Modeling and Performance Evaluation of a Manual Logon System for Electronic Fee Collection

VDE/ITG-Workshop: Communication Applications for Logistics: Maut, Telematics & More
VDE/ITG FA 5.2., Bremen, January 26th., 2006

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German Toll Collection System "TollCollect"

- 2005, Germany introduced an Electronic Fee Collection System (EFC)
- Global navigation satellite system and cellular network (GNSS/CN)
- Currently > 700,000 registered users
  By 2012, might grow to over 9 million in Europe
- Three approaches for payment

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<th>Automatic Logon</th>
<th>Manual Logon</th>
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<td><img src="image1" alt="On-board unit" /></td>
<td><img src="image2" alt="Internet and Call Centre" /></td>
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<tr>
<td><strong>On-board unit</strong></td>
<td><strong>Internet and Call Centre</strong></td>
</tr>
<tr>
<td>• &gt; 460,000 (July 2005)</td>
<td>• approx. 3600 terminals</td>
</tr>
</tbody>
</table>
| • approx. 80% revenue | • marginal and declining | • approx. 400 frequently used terminals
  • approx. 400 rarely used terminals |
TollCollect’s Manual Logon Process for EFC
TollCollect’s Manual Logon Process for EFC

- Billing data records have to be transferred quickly for enforcement
- System behavior after failure or outage is critical
Challenging Scenarios

- System failure or breakdown of key components
  - Billing and Data Centre
  - Remote Access Server (RAS)
- Overload situation
  - Breakdown of the automatic GNSS/CN EFC system
  - Specific and unexpected peaks

→ Financial losses and negative standing for the operator

Aim of this work

- Model and evaluate the overall manual logon process regarding performance and scalability
- Optimize the algorithm and parameters for transmission of billing data records after system outage
Normal operational mode

Failure-free billing data records (BDR) delivering

User/Driver

T_{\text{connect}} \sim 10 \text{ s.}

T_{\text{ServerTimeout}} 35 \text{ s.}

Timer abort

T_{\text{followup}} 45 \text{ s.}

Connection request

ACK

BDR

Connection termination

ACK

BDR

ACK

T_{\text{op}}
Autonomous mode

Erroneous connection establishment

User/Driver

\[ T_{\text{connect}} \approx 10 \text{ s.} \]

Enter autonomous mode

\[ T_{\text{server\_timeout}} = 35 \text{ s.} \]

Connection request

ACK

BDR

Connection termination

\[ T_{\text{op}} \]
Billing data records (BDR) delivering

Parameters
- AutoReconnectInterval \( ARI \)
- AutoSendInterval \( ASI \)
- Number of delivered BDRs \( n \)
- Time to transfer one BDR \( t_{BDR} \)

Relations
\[
 n = \begin{cases} 
 1 & \text{ASI} < t_{BDR} \\
 \frac{ASI}{t_{BDR}} & \text{ASI} \geq t_{BDR} 
\end{cases}
\]
Open queueing network

- **Frontend** comprises the terminals and the RAS
- **Backend** represents the BDM as a M/D/k-Multi-Server-Delay-System
Performance evaluation

Scenario

Terminal queues

BDR arrivals

Normal operation mode

1 h outage

Autonomous mode

$T_{\text{recovery}}$

$t$
Performance evaluation

Scenario

Terminal queues

- Normal operation mode
- 1 h outage
- Autonomous mode

- BDR arrivals
- $\lambda_{IRS} = 160 \text{ s}^{-1}$
- $\lambda_{BDM}$
- $k = 50$
- $h = 2 \text{ s}$
- 3600 terminals
- 1920 RAS ports connection requests $24 \text{ s}^{-1}$
- $T_{recovery}$
- $\lambda_{BDM}$
Scenario

**Performance evaluation**

- **Scenario**
  - Homogeneous scenario
    - IAT = 180 s
    - 3600 terminals
  - 1920 RAS ports
    - Connection requests 24 s\(^{-1}\)
  - 1 h outage
  - Autonomous mode
  - Normal operation mode
  - \(\lambda\_{IRS} = 160\ \text{s}^{-1}\)
  - \(\lambda\_{BDM}\)

- **Parameters**
  - \(k = 50\)
  - \(h = 2\ \text{s}\)
Performance evaluation

CDF of the queue processing (n = 1)

- With default configuration (ARI = 150 s) approximately $T_{\text{recovery}} = 2.5$ h
Performance evaluation

CDF of the queue processing (n = 1)

- Decreasing ARI values reduce $T_{recovery}$
Performance evaluation

BDM utilization (n = 1)

- ARI = 150 s cannot utilize the BDM continuously
Smaller ARI values are feasible due to *RAS boundary*.
So far, deterministic approach

- ARI and $n$ are constant values for all terminals
- Periodic system behavior $\rightarrow$ possible instability
- Default of the recovery algorithm is too restrictive
  - The parameters after an outage are not optimal

- Challenge: improvement and optimization of the algorithm and parameters
- Aim: minimization of the recovery duration with controlled BDM load
Backoff Algorithm (2)

New approach for the backoff algorithm

Initial configuration in the autonomous mode  \( \text{ARI}_0 = 150 \text{ s}, n_0 = 2 \)

**Failure-free case**  Connection to RAS could be established successfully

\[
\text{ARI}_{i+1} = \text{ARI}_0 + \frac{\text{ARI}_i}{2}, \quad n_{i+1} = \begin{cases} 
  n_i \cdot 2 & \text{if } 2n \leq q \ell \\
  q \ell & \text{else}
\end{cases}
\]

**Failure case**  Connection to RAS could not be established

\[
\text{ARI}_{i+1} = \begin{cases} 
  \text{ARI}_i - \frac{\text{ARI}_i}{2} & \text{if } \left( \text{ARI}_i - \frac{\text{ARI}_i}{2} \right) \geq \text{ARI}_0 \\
  \text{ARI}_0 & \text{else}
\end{cases}
\]

\[
\frac{n_i}{2} & \text{if } \frac{n_i}{2} \geq n_0 \\
\text{ \quad \quad } n_0 & \text{else}
\]
Conclusion and outlook

• Modeled the manual logon process (users and system)
• Evaluated the recovery process in the autonomous mode
• Introduced a new approach for the backoff resolution

-default manual logon process works stable, but is restrictive after an outage

• System behaviour depending on different downtime scenarios
• Optimization of the Backoff Algorithm to minimize RAS and BDM utilization
• Make the Backoff Algorithm dependant on state of
  - terminal queue
  - BDM
• Evaluate heterogeneous scenarios
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