicleDetector, Cameras, Lights

Main Success Scenario:

1. VehicleDetector notifies System that a vehicle is approaching.
2. System turns on the Lights.
3. System triggers the Cameras.
4. Cameras send images to System.
5. System determines licence plate based on images.

Extensions:

- 3a. Exception{LightFailure} Use case continues at step 2.
- 4a. Exception{CameraFailure} Use case ends in failure.
- 5a. Licence plate recognition fails.
 - 5a.1. System displays pictures on an OperatorTerminal.
 - 5a.2. Operator recognizes picture and sends licence plate information to System.

ClassifyVehicle Use Case

Use Case: ClassifyVehicle

Scope: 407 ETR System

Level: Sub-Function

Intention in Context: The System wants to classify the approaching vehicle as light vehicle, heavy single unit vehicle, or heavy multiple unit vehicle.

Multiplicity: The System must be able to classify multiple vehicles simultaneously.

Primary Actor: N/A

Secondary Actor: LaserScanner

Main Success Scenario:

1. System activates LaserScanner.
2. LaserScanner sends vehicle dimensions to System.
3. System classifies vehicle and records classification in trip information.

Extensions:

- 2a. Exception{LaserScannerFailure} System records classification failure in trip information. Use case ends in failure.

PayByCreditCard Use Case

Use Case: PayByCreditCard

Scope: 407 ETR System

Level: User Goal

Intention in Context: The goal of the Driver is pay for his trip by credit card.

Multiplicity: Every driver pays for his trips once a month. The system must support concurrent payments of different drivers, be it by credit card or by check.

Primary Actor: Driver

Secondary Actor: OperatorTerminal, CreditCardCompany

Main Success Scenario:

Driver interacts with System by calling an Operator.

1. Operator provides System with credit card information.
2. System contacts CreditCardCompany to validate credit.
3. CreditCardCompany notifies System of successful validation.

4. System notifies Operator of success.

Extensions:

2a. Exception{CreditCardCompanyUnavailable}: System notifies Operator. Use case ends in failure.

3a. Exception{InsufficientCredit}: System notifies Operator. Use case ends in failure.

PayByCheck Use Case

Use Case: PayByCheck

Scope: 407 ETR System

Level: User Goal

Intention in Context: The goal of the Driver is pay for his trip by check.

Multiplicity: Every driver pays for his trips once a month. The system must support concurrent payments of different drivers, be it by credit card or by check.

Primary Actor: Driver

Secondary Actor: OperatorTerminal

Main Success Scenario:

Driver sends check to Operator.

1. Operator notifies System that check has been received.

Operator cashes check with Bank.

2. Bank notifies System that check has been cleared.

Extensions:

2a. Exception{BouncedCheck}: System notifies Driver. Use case ends in failure.

CancelRegistration Use Case

Use Case: CancelRegistration

Scope: 407 ETR System

Level: User Goal

Intention in Context: The goal of the Driver is to unregister a vehicle and potentially cancel his account with the 407 ETR system.

Multiplicity: A driver unregisters a vehicle one at a time. The system should be able to handle multiple concurrent unregistrations of different drivers.

Primary Actor: Driver

Secondary Actor: OperatorTerminal

Main Success Scenario:

Driver interacts with System by calling an Operator.

1. Operator notifies System that Driver wants to cancel his registration for a vehicle.

2. System marks vehicle registration as suspended and does not charge monthly fees anymore.

Driver sends transponder to Operator.

3. Operator notifies System that transponder has been received.

4. System cancels vehicle registration.

5. If Driver has no vehicles registered with the system anymore, System cancels driver account.

Extensions:

3a. Exception{TransponderUsed}: System reactivates registration. Use case ends in failure.

Architectural Decisions

After an initial analysis, the developing team determined that it would be very inefficient and unreliable to have one central computer handle the hardware of each gantry. They decided to assign a *gantry controller device* to each gantry. The device coordinates the *LocatorAntenna*, *R/WAntenna*, *VehicleDetector*, *LaserScanner*, *Camera* and *Lights*, collects all information for a passing vehicle, and then sends the completed trip information to the backend system.

As a result, the system development is now split into two systems: the *gantry controller system* and the *407 backend system*. You have been assigned to the team that develops the backend. An environment and concept model for the backend system are shown in figure 5 and figure 6.

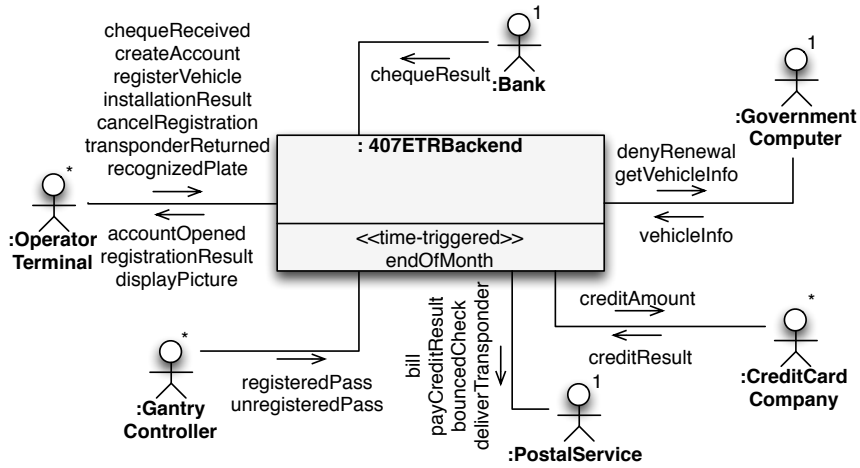


Figure 5: 407 ETR Backend Environment Model

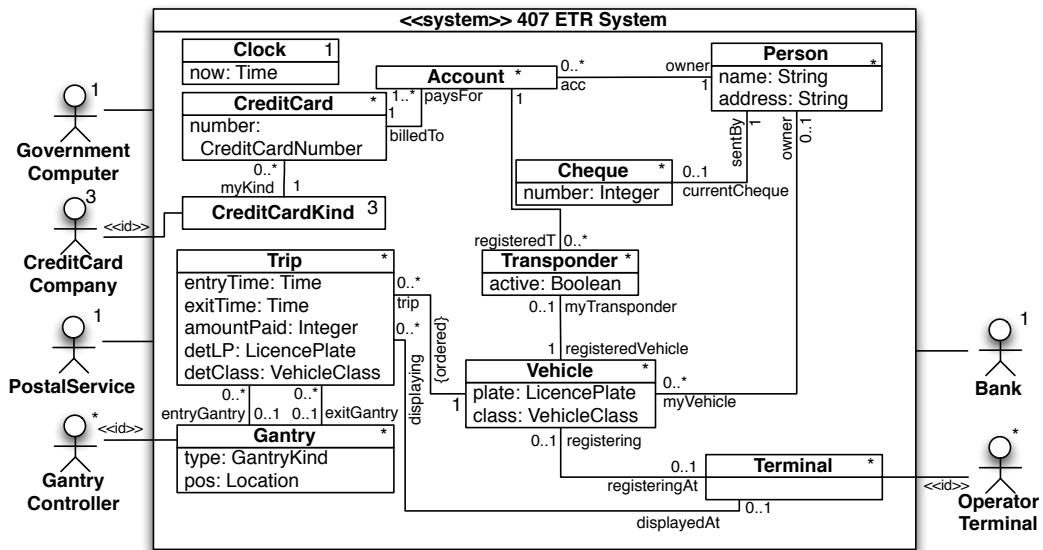


Figure 6: 407 ETR Backend Concept Model

Type Definitions

The environment model and concept model assume the existence of the following types:

- **Picture**: a type encoding a series of pictures taken by the licence plate cameras.
- **CreditCardNumber**: a type encoding a credit card number.
- **ChequeNumber**: a type encoding a cheque number.
- **LicencePlate**: a type encoding a licence plate number.
- **Time**: a type encoding time.
- **Location**: a type encoding a location on the highway.
- `type VehicleClass is enum {light, heavy_single, heavy_multiple, undetermined}`
- `type GantryKind is enum {entry, exit}`
- `type TransactionKind is enum {monthlyFee, registeredTrip, unregisteredTrip, fine}`
- `type Transaction is TupleType {kind: TransactionKind, description: String, amount: Integer}`

Input Messages

- `registeredPass(t: Transponder, when: Time, class: VehicleClass, pict: Picture)`
- `unregisteredPass(when: Time, class: VehicleClass, pict: Picture)`
- `vehicleInfo(lp: LicencePlate, class: VehicleClass, ownerName: String, ownerAddress: String)`: sent by *GovernmentComputer* to transmit vehicle information to System.
- `creditResult(c: CreditCardNumber, amount: Integer, outcome: Boolean)`: sent by *CreditCardCompany* to notify System of credit request result. You can assume that the amount is equal to the amount that you requested.
- `chequeReceived(p: Person, cheque: ChequeNumber)`: sent by *Operator* when he receives a check from an unregistered driver.
- `chequeResult(cheque: ChequeNumber, amount: Integer, outcome: Boolean)`: sent by *Bank* when a cheque clears or is rejected. The value of amount does not necessarily cover all outstanding trips.
- `createAccount(name: String, address: String, cardnumber: CreditCardNumber)`: sent by *Operator* to create a new account for a person identified by a name and an address, and register for auto-payment by credit card. The person identified by the name and address could already be part of the conceptual system state, but does not have to be. Same for the credit card.
- `registerVehicle(a: Account, lp: LicencePlate, class: VehicleClass)`: sent by *Operator* when a driver wants to register a new car.
- `installationResult(t: Transponder, outcome: Boolean)`: sent by *Operator* to notify System of successful or unsuccessful installation of transponder.
- `cancelRegistration(t: Transponder)`: sent by *Operator* to notify System that a driver wants to return the transponder and cancel the registration of his vehicle.
- `transponderReturned(t: Transponder)`: sent by *Operator* to notify System of the return of a transponder.
- `recognizedPlate(t: Trip, lp: LicensePlate)`: sent by *Operator* after he recognized a licence plate image.

- <<time-triggered>>endOfMonth(): triggered at the end of the month to notify the System to send out the bills to all drivers. For accounts that are registered for auto-payment by credit card, the trips of the month are automatically billed to the credit card. In case a person has trips that are older than 3 months that he did not pay for, the government should be notified to deny future license plate renewals.

Output Messages

- displayPicture(trip: Trip, pict: Picture): sent to *Operator* when a licence plate is unrecognizable.
- getVehicleInfo(lp: LicencePlate): sent to the *GovernmentComputer* to obtain the vehicle information for the vehicle identified by the given licence plate.
- bill(addressee: Person, transactions: Set(Transaction)): sent to *PostalService* at the end of the month to inform driver about his transactions (trips, fines and monthly transponder lease).
- bouncedCheque(addressee: Person, cheque: ChequeNumber): sent to *PostalService* to inform driver about a bounced check.
- deliverTransponder(addressee: Person, t: Transponder): sent to *PostalService* in order to deliver a transponder to a registered driver.
- accountOpened(a: Account): sent to *Operator* to notify driver of the opening of a new account.
- registrationResult(outcome: Boolean): sent to *Operator* to notify driver of the success or failure of vehicle registration.
- payCreditResult(addressee: Person, outcome: Boolean): sent to *PostalService* to notify driver of the success or failure of credit card payment.
- creditAmount(c: CreditCardNumber, amount: Integer): sent to *CreditCardCompany* in order to check for the validity and solvency of a credit card.
- denyRenewal(lp: LicencePlate): sent to the *GovernmentComputer* to block the licence plate renewal of the vehicle.