On January 1, 2005, Toll Collect GmbH introduced in Germany a distance-based road-charging system for trucks with a permissible total weight of 12 tons or more depending on the number of axles and the emissions category of the truck. The system covers the entire German Autobahn (motorway) system of more than 12,000 kilometers representing more than 5,300 sections. (Passenger vehicles and trucks under 12 tons do not incur a toll.)

The system was required to meet several key criteria, as defined by the German government. Specifically, it had to:

- Operate as a free-flow system without roadside structures such as toll plazas;
- Use distance-based tolls, with tariffs depending on number of axles and emissions class;
- Be nondiscriminatory, to allow, for instance, foreign trucks to use the tolled network on an equal basis with domestic trucks;
- Have the highest possible degree of flexibility, to allow for as-needed modifications to tariffs and to the motorway network itself and to permit charges to be extended to main roads;
- Ensure technical compatibility for interoperability within Europe; and
- Allow compatibility with future intelligent traffic management and value-added services.
Toll Collect GmbH—a subsidiary of DaimlerChrysler Financial Services, telecommunications firm Deutsche Telekom, and concessionaire Cofiroute—chose an innovative solution to establish the system based on Global Navigation Satellite System (GNSS) position location and mobile communications via GSM (global system for mobile communications). Toll Collect (TC) developed, implemented, and now operates this new system under a public–private partnership contract with the Federal Republic of Germany.

The system and its start-up phase were originally described in the article “New Technologies, New Challenges: The German Toll Collect GPS-GSM System” in the Winter 2006 issue of Tollways. The current article presents some of the lessons learned after two years of operation.

**Major Components of the Toll Collect System**

Under the TC system, an onboard unit (OBU) installed in the truck stores all the relevant vehicle data and automatically locates the vehicle’s position on motorways using signals from a global positioning satellite (GPS) system. The OBU determines whether the road segment the vehicle is driving on is subject to a toll and, if so, which rates apply. The unit calculates the toll due and periodically transmits such data to a central services and databases, or computing, center (see Figure 1).

As alluded to above, transmission of the toll information between the OBU and the computing center is conducted via cellular GSM networks. These same networks are used to automatically transmit software or database updates to the OBU, or end user. Currently, this mobile communication system connects approximately 542,000 end users with the central computing center.

The computing center is the focal point of the TC system. It operates all central application databases, which house information including vehicle registration and OBU administration data. The center also stores all billing records, produces invoices to be sent to registered users, and controls the overall system’s performance. To optimize functionality and system performance, state-of-the-art billing and customer service is provided. The German GNSS tolling system requires basically no roadside infrastructure. Courtesy E & L Verlag, “Highway Deutschland.”
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relations management (CRM) systems are employed in the center to handle the heavy transaction load associated with serving more than 116,000 registered trucking companies in Germany and abroad.

Drivers whose trucks aren’t equipped with an OBU and who don’t regularly use Germany’s motorways can book and pay for their journey via a network of point-of-sale (POS) terminals at more than 3,500 points in Germany and neighboring countries. The terminals are located mostly in service (petrol) stations along all major roads. They are also available in urban areas, as delineated on TC’s Web site (www.toll-collect.de). Alternatively, truckers without an OBU can register to use an Internet booking system, which permits them to book their trip online and receive a bill subsequently by mail.

Figure 1: System Architecture
Unauthorized or malicious use of the toll network is deterred by means of a state-of-the-art enforcement system, which comprises the following main components:

- Stationary enforcement gantries, equipped with sensors to detect noncompliant users and collect evidence of violation.
- Mobile enforcement units that conduct drive-by checks to possibly stop and control violators.
- An enforcement center that verifies and stores evidence data, collects fines, and, if necessary, initiates prosecution.

**System Accuracy**

Trucks drove 23.9 billion kilometers in 2005 and 25.9 billion kilometers in 2006 on the German motorway system, and TC collected, respectively in those years, 2.86 billion euros and 3.08 billion euros with a high degree of precision.

The collection-accuracy rate of the system is measured year-round by the German Ministry of Transport together with an independent body. More than 50,000 measurements are made throughout the year to verify whether all the sections and all the trucks are being properly charged. This means determining not only that the OBUs are working correctly, but also that the network modeling is adequate, that the transmission of data between OBUs and the computing center is complete, and that the transactions are being properly billed.

According to TC’s contract with the German government, the system should be 99 percent accurate. If it is less than 99 percent correct, TC is obligated to pay penalties to compensate for toll losses. If, conversely, the rate exceeds 99 percent, TC is entitled to a bonus. In its first year of operation, the system was 99.50 percent accurate, and in the second year it reached 99.75 percent.

**Quality and Environment Management**

TC has developed comprehensive quality management and environment management systems. The quality management system has been certified to ISO 9001:2000 for all of its 52 processes since June 2004. That means that TC fulfills its customers’ quality requirements and the applicable regulatory requirements while aiming to enhance customer satisfaction and continually improve its performance in pursuit of these objectives.

The environment management system has been certified to ISO 14001:2004 since June 2005. That means that TC minimizes the harmful effects of its activities on the environment while trying continually to improve its environmental performance.

Whereas the vast majority of ISO standards are highly specific to a particular product, material, or process, the ISO 9000 and ISO 14000 families have earned a worldwide reputation as...
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“generic management system standards.” Both certifications have been successfully audited on a yearly basis by independent auditor Bureau Veritas.

Because the implementation of these systems was practically concomitant with the start of operations, a “process culture” has developed within TC whereby the employees consider it natural to describe and “live” their daily work within a process framework. This is a source of continual optimization and savings, partly because the process framework fosters efficiency.

Ecologically, the toll charging system so far has yielded two positive effects. First, since January 2005, the number of empty (non-cargo-carrying) trucks driving on the German motorways has decreased to 9 percent, according to the German Ministry of Transport. Second, as indicated in Figure 2, the share of registered trucks with a “bad” emissions class (classes 1 and 2) declined between December 2004 and December 2006, while the number of clean trucks (classes 3 through 6) increased.

When they renew their fleets, transport companies buy cleaner vehicles, both new and used. This trend should evolve further because class 2 and 4 trucks are now charged two additional eurocents per kilometer as of October 1, 2006. This means that

Figure 2: Ecological Effects of the Toll Collect System

The emissions classes of the trucks registered with TC have improved steadily since December 2004. (Class 1 is the most polluting; class 6, the least polluting.)
More than 542,000 trucks now have an OBU installed, an increase of 60 percent over the January 2005 figure. Truck manufacturers, as well, have adopted the OBU.

a class 2 or 4 truck driving 100,000 kilometers a year will have to pay 2,000 euros more than it did the year before.

**Customer Acceptance and Compliance**

The acceptance of this first satellite-based toll system by German and non-German customers continued to rise throughout 2006, particularly in regard to paying tolls automatically via OBU. Whereas in January 2005, the proportion of automatic toll paying was about 72 percent, the current share is nearly 90 percent. More than 542,000 trucks now have an OBU installed, an increase of 60 percent over the January 2005 figure. Truck manufacturers, as well, have adopted the OBU. DaimlerChrysler, DAF, MAN, Volvo, Scania, and Iveco all offer to configure their new trucks to accept OBU installation, and Renault should start offering the same service soon.

Most users of the manual system are truck drivers from eastern nations who prefer to pay in cash because credit cards or petroleum cards are not very
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popular in their countries (see Figure 3). Other customers say they trust the automatic system because it is simple to use and transparent. As they drive, they can see on their OBU’s display the amounts that have been charged, and they have found the monthly invoices they receive to be accurate. The very low number of customer complaints TC has received clearly indicates the system’s smooth operation. Over the spot-checks of trucks traveling the motorways. The number of such checks has to be high enough to achieve the proper deterrent effect but can’t be so high as to be prohibitively costly. Over several months, for example, we sampled 10 percent and then 20 percent of trucks on the motorways. In both cases, the same violator rate was observed. Consequently, today, for cost-efficiency purposes, 10 percent of the trucks are

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The number of violators, too, has been very reasonable in such a free-flow system. In the first month of operation, about 4 percent of customers committed violations, mainly because the system was new. That rate rapidly fell and remains continuously under 2 percent.

To deter violators, TC conducts spot-checked, 5 percent using mobile enforcement (where special vans verify whether a truck has paid its toll as they drive by) and 5 percent using the 300 enforcement gantries installed on the motorways. This represents approximately 18 million trucks a year.

Evolution of Costs
A good toll system by definition has to collect the right amount of money for the lowest possible cost. Thus, the costs of implementing and operating such a system are key factors when it comes to choosing between different free-flow setups.

The first dedicated short-range
Since 2003, TC’s modeling techniques for the network have evolved, allowing its algorithms to become more accurate. Thus, instead of needing more than 190 support beacons, as was initially the case, today fewer than 110 beacons are required. That number can be further reduced as the modeling methods continue to improve.

The same evolution can be observed with the GPS system. The major cost elements in a GNSS system are the support beacons and OBUs (in terms of capital investment) and the telecommunications system (in terms of operations).

Support-beacon reduction.

Because of motorway geometry, in certain circumstances support beacons are required in addition to the GPS system in order to determine whether a vehicle is on the motorway or on an adjacent road. This occurs on short road segments where there are many parallel roads in a narrow corridor.

communications (DSRC) monolane systems were implemented in the late 1980s, and the first free-flow system was begun in 1995 on the 91 Express Lanes in California. Since then, these systems have expanded worldwide, and tens of millions of transponders have been produced. The quality of the different components involved, including the transponders, has improved in tandem, and their costs have decreased.

Sonnborner Kreuz: Here, only one support beacon is needed to differentiate the tolled motorway (AB) from the free road (L74).
Declining costs of OBUs. The cost of the OBU is following the classic pattern of economies of scale. In 2003, OBUs cost slightly more than 500 euros each. In 2006, they cost approximately 250 euros each and by 2010 are expected to fall below 100 euros apiece. By then, OBU installation, as well, should be much easier and less expensive.

An OBU’s ability to communicate with the TC system doesn’t require that the unit be in Germany. Prior to arriving in Germany, however, the OBU must receive any necessary software, network, and tariff updates before crossing the border so as not to be mistaken as a violator. Communication costs consist of a flat rate for national communication and variable costs for roaming abroad.

After several optimization processes, the communication costs per OBU were reduced from an average of more than 5 euros per month to less than 3.5 euros per month, and it is expected that by 2010 the cost will fall below 1 euro per month.

Motorway Flexibility
A motorway network isn’t static. Germany’s motorways experience approximately 100 changes per quarter, such as newly built tolled sections, modified interchanges, sections that are no longer tolled, work on sections leading to temporary modifications, and so on.

In Germany, the number of sections in the network grew from 5,186 in...
November 2005 to 5,371 in January 2007, with a partial peak of 5,254 sections in March 2006 (see Figure 4).

With DSRC tolling technology, such motorway changes would have dictated an additional investment for adding and dismantling tolling gantries. With GPS/GSM tolling technology, however, new network data are sent “through the air” to the OBUs, and the cost is already included in the communication costs noted above.

In January 2005, when charges were introduced on the German motorways, a portion of traffic was diverted to parallel main roads (Bundesstrassen). This caused problems for the surrounding neighborhoods, such as excess congestion and increased noise (see Figure 5).

After an extensive political process, the Bundesrat (the upper house of the German parliament) voted on October 13, 2006, to extend tolling to three main roads, representing a distance of 50 kilometers, beginning on January 1, 2007.

Tolling main roads is usually much more complicated than tolling motorways because of the large number of noncontrolled access roads involved, leading to a multitude of sections. The amount of tolls expected isn’t an important criterion in this case because the aim isn’t so much to raise revenues as it is to re divert trucks back onto the motorway. Hence, here, tolling is used as a traffic management tool. That means that the investment in such tolling should be as little as
possible and the erection of gantries should be avoided.

The modeling of these roads was conducted within a few weeks and the data transmitted automatically to registered OBU and POS terminals. (Had gantries been needed, their design and erection wouldn’t have been possible by the January 1, 2007, start date.)

**Innovative Mobile Enforcement**

The motorway network’s mobile enforcement vans have a reader on the roof, to read on the right-hand side when they pass a truck on a motorway. On a two-lane (one per direction) road, however, it is difficult to pass other vehicles. To solve this problem, Toll Collect developed a new generation of mobile enforcement vans with two readers on the roof, one on each side (see Figure 6). The one on the left-hand side can rotate, permitting mobile enforcement from a variety of vantage points. In addition, a portable camera can be added upstream when traffic intensity dictates.

**A Promising Future**

The GNSS-based system developed in Germany is working well and very smoothly. After two years of experience, we can conclude the following:

- A motorway network is a “living” object, with many sections being added or modified each month. Thus, when comparing tolling techniques for such a network, one should measure the investment over many years.
- Flexibility in a tolled network is very important, especially in a case such as Germany, where motorway sections are removed and added on a regular basis. There, after the government voted to extend tolling to some main roads as of January 1, 2007, Toll Collect found a rapid and economical way to implement this decision. In each case, only a remodeling of the network software, not an investment in new infrastructure, was required.
- The component costs of the network have followed the normal pattern of a product’s life cycle: New components were expensive at first, but their costs have sunk as production has increased. Within less than 10

Example of a section of a main road in Germany being tolled as of January 1, 2007.
years, the investment costs will be reduced fivefold.
- If this technology were extended to private cars, the economies of scale would be even greater and the costs could be reduced even more.
- Once an operator is in charge and is given the right financial incentives, he can optimize operation costs. Such optimization, however, results from small daily improvements requiring consistent effort.
- To surpass the achievements we have already attained, and because, as the old saying goes, “only what can be measured can be improved,” TC is tackling costs from another point of view. At first, our process-oriented system allowed us to calculate the total costs of each of our end-to-end processes (including amortization of the investment), such as automated or manual transactions, invoices, contacts with customers, and so on. Then, we looked at benchmarks for each process. When we found no such benchmarks in our industry (which was the case for many of the...
Processes (processes), we had to look at industries with similar processes. Ultimately, we started a benchmarking process with other operators, under confidentiality agreements, to determine whether those operators are more efficient and, if so, why. As a result, we are sure that within two to three years, we shall be able to achieve further and recurrent substantial savings.

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