Beginner's Roadmap to Working with Driving Behavior Data

Jim Weiss, FCAS, MAAA, CPCU

Jared Smollik, FCAS, MAAA, CPCU

Abstract

Motivation: Usage-based auto insurance has received considerable publicity, but the driving behavior data that fuels these programs has been the subject of limited academic scrutiny. In this paper, we expose the challenges and risks that result from working with this data, and we discuss how actuaries may collect, organize, and analyze driving behaviors for use in insurance applications.

Method: In this paper, we use historical context to identify objectives, challenges, and risks in working with driving behavior data. We identify key tenets of the infrastructure required to support data collection, with a focus on vehicle telematics. We look at sample driving behavior data and how it may be organized into databases for predictive modeling and classification. We conclude with a discussion of sample use cases for the data.

Results: Driving behavior data allows insurers to achieve unique goals in pricing, underwriting, and loss control or mitigation, but it also presents unique challenges and risks.

Conclusions: Sound data management allows insurers to use driving behavior data to achieve organizational goals while rising to the challenges and risks this data presents.

Keywords: Driving behavior data; usage-based insurance; vehicle telematics; black boxes.

1. INTRODUCTION

Usage-based auto insurance (UBI) is defined as "a rating structure that is based, in whole or in part, on the electronic accumulation of data, through a device installed in a motor vehicle, in which an individual's daily driving habits are used to determine a premium rate."[1] The technological framework underlying UBI is referred to as vehicle telematics, that is, "the use of global positioning system (GPS) technology integrated with computers and mobile communications technology in automotive navigation systems."[2] The information generated using telematics—including when, where, how often, and the manner in which a vehicle is operated—is called driving behavior data (DBD). Telematics makes large quantities of detailed DBD accessible to actuaries, who may then use this information as the foundation upon which to build innovative and statistically supportable UBI rating plans.

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[1] From Colorado Department of Regulatory Agencies, page 2.
[2] From Telecommunications Systems, Inc., page 4.

The potential uses of DBD are captivating. In *Personal Automobile: Cost Drivers, Pricing, and Public Policy,* Conners and Feldblum observe that "traditional actuarial focus on ratemaking and classification systems has led to an emphasis on pre-accident factors—particularly driver, vehicle, and geographic characteristics—to the virtual exclusion of other factors."[3] They suggest that pre-accident factors relate primarily to claim frequency, while neglected "post-accident factors" such as injury types, medical treatment, and attorney involvement could be more predictive of loss severity. DBD has the potential to bridge the gap between pre- and post-accident factors. For example, vehicles' average speeds may help predict not only accident occurrence but also resulting injury types, and locations of driving may help predict the quality of medical care or likelihood of attorney involvement. DBD may be used to statistically model these and other effects.

Despite its intuitive appeal, UBI uptake has been slow. While over 90% of personal insurers were actively using insureds' credit histories within approximately five years of the earliest adopters, insurers representing only three-fifths of the auto market have implemented UBI programs in the decade-plus since Progressive Casualty Insurance Company (Progressive) launched the first pilot.[4] As a result, little has emerged in the way of academic consensus or a universal model for effectively managing DBD, and individuals new to the UBI space may have difficulty locating resources geared towards the beginner. Strube and Russell developed a model for handling challenges in the modern high-volume transactional processing environment (HVTPE). In it, actuaries identify, procure, and maintain necessary data from various business areas while creating "user-defined" fields to facilitate their own analyses.[5] Many of the lessons learned from HVTPEs are applicable to DBD, but transactional data originates when policies are written, renewed, or endorsed, or when claims are reported or serviced. DBD adds a new dimension by collecting potentially sensitive information at higher frequencies, often remotely, and over an extended period of time. This presents a unique set of data management challenges for the actuarial data manager (ADM). The objective of this paper is to provide a beginner's road map for actuaries and other insurance professionals interested in working with DBD.

The remainder of the paper shall proceed as follows: Section 2 will provide historical background information, identify objectives in working with DBD, and examine key challenges in

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[3] From Conners and Feldblum, page 322.
[4] Figures are taken from Sturgeon, page 1 and Towers Watson, paragraph 8. According to Oregon Department of Consumer and Business Services, insurers began using credit history for personal lines of insurance in 1995. Conning survey referenced in Sturgeon was taken in 2001.
[5] See Strube and Russell, page 287.

doing so. Section 3 will focus on one specific challenge: establishing the technological infrastructure required to collect and analyze DBD, i.e., telematics. Section 4 will discuss organizing DBD into databases which may be used for predictive modeling and classification. Section 5 will discuss issues related to utilization of DBD now and in the future. The final section, Section 6, will offer our conclusions.

2. ORIGINS, DESTINATIONS, AND ROADBLOCKS

In his 1929 paper *Notes on Premium and Exposure Bases*, Dorweiler identified critical conditions affecting the "hazard covered by automobile liability insurance, or that cause deviations in this hazard."[6] They were:

- The car—age, condition, etc.
- Highways—road beds, curves, visibility, etc.
- Traffic density
- Laws, regulations, and their enforcement
- Efficiency of driver—age, experience, habits, impairments, etc.
- Mileage
- Speed
- Weather conditions
- Seasonal use of car
- Day and/or night use of car

Most of these data elements, especially the last six, can be considered DBD, but Dorweiler correctly concluded that the lack of necessary "devices and records" (i.e., telematics and the resulting DBD) made the use of such information (i.e., UBI) "impractical under [then] present conditions."[7] As a result, actuaries in the ensuing decades came to rely on what Conners and Feldblum call "proxies for the true ("causative") factors affecting loss costs," such as age, gender, or garaging

[6] Quotes and bullet-list have been reproduced verbatim from Dorweiler, page 337.
[7] Ibid., page 338.

territory.[8] In the 1980s, states such as California and Michigan began to require the use of more "causative"[9] rating variables such as mileage and driver safety record, but even these variables' predictive abilities were contingent upon the veracity of mileage estimates and the credibility of individual driving records.[10] Three distinct waves of innovation helped transform early prophesies of UBI from voices in the wilderness into winds of change.

The first wave was "the computerization of vehicles," which began with the invention of the microprocessor in 1971. Government regulations regarding emissions, safety, and fuel economy in the years that followed effectively required automakers to utilize the new technology to install electronically controlled engines and safety devices in vehicles. Microprocessor-based controls soon took hold of other vehicle systems (e.g., braking). The result was a wealth of DBD describing vehicles' operating conditions, but no efficient way to collect or analyze it. Symptomatic of this was a failed California Senate Bill in 1993 which would have required auto insurance to be purchased by gallon of fuel at the pump.[11] After decades of technological innovation, the highest profile UBI proposal involved collecting DBD with a century-old device (the fuel pump) that Dorweiler had long since rejected as impractical.

The second wave of innovation was "The Computerization of Society." In 1978, the same year the first GPS satellite was launched, Nora and Minc defined *télématique* as the "increasing interconnection between computers and telecommunications."[12] Their vision became a reality in the 1990s with the confluent emergence of satellite-based positioning systems, platforms capable of interfacing with vehicles' on-board computers, and expanded two-way wireless communication abilities. In 1996, President Clinton signed a directive transforming GPS from a primarily military technology into an "international informational utility," and a large market for factory-installed and aftermarket GPS equipment was developed. Federal law effective that year also required all new vehicles to be outfitted with On-Board Diagnostic (OBDII) ports capable of reporting the output from vehicles' various sensors. Finally, the launch of the General Packet Radio Service (GPRS) in 1997 allowed for "always-on" wireless data services. The resulting birth of vehicle telematics

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[8] From Conners and Feldblum, pages 330-331.
[9] The Actuarial Standards Board's (ASB) Actuarial Standard of Practice (ASOP) No. 12 on Risk Classification states that "it is not necessary for the actuary to establish a cause and effect relationship between the risk characteristic and expected outcome in order to use a specific risk characteristic" (page 4).
[10] See Mahler for more information on the credibility of a single driver.
[11] See "California Lawmakers Reject 'Pay at the Pump' Insurance,", *New York Times*, May 27, 1993.
[12] From Shanken, pages 51-52.

provided more detailed DBD than ever (including locations) and, more importantly, a way to communicate it outside the vehicle using everyday technology.

The third wave of innovation we have named "the automization of auto insurance." One of the first sectors to successfully utilize telematics was commercial trucking, where fleet operators tracked the locations and physical conditions (e.g., fuel level) of their equipment for optimization, preventative maintenance, and other purposes. Progressive brought telematics to the insurance sector with their Autograph pilot in 1998. As part of the voluntary program, the company installed GPS-capable devices in participating insureds' vehicles to record DBD such as the amount of time spent driving at different times of day or located in different "risk zones," all for use in premium determination.[13] Although the effort was allegedly popular with insureds that enjoyed having more control over their premiums, the program was discontinued in 2001 due to technological cost considerations. Undeterred, a number of insurers and organizations serving the industry, including Progressive (who reemerged with another initiative in 2004), have tested or gone to market with different "flavors" of UBI as the third wave continues into the present.

Organizations choosing to work with DBD have various objectives. A primary objective for actuaries is to more effectively segment their employer's book of business. The ASB ASOP No. 12 regarding risk classification observes that "if the variation of expected outcomes within a risk class is too great, adverse selection is likely to occur."[14] Autograph actually functioned more like a monthly utility bill than a risk classification system, retroactively billing insureds based on usage and effectively achieving individual risk segmentation. However, more recent efforts (including Progressive's) have employed risk characteristics such as mileage, time of day, speed, and extreme braking to determine discounts in the future. This is more consistent with the traditional classification approach of "assign[ing] risks to groups based upon the expected cost or benefit of the coverage or services provided."[15] With the potential behavioral variations between drivers of, say, the same age, gender, and credit score, the use of DBD in risk classification has great promise in helping achieve ASB ASOP No. 12's recommended "homogeneity with respect to expected outcomes" in order to avoid adverse selection.

A second objective of DBD is not simply to avoid adverse selection, but rather to actively pursue a more profitable portfolio of insured risks using telematics. Insurers who request DBD from

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[13] See Figure 8.7 on page 185 of Cady and McGregor.
[14] From ASB ASOP No. 12, page 5.
[15] Ibid., page 3.

prospective insureds may get fewer applications from individuals who would falsify their garaging location or annual mileage in order to fraudulently lower their premiums, since such information is verifiable using telematics. Furthermore, in 2004, General Motors Acceptance Corporation Insurance Company (GMAC) began offering a discount to insureds for subscribing to OnStar®, a vehicle safety and security service which used telematics equipment factory-installed in General Motors (GM) vehicles. It could be argued that OnStar subscribers were likely to produce fewer or less severe insured losses due to OnStar's possession of their DBD and insureds' resulting access to roadside assistance, emergency response, and stolen vehicle location assistance services. GMAC also offered additional discounts to subscribers for low mileage indicated by their OnStar DBD. Recent announcements from State Farm and the Automobile Association of America Insurance Company (AAA) illustrate similar uses of telematics. Such examples suggest that a sophisticated classification system may not be the only way insurers can use DBD to benefit from positive selection effects.

The GMAC/OnStar case highlights a third objective of DBD, which is to mitigate losses after they occur. Several insurers offer roadside assistance services similar to OnStar which send help to the scene of an event when an emergency phone call is received. Telematics with real-time tracking can enable insurers to respond sooner, such as when an airbag is deployed or a harsh braking event is detected in the DBD. This would be of particular value when a victim is physically unable to make a phone call. Faster response time has the potential to reduce the extent of insured injuries or property damage. Also, DBD's loss reduction capability may not be limited to legitimate claims. The National Highway Transportation Safety Authority (NHTSA) requires that Event Data Recorders (EDRs) voluntarily installed in private passenger and other light vehicles record a minimum set of data elements to facilitate vehicle safety research. EDRs log vehicle data before and after accidents. Such DBD could be used by insurers to analyze for fraudulent claims, so long as it is done in a way that complies with applicable laws governing the use of data from EDRs.

A fourth objective of DBD is to modify risky behavior. Just as fleet managers have long analyzed DBD to recommend safer or more economical driving habits to their drivers, insurers have set up UBI programs that empower individuals to serve as *de facto* fleet managers for their book of insured vehicles. For example, Safeco Insurance's Teen Safe Driver Discount program, introduced in 2008, offers parents weekly reports on participating teens' driving behaviors. Parents are in turn encouraged to review the reports regularly with their teens. In 2009, Liberty Northwest developed a similar tool for commercial fleets called OnBoard Advisor with "accountability features" regarding fuel, maintenance, and overtime.[16] Both programs award discounts to insureds who exhibit safe driving behaviors. In cases like these, providing insureds with DBD summarized in a meaningful manner may benefit both the insurer and the insured.

Finally, insurance organizations may have objectives not strictly related to their insured books of business. Some may wish to utilize DBD to optimize the performance of their own fleets of auditors' or claims adjusters' vehicles. Others may elect to provide DBD to academia or nonprofits for use in research, such as the recent study that took place in Massachusetts with data supplied by the Commonwealth Automobile Reinsurers. This report concluded that insurers' use of mileage in rating would reduce driving and, hence, greenhouse emissions. The reader will recall that one of the original motivating factors behind the computerization of vehicles was the ability to control emissions, and DBD gives insurers or anyone looking to "go green" a valuable tool to monitor progress. The number of different objectives insurers could have in working with DBD is evident in the many variations on UBI which have gone to market.

While DBD makes various goals achievable, it also presents unique challenges. One such challenge is the "fortress of intellectual property (IP) protection"[17] obtained by Progressive and other innovators in the UBI and telematics spaces. In 1998's State Street Bank decision, the U.S. Court of Appeals of the Federal Circuit ruled that "methods of doing business" could be patented, opening the door for so-called "insurance development labs."[18] One beneficiary was Progressive, who in 1996 (before bringing Autograph to market) initiated the unique step of patenting what they called "the kitchen sink."[19] Their "Motor Vehicle System for Determining a Cost of Insurance" patent protects broad systems for acquiring DBD and methods for using it to produce actuarial classification systems or determine premiums. Subsequent improvements to the invention, including methods of building databases and communicating DBD back to the insured, have also been protected. Similar patents were obtained by other insurers, telematics service providers (TSPs), and non-practicing entities (NPEs, also called "patent trolls").[20]

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[16] This program later became the subject of litigation. See Bricketto.
[17] "Fortress" characterization is from Bakos and Nowotarski.
[18] "Insurance development lab" characterization is used by Nowotarski in Chartrand article.
[19] "Kitchen sink" characterization was used by Progressive marketing executive Bob McMillan in Hendricks to describe the extensive surveillance capabilities listed in the patent.
[20] A TSP is defined by Langevoort as an organization that "collects, summarizes or stores data from several sources; runs a telematics gateway or backend system; or provides data or services to several clients based on service subscription or demand" (page 11). An NPE is defined by Kauth as an entity that "holds patents, but does not practice the claimed inventions" (paragraph 3).

The jury is still out on the enforceability of UBI- and telematics-related patents. Many hoped the Bilski decision in June 2010[21] would clarify the patentability (or lack thereof) of business processes. Instead, the Supreme Court issued a narrow ruling rejecting the petitioner's application as overly abstract, but not prescribing specific tests for what constitutes a (patentable) business process. That same month, Progressive began suing multiple insurers for patent infringement. Even insurers whose own use of DBD steers clear of the IP fortress risk working with TSPs who may be litigated against. For example, Progressive recently sought to have another insurer's device supplier's patents invalidated for obviousness.[22] That device supplier had also sued Progressive's supplier; it is common for TSPs and/or NPEs to litigate against each other over technology or fleet management techniques. Some analysis suggests that the broadness of patents and their plenitude in this space may adversely impact defensibility.[23] Patents eventually expire, but in the meantime, organizations considering working with DBD must consider the legal and reputation risk involved. If they decide to proceed, actuaries and others should work closely with their companies' legal departments to select reputable TSPs and ensure that uses of the data are respectful of the rights of all parties involved.

A second challenge to working with DBD is consumer privacy. A survey sponsored by the Insurance Services Office (ISO) indicates that approximately 60% of drivers are unlikely to share DBD such as driving locations, speeds, or instances of hard braking and acceleration with their insurers. One reason may be that such data is discoverable and can be subpoenaed. To illustrate, consider that electronic toll collection data has been suggested for use in issuing speeding tickets to individuals who pass between two toll plazas in too short a period of time. DBD presents even greater revenue-generating possibilities for law enforcement. Another privacy threat to insureds is that GPS-detailed data will be sold to third parties for use in location-targeted marketing. Even insurers who abstain from such practices could find their databases hacked, as Epsilon Data Management was hacked in the banking and retail sectors.[24] Finally, insurers who do not clearly explicate the information they collect or how it will be used may face unwanted publicity similar to Apple's following revelations over iPhones' location-tracking capabilities. Such examples illustrate the difficulty even the best-intentioned insurers have in positioning DBD-based initiatives to the public.

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[21] *Bilski v. Kappos*, 130 S. Ct. 3218, 561 US __, 177 L. Ed. 2d 792 (2010).
[22] See Vanderford.
[23] For example, see M-Cam, Inc., page 2.
[24] See Svensson.

Defenses exist which help make UBI offerings more acceptable to all parties involved from a privacy perspective. Insurers have been able to address some concerns simply by not collecting GPS information. Beyond that, programs using DBD should at a minimum be opt-in instead of opt-out, especially since most require the installation of hardware in insured vehicles. Duri et al. propose a broader framework in which various privacy options, including different use cases and degrees of DBD collection, are selected from upon enrollment, with financial incentives for greater sharing (i.e., discounts). Under this structure, TSPs would be used to manage privacy preferences and share data with the insurer and insured as appropriate. Custom software modules in vehicles would further reduce the transfer of sensitive information by performing necessary calculations on-board. Insureds themselves would not have the ability to hack and manipulate DBD for financial gain.[25] While not bound to this structure, insurers should continually evaluate the adequacy and appropriateness of their own privacy policies.

Laws and regulations regarding privacy further impact insurers' ability to utilize DBD. For example, California prohibits use of location data for most insurance purposes and was the first of many states to implement EDR statutes which require vehicle owners' consent before retrieving accident reconstruction information. Such laws potentially limit insurers' ability to investigate fraudulent claims using DBD. More generally, DBD may be linked with, and has the potential to reveal, personally-identifiable information (PII), a protected class of data which places the insurer under the purview of a multitude of additional legislation.[26] At least one Department of Transportation report concedes "today's patchwork of privacy legislation from federal, state and local governments make it impossible to identify a lowest common denominator for privacy regulations."[27] Nevertheless, it is the responsibility of insurers to make sure UBI programs are mindful and compliant with this evolving body of law to the extent possible.

Perhaps the greatest challenge to successfully utilizing DBD is establishing the required infrastructure. The *Practitioner's Guide to Generalized Linear Models* asserts that credible modeling results are generally achieved using 100,000 or more vehicle-years of data.[28] Given IP and privacy challenges, insurers may find it difficult to enroll enough insureds in UBI to amass so much DBD over a short period of time. Before even thinking about that, however, insurers must first

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[25] See Duri et al. for more information on the framework discussed throughout this paragraph.
[26] Hughes Telematics, Inc. asserts such laws "could include the Federal Trade Commission Act, the Fair Credit Reporting Act, the Gramm-Leach Bliley Act, as well as various state laws and related regulations" (page 10).
[27] From U.S. Department of Transportation (NG-911 Transition Issues Report), page 6.
[28] See Anderson et al., page 40.

appropriate costly hardware to collect, transmit, and store the data; software and algorithms to process it; and personnel (e.g., actuaries) to implement and oversee the endeavor. The next section describes some of those challenges.

3. INFRASTRUCTURE

Implementing any sort of UBI program requires resources that many insurance companies do not have. Some of these resources are physical, such as the devices used to collect the data or the computers used to store and process it, and can be purchased, often at significant expense. Others, such as the knowledge and skills required to work with and derive value from the data, must be learned or outsourced. For these reasons, no UBI program should be considered a small endeavor, and insurers must have a clear vision for the form that the program will ultimately take. Such a vision will offer guidance with regard to what types of devices are required to collect, transmit, store, and process DBD. Additionally, many insurers may choose to begin the journey toward a full-fledged UBI program with a pilot to determine its viability and to minimize up-front costs while resources and knowledge are accumulated.

There are a wide variety of devices available on the market to collect DBD, and selecting the most appropriate device or devices for a UBI program depends on evaluating numerous factors. Any robust program will need a comprehensive set of rating variables, such as some of those listed in Section 2, to be as granular as possible. Devices capable of providing the data elements to feed such a program need to have a robust feature set and extensive capabilities. Such devices are currently expected to include GPS technology, accelerometers for each axis of motion, and the ability to read data from the vehicles' own sensors via the OBDII port. Devices like this currently cost between $100 and $200 each, which is down from $300 to $400 just a few years ago for less capable devices and, as expected for almost any form of technology, prices are always dropping. In the future, devices may include additional accelerometers or gyroscopes to determine angular acceleration, in addition to the rectilinear acceleration currently being measured, and vehicle orientation. Programs that only need to rely on a narrower set of rating variables require less capable and less expensive devices for implementation.

Aside from the technical capabilities of a device for collecting DBD, another consideration in device selection is data transmission. Generally, a device will buffer behavior and event data for some period of time and, depending on the type of UBI program, may need to be transmitted periodically to the administrator or service provider for the program. Transmission can be manual or automatic, wired or wireless. For some programs, ongoing data collection may not be required and the easiest way to transmit the data may be to return the device to the program administrator. The data can be retrieved from the device and the device redeployed in another vehicle, which reduces the cost of purchasing devices to be used in as many vehicles as desired. However, more robust programs do require ongoing data collection and mailing devices back and forth is not a viable option. Any such program requires a device capable of data transmission from a remote location.

In order to keep transmission costs down, some devices allow a user to plug a data cable into the device so that the DBD can be transferred to a computer and subsequently transmitted to the program administrator. While inexpensive, manual transmission has a few drawbacks. Users may find manual transmission to be inconvenient and time consuming, making the UBI program, already considered by some to be a hard sell, less attractive to consumers. Furthermore, if the user forgets or neglects to transmit data periodically and in a timely manner, data may be lost if the device buffer does not have enough capacity to store the data collected between transmissions. Users may also choose intentionally not to report data if they believe, for whatever reason, that it will reflect poorly on their driving behavior and somehow negatively impact them. Another consideration is that not all areas, especially some rural locations, have ready access to high-speed Internet. The DBD files may be quite large for the most devices and some users may not be able to transmit such files on their own. For these reasons, automatic transmission of data is often preferred.

Devices that transmit data automatically are generally outfitted with a cellular or Wireless Fidelity (Wi-Fi) radio. The main benefit of cellular radios is that they can transmit data almost anywhere at any time. The transmission trigger could be a predetermined time or period, such as 300 hours since the last transmission, or based on the amount of data collected, for example it could be programmed to transmit whenever the data buffer is 80% full. Whatever the trigger, it should be selected so that data loss is minimized if there is a lag between when the device is programmed to transmit the data and when it actually can, which may happen if the device falls out of range of the cellular network for a brief period after transmission is triggered. However, ubiquity of transmission comes at a cost: data charges for cellular transmission can be expensive. Cellular data plans currently cost between $10 and $20 per month and thus make up a significant portion of plan administration.[29]

[29] For example, see Bird, paragraph 4.

An alternative to cellular transmission is Wi-Fi. If a device is outfitted with a Wi-Fi radio, the cost of transmitting data via cellular network can be eliminated. Devices with Wi-Fi radios are most useful when the vehicle is regularly garaged at locations where Wi-Fi routers can be installed for purposes of data transmission. For example, if a user returns home most nights, the device could be set up to connect to a router within range of the garage and transmit whenever that connection is made. Similarly, an entire fleet of vehicles that is regularly garaged overnight at a particular location could be outfitted with devices that transmit whenever in range of a router at the garage. Or, if a business has multiple garaging locations, a router could be installed at each so that no matter the location at which vehicles are being garaged, they can transmit data as long as they have a network connection.

Devices with Bluetooth technology are beginning to appear on the market. Instead of transmitting data directly to the program administrator or service provider, these devices connect to other Bluetooth-capable devices, such as smart phones, for transmission via whatever mechanism the other device is able to utilize. This is usually Wi-Fi or cellular, and in any case it offloads the cost of transmission to the user. If the user already has a data plan for his or her cellular phone, there is no need to purchase a dedicated cellular plan for the vehicle's device, but the user must be aware of the amount of data being transmitted so as not to incur additional data overage fees.

Once the type of device required by a UBI program of the desired scope is determined, it is recommended that the program administrator evaluate and test various devices from different manufacturers and service providers to find the one that best meets the program's needs. Alternatively, the robustness and viability of any program can be increased if it is flexible enough to be able to use data collected by any device that meets a minimum set of required criteria. It is easier to outfit large fleets in a short amount of time when devices can be purchased from multiple manufacturers. In cases where devices have already been bought for and installed within vehicles, a particular UBI program may be more attractive if it doesn't require a different device.

As far as the infrastructure for any UBI program goes, the devices installed in vehicles, while crucial, only represent part of the picture. In order to be useful, the data collected and transmitted must be stored until it can be processed and this requires additional hardware and software that may not already be available.

Although it depends on how comprehensive a database is desired and the particular specifications for each data element collected, such as precision and frequency, a typical device will transmit between three and twenty megabytes of data per month. Devices installed in commercial vehicles tend to report amounts on the higher end of this spectrum because the vehicles are being used more. This is generally due to the nature of the business and the fact that commercial vehicles may be used by different drivers during multiple shifts throughout the day. So, depending on the number of vehicles participating in the UBI program, the data could add up rather quickly. As mentioned earlier, credible modeling results are generally achieved using at least 100,000 vehicle-years of data.[30] At the stated rate of data collection, that amounts to between four and twenty-five terabytes, at a minimum, for credible results. There are currently over 250 million vehicles (2,500 times the minimum credibility standard) registered for use in the United States.[31] While no one is suggesting that every vehicle will be outfitted with telematics devices for collecting DBD in the near future, as UBI programs gain acceptance from consumers and insurance producers alike, the sizes of these databases are expected to grow, as are the costs of storing the data. Every enterprise must also have a plan for backing up data in case of loss. This data redundancy also adds significantly to the cost of maintaining a UBI program.

While storage capacity is one consideration for the database, a company must also have the right software to process and work with it. Some database and statistical packages are not able to adequately handle tens or hundreds, or more, terabytes of data. Consider software packages that can utilize efficient algorithms and parallel processing to speed calculations and analysis. Additionally, some software is constrained by Random Access Memory (RAM) in how large the working database can be. Working with this software requires programming expertise to access the entirety of the data. Instead, consider packages that do not have such constraints on database size.

In addition to working with the data to develop UBI programs, many vendors are providing policyholder-facing software to add value and incentive to customers. Many personal auto policyholders are looking for, or even expect to see, real-time information about where their cars have been driven and whether and when any usage events, such as speeding, hard braking or turning sharply, occurred during a trip. They may also want to be able to locate their vehicle when stolen, which benefits both the policyholder and the insurer because the quicker a vehicle is located and reacquired, the less expensive the claim is likely to be and the more satisfied the insured is. Parents may also prefer to use this information to track teen drivers. Commercial auto policyholders are already using information like this for fleet management purposes, including routing and fuel consumption, as well as ensuring that fleet drivers are following various laws and regulations or fleet

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[30] See footnote 27 of this paper.
[31] From U.S. Department of Transportation (Bureau of Transportation Statistics), Table 11-1.

safety guidelines. Thus, the software and hardware infrastructure required for providing these services to policyholders should be considered when determining the features and costs of a competitive UBI program.

Finally, as with any company's database, the administrator of a UBI program must make security a top priority. In recent years, company databases have been hacked for e-mail addresses and passwords, and cases such as these have become more prevalent. A few higher-profile cases have resulted in release of names, addresses, and even credit card numbers. Many people would, and should, be wary of databases containing multiple terabytes of data with so much private, identifiable behavior information. Secure access controls must be implemented so that only the people who should be able to see the data are able to. In addition, any information transmitted to or from the policyholder should be done so in a secure manner with data encryption. A data retention policy must also be put into place to minimize data loss, should it occur. When data is no longer needed, it should be deleted from the working database and all backup copies.

In the next section we turn from discussing the infrastructure necessary to collect and use the data to actually working with it.

4. NAVIGATING THE DATA

The driving behavior data elements collected to support UBI vary depending on the technology used to collect them. Telematics devices typically record time-stamped location and vehicle identification information with every observation. Some devices further identify the driver of the vehicle through tags, PIN codes, or fingerprinting. The American Association of Equipment Management Professionals' telematics data standard focuses on location and three additional data points: distance traveled, driving time, and fuel consumption. The organization finds that these four data elements support 80% of their constituency's reporting needs.[32] Speed, acceleration, deceleration, and braking are less standard elements but are also commonly used in UBI. Such values may be estimated if not collected through telematics. For example, average speed may be estimated using time and mileage, and average acceleration may be estimated using time-velocity formulae. The accuracy of the estimates depends on the frequency at which observations are recorded. More detailed DBD such as seat belt usage, turn signaling, and on-board entertainment (e.g., radio stations) have been suggested for use within patents but are not typical of UBI initiatives to date.

[32] See Bennink, page 1.

When choosing which data elements to collect, actuaries should balance the desire for greater predictive power with the cost of collecting more data.

Table 4.1 displays sample DBD. This table is illustrative and does not represent the data collectible from any particular telematics device. In the example, nine data elements are recorded at sixty-second intervals beginning and ending when the ignition is switched on and off, respectively. Such a series of records is referred to as a "journey." The first and second columns of Table 4.1 show that the driver's journey on April 8, 2012, begins at 8:45 AM and concludes at 8:53 AM.[33] The GPS coordinates in the third and fourth columns indicate that he changes heading at least twice: in the fourth observation, he ceases heading Due North, and in the seventh, he begins heading Due West. Columns five, six, and seven show that the driver's cumulative time, mileage, and fuel consumption, respectively, increase with each observation except the second, when his vehicle has been powered on but has not traveled any mileage. The speeds and accelerations in columns eight and nine show that the driver experiences different driving conditions during each leg of his journey. Because insurance policies are typically written or renewed every six to twelve months, and not every minute or journey, the information in Table 4.1 does not immediately lend itself to use in rating or underwriting.

Table 4.1 — Sample DBD for Single Journey

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Obs.	Date	UTC	Degrees Latitude	Degrees Longitude	Seconds	Miles	Gallons	Miles per hour	g-force
1	4/8/2012	14:45:30	-27.117	-109.367	0:00:00	0.000	0.000	0	0.000
2	4/8/2012	14:46:30	-27.118	-109.364	0:01:00	0.000	0.050	0	0.000
3	4/8/2012	14:47:30	-27.117	-109.371	0:02:00	0.080	0.055	20	0.030
4	4/8/2012	14:48:30	-27.150	-109.379	0:03:00	0.552	0.060	50	0.060
5	4/8/2012	14:49:30	-27.109	-109.388	0:04:00	1.499	0.078	65	-0.100
6	4/8/2012	14:50:30	-27.098	-109.398	0:05:00	2.538	0.091	59	0.010
7	4/8/2012	14:51:30	-27.093	-109.410	0:06:00	3.234	0.105	40	-0.070
8	4/8/2012	14:52:30	-27.084	-109.409	0:07:00	3.916	0.124	35	-0.015
9	4/8/2012	14:53:30	-27.076	-109.409	0:08:00	4.445	0.143	0	0.000

[33] Pacific/Easter Time is six hours behind Coordinated Universal Time (UTC) when Daylight Saving Time is not in effect.

Table 4.1 (Continued)

Columns (1) and (2) represent the date and time of each observation in UTC.

Columns (3) and (4) represent the GPS coordinates of each observation in decimal notation.

Column (5) represents the cumulative amount of time elapsed at each observation in seconds.

Column (6) represents the cumulative distance traveled at each observation in miles.

Column (7) represents the cumulative amount of fuel consumed at each observation in gallons.

Column (8) represents the speed at each observation in miles per hour.

Column (9) represents the amount of acceleration or deceleration at each observation in g-force.

The first step in making sense of DBD is to identify when different aspects of vehicle operation occur. When a vehicle is powered off, it is referred to as "parked" or "garaged." The device in our example does not record observations while parked, but some devices do record periodic observations at such times. A vehicle may also be powered on but not in motion (e.g., the second observation of Table 4.1), in which case it is considered "idle." Time spent parking or idling may be of value to fleet managers looking to optimize drivers' fuel consumption or actuaries looking to price the theft peril. Of greater interest, however, are events and conditions which occur when a vehicle is powered on and in motion, i.e., "driving." Periodic observations are excellent at capturing driving conditions as in Table 4.1 but may not identify events which occur in a split second, such as entering a turn at high speed or slamming on the brakes. These maneuvers may directly cause or prevent accidents. As a result, many devices record additional observations when one or more conditions exceeds thresholds or "triggers" prescribed by the actuary, TSP, or the two working in conjunction. For example, braking events may be identified when certain gravitational forces (g-force) are registered and/or decelerations occur over a prescribed duration (e.g., Kantowitz defined braking events by a 0.2 g-force deceleration rate over five seconds). Resulting observations may indicate that a given type of event occurred and/or the set of conditions that triggered its recording. **Table 4.2** contains sample events that were recorded by the telematics device during the same journey that resulted in the periodic observations displayed in Table 4.1.

Table 4.2 — Sample Events

	(1)	(2)	(3)
Obs.	Date	UTC	Event Description
2.1	4/8/2012	14:47:00	Shift into Drive
6.1	4/8/2012	14:51:00	45-degree turn at high speed
6.2	4/8/2012	14:51:15	-0.4 g-force threshold broken
8.1	4/8/2012	14:53:15	Shift into Park

Once driving and analogous concepts have been identified, they may be quantified. If the cumulative totals in columns five, six, and seven of Table 4.1 and the totality of events in Table 4.2 were the only values of interest, actuaries could save considerable time and expense by accepting just one observation per journey or policy period. To wit, MileMeter offers coverage by the mile, which is verified only at renewal using photographs of vehicles' odometers.[34] Alternatively, some TSPs offer scores based on driving ability which may be used in a manner similar to credit. Actuaries interested in deeper analysis of DBD would prefer to associate events and "incremental" amounts of driving with unique sets of conditions that produce them. This is analogous to associating exposures, losses, and claims with the risks from which they emanate.

Table 4.3 combines the events from Table 4.2 with the periodic observations from Table 4.1 to produce "incremental" driving, parking, and idling totals. For the sake of simplicity, Table 4.3 displays event counts rather than full event detail. (Note that observations denoting transitions between parking, idling, and driving are duplicated to enable proper allocation of incremental totals between vehicle states.) Incremental totals are calculated in two steps: First, as shown in columns (11) through (13), differences are taken between the cumulative totals in columns five through seven of each observation compared to its predecessor record. Next, two-point rolling averages are taken of the differences to obtain the incremental totals in columns (14) through (16). Averages are used because approximately half of the driving between any two observations can be more closely associated with the prior. For example, column (12) shows that 0.472 miles were traveled between observations three and four. Approximately half of this mileage occurred more closely to observation three. Similarly, half of the 0.947 miles traveled between observations four and five may be more closely associated with observation four. Therefore, the incremental mileage shown in column (15) for observation four is estimated as (0.472 + 0.947) ÷ 2 = 0.710. Rolling averages may

[34] MileMeter is described in Furchgott as being "at the non-tech extreme" of UBI (paragraph 9).

be unnecessary if observations are recorded at sufficient frequency that conditions are unlikely to differ significantly between consecutive observations. Determining incremental totals for each observation allows the user to aggregate driving totals over different sets of conditions.

Table 4.3 — Periodic Observations with Events and Incremental Totals

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Obs.	Date	UTC	Degrees Latitude	Degrees Longitude	Seconds	Mileage	Gallons	Miles per hour	g-force
	4/8/2012	14:45:30	-27.117	-109.367	0:00:00	0.000	0.000	0	0.000
1	4/8/2012	14:45:30	-27.117	-109.367	0:00:00	0.000	0.000	0	0.000
2	4/8/2012	14:46:30	-27.118	-109.364	0:01:00	0.000	0.050	0	0.000
2.1	4/8/2012	14:47:00	-27.118	-109.364	0:01:30	0.000	0.053	0	0.000
2.1	4/8/2012	14:47:00	-27.118	-109.364	0:01:30	0.000	0.053	0	0.000
3	4/8/2012	14:47:30	-27.117	-109.371	0:02:00	0.080	0.055	20	0.030
4	4/8/2012	14:48:30	-27.150	-109.379	0:03:00	0.552	0.060	50	0.060
5	4/8/2012	14:49:30	-27.109	-109.388	0:04:00	1.499	0.078	65	-0.100
6	4/8/2012	14:50:30	-27.098	-109.398	0:05:00	2.538	0.091	59	0.010
6.1	4/8/2012	14:51:00	-27.096	-109.404	0:05:30	2.886	0.098	53	-0.050
6.2	4/8/2012	14:51:15	-27.094	-109.407	0:05:45	3.060	0.102	45	-0.430
7	4/8/2012	14:51:30	-27.093	-109.410	0:06:00	3.234	0.105	40	-0.070
8	4/8/2012	14:52:30	-27.084	-109.409	0:07:00	3.916	0.124	35	-0.015
8.1	4/8/2012	14:53:15	-27.076	-109.409	0:07:45	4.445	0.138	0	0.000
8.1	4/8/2012	14:53:15	-27.076	-109.409	0:07:45	4.445	0.138	0	0.000
9	4/8/2012	14:53:30	-27.076	-109.409	0:08:00	4.445	0.143	0	0.000
	4/8/2012	14:53:30	-27.076	-109.409	0:08:00	4.445	0.143	0	0.000

Table 4.3 (Continued)

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
		Differences between Obs.			Incremental Totals				
Obs.	Status	Seconds	Mileage	Gallons	Seconds	Mileage	Gallons	Turns	Brakes
	Parked								
1	Idling	0:00:00	0.000	0.000	0:00:30	0.000	0.025	0	0
2	Idling	0:01:00	0.000	0.050	0:00:45	0.000	0.026	0	0
2.1	Idling	0:00:30	0.000	0.003	0:00:15	0.000	0.001	0	0
2.1	Driving	0:00:00	0.000	0.000	0:00:15	0.040	0.001	0	0
3	Driving	0:00:30	0.080	0.003	0:00:45	0.276	0.004	0	0
4	Driving	0:01:00	0.472	0.005	0:01:00	0.710	0.012	0	0
5	Driving	0:01:00	0.947	0.018	0:01:00	0.993	0.016	0	0
6	Driving	0:01:00	1.039	0.013	0:00:45	0.694	0.010	0	0
6.1	Driving	0:00:30	0.348	0.007	0:00:23	0.261	0.005	1	0
6.2	Driving	0:00:15	0.174	0.004	0:00:15	0.174	0.004	0	1
7	Driving	0:00:15	0.174	0.003	0:00:38	0.428	0.011	0	0
8	Driving	0:01:00	0.682	0.019	0:00:53	0.606	0.017	0	0
8.1	Driving	0:00:45	0.529	0.014	0:00:23	0.265	0.007	0	0
8.1	Idling	0:00:00	0.000	0.000	0:00:08	0.000	0.002	0	0
9	Idling	0:00:15	0.000	0.005	0:00:08	0.000	0.002	0	0
	Parked								

Columns (1) through (9) are described in the notes to Table 4.1.

Column (10) indicates whether the vehicle is parked, idling, or driving at each observation.

Column (11) represents the amount of time elapsed (Column (5)) between the previous observation and the current observation in seconds.

Column (12) represents the distance traveled (Column (6)) between the previous observation and the current observation in miles.

Column (13) represents the amount of fuel consumed (Column (7)) between the previous observation and the current observation in gallons.

Column (14) estimates the amount of time associated with each observation, which is calculated as the average of the differential times in Column (11) for the current and subsequent observations.

Table 4.3 (Continued)

Column (15) estimates the distance traveled associated with each observation, which is calculated as the average of the differential distances in Column (12) for the current and subsequent observations.

Column (16) estimates the fuel consumption associated with each observation, which is calculated as the average of the differential fuel amounts in Column (13) for the current and subsequent observations.

Column (17) represents the number of turns taken at high speed (as identified in Table 4.2) that occurred at each observation.

Column (18) represents the number of heavy braking incidents (as identified in Table 4.2) that occurred at each observation.

Raw DBD describes a relatively limited number of conditions, but resources are available to paint a richer portrait. A simple yet valuable distinction to the actuary might be on-roading versus off-roading. However, GPS coordinates are often imprecise (e.g., due to interference from buildings), so a large percentage of driving may incorrectly appear to be "off-road." In response, algorithms are available to "snap" coordinates to their nearest road segment. Map vendor data may then be used to identify the type of road (e.g., freeways, arterials, or local roads) or speed limit for each segment. Real-time traffic services are also available. GPS and time stamps may even be used to access temperatures, precipitation, or other weather information. Studies into these effects are promising, but a dearth of weather stations in the vicinities of driving may limit the success of such efforts. Due to the costs of licensing third-party data and different levels of refinement between raw telematics and third party databases, actuaries may find linking such information to the DBD to be difficult. Simpler calculations may also be performed. Distances between driving locations and journey origins may be a useful check on traditional rating variables such as radius of operation, and may be calculated using publicly available algorithms. Alternatively, ISO proposed a simple, patent-pending metric to describe the riskiness of driving locations in terms of the average garaging loss costs of encompassing territories. In summary, analysis of DBD need not be limited to raw information collected using telematics.

Maintaining a quality database involves more than simply processing incoming DBD. ASB ASOP No. 23 advises that the actuary should identify "data values that are materially questionable or relationships that are materially inconsistent."[35] An abnormally low number of observations may indicate that an insured has installed his device incorrectly or hacked into his own data stream. Frequent "gaps" in the data or large numbers of events may be signs of technological defect.

[35] From ASOP No. 23, page 4.

Insurance claims which do not have corresponding DBD events (e.g., intense g-force) may represent fraud. Such issues should be pursued with the insured, TSP, or claims adjuster as appropriate. Automated checks and corrective measures may also be applied to the data. Observed speeds or distances may be compared to those implied by incremental mileage-to-time ratios or GPS coordinates, respectively. Missing or unreasonable values may be estimated using data from adjacent observations. For example, when a vehicle shifts from idling into drive, its location may be estimated from the previous observation, since which time it has not moved. In contrast, fuel consumption could be estimated using interpolation between the previous and subsequent records' fuel consumption, since fuel is burned while idling. The actuary will not have opportunity to review every record of DBD but should exercise "professional judgment" in determining whether the data is of "sufficient quality to perform [the] analysis."[36]

The aggregate database of DBD may contain observations for several highly similar journeys. It may not be necessary, or desirable from a privacy perspective, to separately identify each one. Dates may be expressed simply as weekdays, weekends, or holidays, while times may be categorized (e.g., early morning, Ante Meridiem (AM) peak, etc.) by the expected degree of traffic congestion. GPS coordinates, which many companies do not even collect for privacy or other reasons, may be discarded after they are used to determine road type, weather, or other qualitative and quantitative information. Conditions such as speed and acceleration may not be retained to the exact miles per hour (MPH) or hundredth of a g-force,, since riskier cases have been separately identified as events. Cumulative totals are somewhat redundant to incremental totals and may be expressed as broader ranges. A one-way analysis of the DBD may be used to identify logical groupings of the data. **Table 4.4** presents Table 4.3 in a slightly different format which better preserves privacy. This approach is consistent with the Law of Large Numbers: "As the volume of similar, independent exposure units increases, the observed experience will approach the "true" experience."[37]

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[36] Ibid., page 5.
[37] From Werner and Modlin, page 216.

Table 4.4 — De-identified DBD

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Cumulative Totals		
Obs.	Date	Time	Road	Weather	Minutes	Miles	Gallons
	Holiday	AM Peak	Local	Partially Cloudy	0	0	0
1	Holiday	AM Peak	Local	Partially Cloudy	(0 , 5]	0	(0 , 0.25]
2	Holiday	AM Peak	Local	Partially Cloudy	(0 , 5]	0	(0 , 0.25]
2.1	Holiday	AM Peak	Local	Partially Cloudy	(0 , 5]	0	(0 , 0.25]
2.1	Holiday	AM Peak	Local	Partially Cloudy	(0 , 5]	(0 , 5]	(0 , 0.25]
3	Holiday	AM Peak	Local	Partially Cloudy	(0 , 5]	(0 , 5]	(0 , 0.25]
4	Holiday	AM Peak	Freeway	Partially Cloudy	(0 , 5]	(0 , 5]	(0 , 0.25]
5	Holiday	AM Peak	Freeway	Partially Cloudy	(0 , 5]	(0 , 5]	(0 , 0.25]
6	Holiday	AM Peak	Freeway	Partially Cloudy	(0 , 5]	(0 , 5]	(0 , 0.25]
6.1	Holiday	AM Peak	Freeway	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
6.2	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
7	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
8	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
8.1	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
8.1	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
9	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]
	Holiday	AM Peak	Arterial	Partially Cloudy	(5, 10]	(0 , 5]	(0 , 0.25]

Column (1) indicates whether each observation is recorded on a Weekday, Weekend, or Holiday.

Column (2) indicates the time of day during which each observation is recorded. "AM Peak" is defined by Jun as occurring between the hours of 6:00 AM and 9:00 AM, Local Time.

Column (3) represents the type of road being traveled at each observation. This is obtained by linking the GPS coordinates in Columns (3) and (4) of Table 4.3 to a map database, similar to Jun.

Column (4) represents the weather conditions at each observation. This is obtained by linking the date, time, and GPS coordinates from Columns (1) through (4) of Table 4.3 to a weather database.

Column (5) expresses Column (5) of Table 4.3 in ranges of five minutes.

Column (6) expresses Column (6) of Table 4.3 in ranges of five miles.

Column (7) expresses Column (7) of Table 4.3 in ranges of 0.025 gallons.

Table 4.4 (Continued)

	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
		Over/Under		Incremental Totals				
Obs.	Speed	Speed Limit	Status	Seconds	Miles	Gallons	Turns	Brakes
	-	-	Parked					
1	-	-	Idling	0:00:30	0.000	0.025	0	0
2	-	-	Idling	0:00:45	0.000	0.026	0	0
2.1	-	-	Idling	0:00:15	0.000	0.001	0	0
2.1	[0 , 2.5]	[-17.5 , -12.5)	Driving	0:00:15	0.040	0.001	0	0
3	(17.5 , 22.5]	[- 2.5 , 2.5]	Driving	0:00:45	0.276	0.004	0	0
4	(47.5 , 52.5]	[-17.5 , -12.5)	Driving	0:01:00	0.710	0.012	0	0
5	(62.5 , 67.5]	[- 2.5 , 2.5]	Driving	0:01:00	0.993	0.016	0	0
6	(57.5 , 62.5]	[- 7.5 , -2.5)	Driving	0:00:45	0.694	0.010	0	0
6.1	(52.5 , 57.5]	[- 12.5 , -7.5)	Driving	0:00:23	0.261	0.005	1	0
6.2	(42.5 , 47.5]	(2.5 , 7.5]	Driving	0:00:15	0.174	0.004	0	1
7	(27.5 , 32.5]	[- 2.5 , 2.5]	Driving	0:00:38	0.428	0.011	0	0
8	(32.5 , 37.5]	[- 7.5 , -2.5)	Driving	0:00:53	0.606	0.017	0	0
8.1	[0 , 2.5]	(-∞, -27.5)	Driving	0:00:23	0.265	0.007	0	0
8.1	-	-	Idling	0:00:08	0.000	0.002	0	0
9	-	-	Idling	0:00:08	0.000	0.002	0	0
	-	-	Parked					

Column (8) expresses the speed from Column (8) of Table 4.3 in ranges of 5 MPH. Speed is not generally applicable when the vehicle is parked or idling.

Column (9) compares the speed from Column (8) of Table 4.3 to the speed limit and expresses the difference in ranges of 5 MPH. Speed limits are obtained by linking GPS coordinates from Columns (3) and (4) of Table 4.3 to a traffic laws database.

Column (10) replicates Column (10) of Table 4.3.

Columns (11) through (15) replicate Columns (14) through (18) of Table 4.3, respectively.

The final step in constructing the database is to associate DBD with traditional insurance data (e.g., premiums and losses). One way to do this is to assign every claim to the observation which immediately precedes it, e.g., one with intense g-force. This may prove challenging because claims are not typically recorded in second-by-second detail, and DBD may become irretrievable if telematics devices are damaged in accidents. Another limitation of this approach is that such observations may only be as frequent (or infrequent) as accidents themselves. Alternatively, actuaries may associate each claim with all the DBD observations that occur during the policy period. This assumes that every moment a vehicle is operated has some impact on its loss propensity. Either of these two approaches supports frequency and severity modeling, because every observation indicates whether or not a claim occurs and, if so, for what amount. If the actuary prefers a pure premium approach, he or she may pro-rate losses to DBD observations based on time, mileage, or fuel consumption, all of which were noted by Dorweiler as potential exposure media for auto. He or she may also consider pro-rating premiums and building a loss ratio model, which would effectively control for the effect of existing rating variables. A more sophisticated approach to account for those effects would be to associate exposure information with the DBD and analyze for interactions. For example, less experienced vehicle operators who partake in risky behaviors may present greater risk than more experienced ones with similar behavioral patterns. Merging traditional insurance data with DBD enables the actuary to take the next step of analyzing the effects of driving behavior on loss experience. The next section looks at how actuaries may act upon this information.

5. APPLICATIONS

There are many potential applications for DBD, including pricing, scoring, underwriting, claims, and others. For actuaries, the endgame is certainly pricing. Actuaries generally already have an informed estimate of the proper aggregate cost of insurance for a group of risks based on traditional methods, but DBD has the potential to make rating individual risks more granular and accurate than ever before. New rating variables can be integrated into old rating schemes as additional variables or by replacing traditional variables. These new rating variables may serve as more accurate measures of the same rating criteria or they may substitute something not previously measurable by using a conventional proxy. For example, in commercial auto the "radius of operations" rating variable is used as an estimate of how much a vehicle is operated since vehicles that tend to be driven further from the garaging location tend to be driven more than vehicles that stay within a smaller radius. This variable can be replaced with a more accurate and verifiable measure of the actual mileage driven and an indicator of how far the vehicle strays from its garaging location based on GPS data. These can help differentiate not only between vehicles used close to and far from the garaging location, but, among these, which are used more frequently than others. Ultimately, total mileage may prove to be more indicative of loss propensity and may supersede distance from the garaging location.

As another example, measurements based on variables that are more closely related with the aggressiveness of the driver, such as speeding and hard braking, could replace traditional proxies like driver age. Younger drivers may tend to be more aggressive, but when actuaries know what aggressive driving looks like in the data, they can apply surcharges only to those drivers exhibiting such behaviors, whether they are youthful or not, instead of an entire class of drivers comprised of operators with varying driving habits. Also, replacing proxies with variables that may be perceived as more causative, while not necessary under ASB ASOP No. 12, should be well received by consumers, who appreciate transparency in rating and desire to know what they can do to affect premiums. This is also true for regulators, who value fairness and accuracy in rating. DBD may also be used to create an entirely new, independent UBI rating plan without reliance on traditional plans or variables.

Other applications for DBD include scoring and underwriting. Scoring is useful for condensing multiple pieces of information into a single number. A credit score, for example, combines information about an individual's payment and delinquency history, credit utilization, length of credit history, and type of credit into a single number ranging from 300 and 850 (for the Fair Isaac Corporation (FICO) score in the United States) to represent the creditworthiness, or likelihood of default, of that individual.[38] At a glance, a financial institution can make a decision about whether or not to extend a loan to an individual, and if so at what rate, based on the expected risk of that person defaulting on the loan. A similar driving behavior score could be developed to summarize the plethora of information contained in DBD and other linked databases. And, similar to the use of credit scoring in personal insurance since the 1990s, a driving behavior score could be used as a rating variable instead of building a model to account for all of the components that make up the score. Actuaries should be wary, however, of the fact that a score, a single number, while indicative of overall risk, does not tell as complete a story as the individual components. And if the underlying composition of the score differs from company to company, scores may not be portable for use in rating or even to indicate how risky one driver is when compared to others or with respect to the producer's own underwriting criteria.

[38] See Gutner or visit FICO.com.

Regarding the use of DBD in underwriting, behavior data, as individual components or as scores, may be used to make decisions about whether or not to cover a risk or which tier, premium, standard, substandard, etc., to place a risk in for pricing. It may take some time for UBI programs and models to gain acceptance from consumers and regulators for pricing, but in the meantime there is no reason that the information cannot be used in underwriting to help place insureds with similar risks for traditional rating.

Another underwriting application of DBD is in verification of rating parameters to prevent premium leakage. Insurers require policyholders to complete an application form before providing coverage and often upon renewal as well. When insureds complete the application form honestly and accurately, the premium charged represents the best estimate of expected loss for that insured. Insureds may on occasion complete the application forms inaccurately if they don't know the exact answer to a question or if they think it will help reduce the premium. Many questions on an application form, such as annual mileage driven, garaging address, business/pleasure use, and distance to work, whether a vehicle is parked in a garage or on the street overnight, etc. could be verified with the use of DBD to ensure that risks are being charged a fair premium.

Some speculate that DBD could be used to determine how many different people regularly use a vehicle, based on how different individual driving habits may be, to verify that the number of named insureds on a policy is correct. Driving behavior data could notify an insurer of potential mid-term policy changes, such as a change of address, before the policyholder contacts the insurer. Applications like this start to push the boundaries of what DBD and UBI are capable of providing to insurers. In order to realize the potential, actuaries, statisticians, and other data scientists will need to carefully and thoroughly analyze behavior data to transform it into valuable information. As was seen with the use of credit for insurance, the first movers may gain expertise that solidifies their position for years to come.

Outside of rating and underwriting, driving behavior data could be used for claims. For example, if a device installed in a vehicle is capable of cellular transmission and is monitoring the vehicle's acceleration and deceleration, it could detect and immediately report when there is a large change in deceleration, indicative of a collision. This is called first notice of loss (FNOL). With FNOL, policyholders can get the help they need more quickly than if they have to seek it themselves. In severe accidents, where people may be incapacitated, automatic notification of an emergency could be the difference between life and death. FNOL has the potential to increase satisfaction among policyholders while decreasing short- and long-term costs for both bodily injury and property damage. The faster a claimant is diagnosed and treated for injuries, the less expensive payments tend to be. Similarly, insurers spend millions of dollars per year in vehicle storages costs as a result of delayed notification of claims and the average payout for claims reported more than a day after an accident is 20% higher than those reported within a day.[39]

Device data could also be used for claim adjustment and fraud prevention. It has been estimated that over 40% of reported bodily injury claims result from fraudulent or exaggerated injuries and that about 20% of every claim payment is attributed to soft fraud.[40] If the devices could be used to help recreate the conditions of an accident, insurers could be given more accurate assessments based on soft-tissue and kinematics studies to determine the authenticity of a claim and to help make estimates of claim payments. Just knowing which claims to deny or investigate helps ensure that resources are being used as effectively as possible.

DBD has non-insurance uses as well. Some applications include making improvements to infrastructure safety and better vehicle traffic planning. Claim and GPS data could be used to determine safety levels of roads and intersections. Additional lights or signs could be installed to help prevent accidents. Congested areas and roads around them could be improved to add new lanes or change traffic patterns to help traffic flow more smoothly and consistently. It is arguable that repurposing DBD for applications like these also has an effect on insurance, as improving safety and trip quality may ultimately reduce accidents due to road and driving conditions or driver attitudes, which reduces overall claim payments. However, before data can be repurposed, there are a few regulatory hurdles that must be considered.

Not all states have passed laws related to vehicle telematics, but those that have generally declared that data from the devices is owned by the owner of the vehicle, not the insurer. Therefore, use of the data for any purpose depends on agreement with the policyholder. This can be easily accomplished with the policy itself as long as the policyholder is made aware of the implications that come with installing a telematics device in a vehicle and transmitting data to the insurer. Alternatively, while many states have decided that telematics data can be used for rating, especially when regulators feel that DBD is indicative of causal behaviors and promotes fairness in rating, some that explicitly allow DBD to be used for rating may prefer that it only be used for premium discounts. Still, other states, like California, have restrictions on which data can be used. California does not allow the use of GPS location data for rating, but encourages the use of mileage. For now,

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[39] From Diamond Management & Technology Consultants analysis cited in Blumer.
[40] From Brockett, pages 245-246.

policyholders that agree to transmit data to an insurer do so because they believe they will get a benefit from doing so, such as premium discounts and other real-time services, and it should not be difficult to find a market for insurers to begin testing or rolling out UBI programs.

6. CONCLUSIONS

It has long been known that DBD allows insurers to achieve unique goals in pricing, underwriting, and loss control or mitigation. However, such data also presents unique challenges and risks. One way to address these roadblocks is through a sound data management strategy. In making the decision to work with DBD, actuaries should be mindful of privacy and intellectual property rights. Once they have committed to UBI, infrastructure should be designed to cost-effectively capture and transmit required information to the insurer and/or insured, with appropriate security measures taken along the way. Telematics is the data collection mechanism that best supports these objectives. As DBD is collected, it should be organized, enriched with third-party information, and de-identified or consolidated to better enable traditional actuarial functions. Automated checks and professional judgment should be used to ensure data is of sufficient quality for analyses. The resulting database serves as the starting point for various UBI applications. Regulatory and technological breakthroughs can only increase DBD's prevalence in an industry that has thus far been reluctant to fully embrace its possibilities.

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7. BIBLIOGRAPHY

[1.] Abdel-Aty, Mohammed et al., "Relating Crash Occurrence to Freeway Loop Data, Weather Conditions, and Geometric Factors," October 1, 2005, http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BD548_04.pdf.

[2.] Actuarial Standards Board, *Actuarial Standard of Practice #12: Risk Classification* (Revised Edition), December 2005, http://www.actuarialstandardsboard.org/pdf/asops/asop012_101.pdf.

[3.] Actuarial Standards Board, *Actuarial Standard of Practice #23: Data Quality* (Revised Edition), December 2004, http://www.actuarialstandardsboard.org/pdf/asops/asop023_097.pdf.

[4.] Anderson, Duncan et al., "A Practitioner's Guide to Generalized Linear Models (Third Edition)," CAS *Discussion Paper Program: Applying and Evaluating Generalized Linear Models*, February, 2007, http://www.casact.org/pubs/dpp/dpp04/04dpp1.pdf.

[5.] Automotive Service Association, Mechanical Division Operations Committee, "Telematics: Past, Present, and Future," May 2008, http://www.asashop.org/news/asaresources/ASAtelematics_0508.pdf.

[6.] Bakos, Tom, and Mark Nowotarski, "Progressive Builds Fortress of Patent Protection," *Insurance IP Bulletin*, Volume 2004, Number 3, October 15, 2004, http://www.bakosenterprises.com/IP/B-10152004/pwcomplete.html.

[7.] Barkouk, Laiss, "Weather Telematics Leverages Truck Fleets to Generate Weather Data," *GPS Business News*, June 7, 2011, http://www.gpsbusinessnews.com/Weather-Telematics-Leverages-Truck-Fleets-to-Generate-Weather-Data_a3070.html.

[8.] Bennink, Curt, "Standard Makes Telematics Practical," *Equipment Today,* July 2011, http://findarticles.com/p/articles/mi_hb5751/is_20110701/ai_n57858839/.

[9.] Bird, Colin, "State Farm Testing OnStar Competitor," Kicking Tires: The Blog for Car Buyers, August 12, 2011, http://blogs.cars.com/kickingtires/2011/08/state-farm-testing-an-onstar-competitor.html.

[10.] Blumer, Fred, "Insurance Telematics: More than Just New Underwriting Criteria," *Insurance & Technology*, November 18, 2010, http://www.insurancetech.com/blogs/228300120.

[11.] Bricketto, Martin, "Allstate, Liberty Face Progressive Patent Suit," *Law360*, January 13, 2011, http://www.law360.com/articles/219920.

[12.] Brinkhoff, Thomas, "Requirements of Traffic Telematics to Spatial Databases," *Proceedings 6th Annual Symposium on Large Spatial Databases*, Hong Kong: Springer, 1999, pp. 365-369, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.84.4932&rep=rep1&type=pdf.

[13.] Brockett, Patricia et al., "Using Kohonen's Self-Organizing Feature Map to Uncover Automobile Bodily Injury Claims Fraud," *Journal of Risk and Insurance*, Vol. 65, No.2, pp. 245-274, 1998, http://www.derrig.com/research/UsingKohonen'sSelf-OrganizingFeatureMap.pdf.

[14.] Cady, Glee Harrah and Pat McGregor, "Connecting the World," *Protect Your Digital Privacy: Survival Skills for the Information Age*, Que 2002, pp. 148-189, http://books.google.com/books?id=WXVc9I_9nlsC&printsec=frontcover&dq=Protect+your+digital+privacy:+survival+skills+for+the+information+a&hl=en&ei=AxtATunmO8-30AH9tPTIAw&sa=X&oi=book_result&ct=result&resnum=1&ved=0CCkQ6AEwAA#v=onepage&q=Protect%20your%20digital%20privacy%3A%20survival%20skills%20for%20the%20information%20a&f=false.

[15.] California Department of Insurance, "About Us: Provisions of Proposition 103 Affecting the Rate Regulation Division," not dated, http://www.insurance.ca.gov/0500-about-us/0500-organization/0400-rate-regulation/prop-103.cfm,

[16.] "California Lawmakers Reject 'Pay at the Pump' Insurance," *New York Times*, May 27, 1993, http://www.nytimes.com/1993/05/27/us/california-lawmakers-reject-pay-at-the-pump-insurance.html.

[17.] Chartrand, Sabra, "Patents; Insurance Protection for Terrorism, Divorces, Frivolous Lawsuits, and Excessive Gambling Losses," *New York Times*, June 30, 2003, http://www.nytimes.com/2003/06/30/technology/30PATE.html?ei=5007&en=01b31db998d0242c&ex=1372392000&partner=USERLAND&pagewanted=print&position=.

[18.] Colorado Department of Regulatory Agencies, Division of Insurance, *Amended Regulation 5-2-12: Concerning Automobile Insurance Consumer Protections*, August 31, 2010, http://www.dora.state.co.us/Insurance/regs/F5-2-12_083110.pdf.

[19.] Commercial Carrier Journal, "Qualcomm Touts Insurance Telematics, Driver Safety Solution," February 14, 2011, http://www.ccjdigital.com/qualcomm-touts-insurance-telematics-driver-safety-solution/.

[20.] Conners, John B. and Sholom Feldblum, "Personal Automobile: Cost Drivers, Pricing, and Public Policy," CAS *Forum* Winter 1997, pp. 317-341, http://www.casact.org/pubs/forum/97wforum/97wf317.pdf.

[21.] Costlow, Terry, "Privacy Issues May Limit Linkup Between Telematics, Insurance," *Automotive Engineering International*, December 3, 2010, http://www.sae.org/mags/aei/9058.

[22.] Craig, Stephen C., "Telematics-Based Insurance Programs: Dreams and Realities," *Verisk Insurance Solutions Auto Newsletter*, June/July 2011, Issue 1, http://www.verisk.com/insurance/auto-insurance/telematics.html.

[23.] Delaware Division of Motor Vehicles, "OBD II FAQs," October 5, 2010, http://www.dmv.de.gov/services/vehicle_services/faqs/ve_faqs_obdi.shtml.

[24.] Digi International, "Digi Launches Industry's First Fleet Management Telematics Device Family Featuring Five Different Wireless Technologies," October 5, 2009, http://www.digi.com/news/pressrelease?prid=625.

[25.] Dorweiler, Paul, "Notes on Exposure and Premium Bases," CAS *Proceedings* 1929, Volume XVI, Number 33, pp. 319-343, http://www.casact.org/pubs/proceed/proceed29/29319.pdf.

[26.] DriveCam, Inc., "DriveCam Files Patent Infringement Lawsuit Against SmartDrive," Reuters, May 16, 2011, http://www.reuters.com/article/2011/05/06/idUS229826+06-May-2011+BW20110506.

[27.] Duri, Sastri, et al., "Framework for Security and Privacy in Automotive Telematics," *Proceedings of the 2nd International Workshop on Mobile Commerce*, New York: ACM, 2002, http://www.cc.gatech.edu/projects/disl/courses/8803/backup/readinglist_files/p25-duri.pdf.

[28.] Ealey, Lance and Glenn Mercer, "Telematics: Where the Radio Meets the Road," *McKinsey Quarterly*, May 1999, http://mkqpreview2.qdweb.net/Telematics_Where_the_radio_meets_the_road_344.

[29.] Elliott, Peter, and Barry Jennings, "Data Protection Issues with Intelligent Transport Systems, Vehicle Telematics, and Road Pricing," January 7, 2009, http://www.twobirds.com/English/News/Articles/Pages/Data_protection_intelligent_transport_systems_010709.Aspx.

[30.] Ethier, Sheridan, and Randy Martin, "Fast Booting Techniques May Meet Automotive Infotainment/Telematics Activation Needs," *EE Times*, November 17, 2006, http://www.eetimes.com/design/automotive-design/4011112/Fast-booting-techniques-meet-automotive-infotainment-telematics-activation-needs.

[31.] Ferreira Jr., Joseph and Erik Minikel, "Pay-As-You-Drive Auto Insurance in Massachusetts," November, 2010, http://mit.edu/jf/www/payd/PAYD_CLF_Study_Nov2010.pdf.

[32.] Finnegan, Daniel and Christopher Sirota, "Is Vehicle Data Recording Auto Insurance's Future?," June 1, 2005, https://www.qualityplanning.com/media/1185/iso.qpc.vehicle%20data%20recording.v5links.pdf.

[33.] Fletcher, Lauren, and Grace Suizo, "Telematics Use in Work Truck Fleets," Work Truck, March 2011, http://www.worktruckonline.com/Article/Print/Story/2011/03/Telematics-Use-in-Work-Truck-Fleets.aspx.

[34.] Frost and Sullivan, "North America: Slow Takeoff for Telematics-enabled Usage-based Insurance," *GPS Wire News*, June 17, 2011, http://gpswire.net/?p=2290.

[35.] Furchgott, Roy, "More Consumers Are Letting Insurers Monitor Their Mileage," *New York Times*, December 24, 2010, http://www.nytimes.com/2010/12/26/automobiles/26INSURE.html.

[36.] Garth, Denise, "Telematics Data: The Next Level," *IDM Quarterly*, Volume 7, Issue 1, Winter 2010, pp. 1-3, http://www.innovation-group.com/files/documents/Public%20Files/News_Articles/Telematics_Article-_IDM_Quarterly_2010_Winter.pdf.

[37.] GMAC Insurance, "GMAC Insurance and OnStar Create Innovative Insurance Products," January 28, 2004, Ally, http://media.ally.com/index.php?s=43&item=161.

[38.] Gutner, Toddi, "Anatomy of a Credit Score," *Business Week*, November 28, 2005, http://www.businessweek.com/magazine/content/05_48/b3961124.htm.

[39.] Hales, Mike, et al., "Telematics: Reinventing Auto Insurance Part II," *Insurance & Technology*, September 8, 2010, http://www.insurancetech.com/blogs/227400412.

[40.] Harris, Jim, "Event Data Recorders - State Statutes and Legal Considerations," *Accident Reconstruction Journal*, Vol. 18, No. 1, January/February, 2008, http://www.harristechnical.com/downloads/Harris_EDR_article.pdf.

[41.] Helft, Miguel, "Jobs Says Apple Made Mistakes with iPhone Data," *New York Times*, April 27, 2011, http://www.nytimes.com/2011/04/28/technology/28apple.html?_r=2.

[42.] Hendel, John, "Telematics and UBI: The Regulatory Opportunities," *Telematics Update*, September 5, 2011, http://social.telematicsupdate.com/insurance-telematics/telematics-and-ubi-regulatory-opportunities.

[43.] Hendricks, Evan, "Insurer's Patent Targets Driver's Every Move," *The Privacy Times*, November 4, 1999, http://www.privacytimes.com/NewWebstories/home_priv_11_16.htm.

[44.] Hughes Telematics, Inc., "Amendment No. 1 to Form S-1 Registration Statement under the Securities Act of 1933," April 6, 2010, http://www.faqs.org/sec-filings/100407/HUGHES-Telematics-Inc_S-1.A/.

[45.] Hughes Telematics, Inc., "Insurance and Telematics: More Than Just Better Underwriting," not dated, http://www.hughestelematics.com/pp/whitepapers/insurancewp.php.

[46.] Hunkins, Dave, "Emergence of Consumer Solutions in Vehicle Telematics," December 29, 2003, http://www.cs.clemson.edu/~johnmc/courses/cpsc875/projects/emerge.pdf.

[47.] InCode Telecom Group, "Telematics: How Economic and Technological Forces Will Shape the Industry in the U.S.," May 2001, https://confluence.engin.umich.edu/download/attachments/1605717/Telematics_Position_Paper_v11.pdf.

[48.] Insurance Institute for Highway Safety, "Q&A: Event Data Recorders," *Research: Event Data Recorders*, November 2010, http://www.iihs.org/research/qanda/edr.html.

[49.] Ippisch, Tobias, "Telematics Data in Motor Insurance: Creating Value by Understanding the Impact of Accidents on Vehicle Use," Lulu Enterprises 2010, http://www1.unisg.ch/www/edis.nsf/SysLkpByIdentifier/3829/$FILE/dis3829.pdf.

[50.] Iqbal, Muhammad Usman and Samsung Lim, "Location Privacy in Automotive Telematics," August 25, 2009, http://www.gmat.unsw.edu.au/snap/publications/usman&lim2007a.pdf.

[51.] Jennings, Trip, "Internet Upgrade Headed to Northern New Mexico," *The New Mexican*, August 15, 2011, http://www.santafenewmexican.com/Local%20News/Internet-upgrade-headed-to-region.

[52.] Jones, Steve, "Introduction to Road Data - Part One," *Directions Magazine*, August 25, 2010, http://www.directionsmag.com/articles/introduction-to-road-data-part-1/130105.

[53.] Jun, Jungwook, "Potential Crash Exposure Metrics Based on GPS-Observed Driving Behavior Activity Metrics," Savannah: Georgia Institute of Technology, 2006, http://commuteatlanta.ce.gatech.edu/Resources/jun_jungwook_200612_phd.pdf.

[54.] Kaften, Cheryl, "UPS Delivers Fuel-Per-Package Savings That Equal 63.5 Million Miles Not Driven," *Green Technology World*, August 1, 2011, http://green.tmcnet.com/topics/green/articles/203060-ups-delivers-fuel-per-package-savings-that-equal.htm.

[55.] Kantowitz, Barry H., and Sandeep Premkumar, "Safe Vehicles Using Adaptive Interface Technology (Task 6b): Identify Demand Levels of Telematic Tasks," November 2004, http://www.volpe.dot.gov/hf/roadway/saveit/docs/dec04/finalrep_6b.pdf.

[56.] Kauth, Joel, "Keeping the Patent Trolls at Bay - Defending Your Location-Based Patents and Your Business," *Directions Magazine*, April 18, 2011, http://kppb.com/kppb/index.php?option=com_content&view=article&id=81&catid=3&Item.

[57.] Kramer, Jan, "Bundling Telecommunications Services: Competitive Strategies for Converging Markets," December 13, 2007, http://www.im.uni-karlsruhe.de/Upload/Publications/3d6fe37c-fd87-4ba8-aa55-da0f9d519225.pdf.

[58.] Langevoort, Harry, "Tracking and Tracing in a Complex Environment," September 11, 2007, http://www-05.ibm.com/nl/events/presentations/tracking_and_tracing_in_a_complex_enviroment.pdf.

[59.] Lasky, Michael S., "Real-Time Traffic Info Gets You Past Jams," *PC World*, December 22, 2006, http://www.pcworld.com/article/128294/realtime_traffic_info_gets_you_past_jams.html.

[60.] Lewis, Peter, "Car Insurance Patents Threaten Consumer Choice," *Insure.com*, July 10, 2009, http://www.insure.com/car-insurance/patents.html.

[61.] Liberty Northwest, "Liberty Northwest® Launches Onboard Advisor™ for Commercial Fleets," Business Wire, March 3, 2009, http://www.businesswire.com/news/home/20090303006147/en/Liberty-Northwest%C2%AE-Launches-Onboard-Advisor%E2%84%A2-Commercial-Fleets.

[62.] Madison, Bill, "Tell-Tale Telematics," *Claims Advisor*, January 11, 2011, http://claimsadvisor.com/articles/tell-tale-telematics/2/.

[63.] Magney, Phil, "The Impact of AT&T's New Data Plan on Telematics," IHS iSuppli Market Research, June 28, 2010, http://www.isuppli.com/Automotive-Infotainment-and-Telematics/MarketWatch/Pages/The-Impact-of-ATTs-New-Data-Plan-on-Telematics.aspx.

[64.] M-Cam, Inc., "Intellectual Property Analysis of Progressive's U.S. Patent No. 7,124,088," May 16, 2011, http://www.m-cam.com/sites/www.m-cam.com/files/20110516%20-%20Progressive%20v%20Allstate%20et%20al.pdf.

[65.] Mahler, Howard C., "The Credibility of a Single Private Passenger Driver," CAS *Proceedings* 1991, Volume LXXVIII, Number 148, pp. 146-162, http://www.casact.org/pubs/proceed/proceed91/91146.pdf.

[66.] Melnitzer, Julius, "Bilski Ruling from U.S. Supreme Court," *Financial Post*, June 29, 2010, http://business.financialpost.com/2010/06/29/bilski-ruling-from-us-supreme-court/.

[67.] Mestdagh, Wilfred, "Snap to a Road," *MP2K Magazine*, February 12, 2006, http://www.mp2kmag.com/a130--snap.calcxy.gps.mappoint.html.

[68.] Michigan Department of Licensing and Regulation, Insurance Bureau, "Part III: Rating," *A Year of Change: The Essential Insurance Act of 1981*, June 4, 1982, pp. 13-15, http://www.michigan.gov/documents/dleg/The_Essential_Insurance_Act_in_1981_272421_7.pdf.

[69.] Mobile TeleSystems OJSC, "Telematics (Corporate)", not dated, http://www.corp.mtsgsm.com/upload/contents/301/telematika.pdf/.

[70.] Muckell, Jonathan, et al., "Towards an Intelligent Brokerage Platform: Mining Backhaul Opportunities in Telematics Data," Journal of the Transportation Research Board, Issue 2097, September 1, 2009, pp. 1-8, http://www.jmuckell.org/Publications/TRB_88th%20Meeting%20GE%20GRC%2009-3144.pdf.
[71.] Mueller, Scott, "Microprocessors from 1971 to the Present," *Upgrading and Repairing PCs* (17th Edition), Que 2006, http://www.informit.com/articles/article.aspx?p=482324&seqNum=2.
[72.] Muermann, Alexander, and Daniela Straka, "Asymmetric Information in Auto Insurance: New Evidence from Telematics Data," December 2010, http://www.skinance.com/Papers/2011/Muermann.pdf.
[73.] Neleman, Paul, "What Is First Notice of Loss and Why Is It Important to Policy Holders and Insurers?" November 22, 2010, http://ezinearticles.com/?What-Is-First-Notice-Of-Loss-And-Why-Is-It-Important-To-Both-Policy-Holders-And-Insurers?&id=5386395.
[74.] Nora, Simon and Alain Minc, *The Computerization of Society*, The MIT Press, 1980.
[75.] O' Connor, Amy, "Safe Driving Habits Pay Off for Consumers with Usage-Based Insurance Programs," *Insurance Journal*, August 1, 2011, http://www.insurancejournal.com/magazines/mag-features/2011/08/01/208734.htm.
[76.] O' Connor, Brendan, "Comparison of Data Analysis Packages: R, Matlab, SciPy, Excel, SAS, SPSS, Stata," February 23, 2009, http://brenocon.com/blog/2009/02/comparison-of-data-analysis-packages-r-matlab-scipy-excel-sas-spss-stata/.
[77.] Oregon Department of Consumer and Business Services, "Credit Scoring in Insurance - Questions and Answers," November 2007, http://insurance.oregon.gov/FAQs/credit_scoring-qa.pdf.
[78.] Palmer, W. Scott, "Auto 'Black Box' Data: Industry Update," October 31, 2003, http://www.injurysciences.com/Documents/EDRUpdateArticle.pdf.
[79.] Parnell, Karen, and Beng Ceng, "Telematics Digital Convergence—How to Cope with Emerging Standards and Protocols," May 27, 2003, http://www.xilinx.com/support/documentation/white_papers/wp194.pdf.
[80.] PBS&J, *ITS Orange Book™ - Smart Highways*, Issue 1, 2005, http://northamerica.atkinsglobal.com/Unpublished/PBSJ_Orange_Books/PDF/OrangeBook_Issue2_screen.pdf.
[81.] Penton Media, "Terion Launches Wireless Service for Trucking," *Drivers: Business News for the Professional Trucker*, November 1, 1999, http://driversmag.com/ar/fleet_terion_launches_wireless/.
[82.] Progressive Corporation, "Innovative Auto Insurance Discount Program to be Available to 5,000 Minnesotans," August 8, 2004, http://www.progressive.com/newsroom/2004/August/Tripsense.aspx.
[83.] Progressive Corporation, "Progressive Testing New Product in Texas That Features Revolutionary Auto Insurance Rating Method," The Free Library, October 27, 1999, http://www.thefreelibrary.com/Progressive+Testing+New+Product+in+Texas+That+Features+Revolutionary...-a056960005.
[84.] Property Casualty Insurers Association of America, "The Predictive Value of Credit-based Insurance Scores," February 11, 2009, http://www.pciaa.net/web/sitehome.nsf/lcpublic/402/$file/pcicreditwp021109.pdf.
[85.] Safeco, "Safeco Offers All Parents of Teen Drivers Peace-of-Mind," May 27, 2008, http://www.safeconews.com/pressrelease.php?p_id=169.
[86.] Shanken, Edward A., "From Cybernetics to Telematics: The Art, Theory, and Pedagogy of Roy Ascott," *Telematic Embrace: Visionary Theories of Art, Technology, and Consciousness*, Berkeley and Los Angeles: Universal of California Press, 2003, pp. 1-96, http://books.google.com/books?id=zN85LrAoDwUC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false,
[87.] Simpson, Andrew, "Progressive Goes National with Usage-Based 'Snapshot' Car Insurance Program," *Insurance Journal*, March 14, 2011, http://www.insurancejournal.com/news/national/2011/03/14/190132.htm#.
[88.] ST Microelectronics, "ST Offers Enhanced 3-Axis Digital Gyroscope," *Sensors Magazine*, April 8, 2010, http://www.sensorsmag.com/machine-manufacturing/news/st-offers-enhanced-3-axis-digital-gyroscope-7014.
[89.] State Environmental Resource Center, "Pay-As-You-Drive Auto Insurance Policy Issues Package," May 10, 2004, http://www.serconline.org/payd/background.html.
[90.] Strube, Joseph, and Bryant Russell, "Actuarial Data Management in a High-Volume Transaction Processing Environment," CAS *Forum* Winter 2005, pp. 274-314, http://www.casact.org/pubs/forum/05wforum/05wf274.pdf.
[91.] Sturgeon, Julie, "Bad Credit Hurts in Many Ways," Bankrate.com, July 21, 2006, http://www.bankrate.com/finance/debt/bad-credit-hurts-in-many-ways-1.aspx.

[92.] Svensson, Peter, "Possible E-mail Theft from Epsilon Slams Banks, Retailers," *USA Today*, April 4, 2011, http://www.usatoday.com/money/industries/technology/2011-04-04-e-mail-theft-phishing.htm.
[93.] Swallow, Kevin, "Kinishi Launches Fingerprint ID Telematics for Drivers," February 26, 2010, http://www.roadtransport.com/Articles/2010/02/26/135661/Kinishi-launches-fingerprint-ID-telematics-for-drivers.htm.
[94.] Telecommunications Systems, Inc., *Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934*, March 3, 2009, http://secwatch.com/tsys/10k/annual-report/2009/3/3/2003794/print.
[95.] Towers Watson, "Towers Watson DriveAbility(SM): UBI Taking Hold Among Auto Insurers," *Market Watch*, June 22, 2011, http://www.marketwatch.com/story/towers-watson-driveabilitysm-ubi-taking-hold-among-auto-insurers-2011-06-22.
[96.] U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Office of Analysis, Research, and Technology, "100 Car Naturalistic Study," March 2006, http://www.fmcsa.dot.gov/facts-research/research-technology/report/100-car-naturalistic-study/100-car-naturalistic-study.pdf.
[97.] U.S. Department of Transportation, Intelligent Transportation Systems, Next Generation 9-1-1 (NG9-1-1) System Initiative, "NG9-1-1 Transition Issues Report," February 2008, http://www.its.dot.gov/ng911/pdf/NG911_TransitionIssuesReport_FINAL_v1.0.pdf.
[98.] U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, "Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances," National Transportation Statistics, 2011, http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html.
[99.] Vanderford, Richard, "Progressive Sues HTI Over Car Monitoring Patents," *Law360*, September 16, 2010, http://www.law360.com/articles/194102/progressive-sues-hti-over-car-monitoring-patents,
[100.] Veness, Chris, "Calculate Distance, Bearing, and More Between Latitude/Longitude Points," not dated, http://www.movable-type.co.uk/scripts/latlong.html.
[101.] Verisk Analytics, "ISO Equips Fleet with Telematics Devices to Develop Analytical Methods for Personal and Commercial Auto Insurance," September 21, 2010, http://www.verisk.com/Press-Releases/2010/ISO-Equips-Fleet-with-Telematics-Devices.html,
[102.] Verisk Analytics, "Will Consumers Agree to Install Telematics Devices in Their Cars?," October 2010, http://www.verisk.com/dloads/applied-informatix/verisk-telematics.pdf.
[103.] Walsh, James, "The Best Insurance—Data Backup," Wealth Mountains, not dated, http://www.wealthmountains.com/articles/Article/The-Best-Insurance---Data-Backup/2189.
[104.] Werner, Geoff, and Claudine Modlin, *Basic Ratemaking* (Version 4), Casualty Actuarial Society 2010, http://www.casact.org/pubs/Werner_Modlin_Ratemaking.pdf.
[105.] Ykovv, Liane, "AAA to Offer Customers In-Drive Emergency Response Telematics," August 15, 2011, http://reviews.cnet.com/8301-13746_7-20092469-48/aaa-to-offer-customers-in-drive-emergency-response-telematics/.
[106.] Ziegler, Chris, "2G, 3G, 4G, and Everything in Between: An Engadget Wireless Primer," January 17, 2011, http://www.engadget.com/2011/01/17/2g-3g-4g-and-everything-in-between-an-engadget-wireless-prim/.

Abbreviations and notations

AAA, Automobile Association of America Insurance Company
ADM, Actuarial Data Manager
AM, Ante Meridiem
ASB, Actuarial Standards Board
ASOP, Actuarial Standard of Practice
DBD, Driving Behavior Data
EDR, Event Data Recorder
FICO, Fair Isaac Corporation
FNOL, First Notice of Loss
G-Force, Gravitational Force
GM General Motors
GMAC, General Motors Acceptance Corporation Insurance Company

GPS, Global Positioning System
GPRS, General Packet Radio Service
HVTPE, High-Volume Transactional Processing Environment
IP, Intellectual Property
ISO, Insurance Services Office, Inc.
MPH, Miles Per Hour
NHTSA, National Highway Transportation Safety Administration
NPE, Non-Practicing Entity
OBDII, On-Board Diagnostics II
RAM, Random Access Memory
TSP, Telematics Services Provider
UBI, Usage-Based Automobile Insurance
UTC, Coordinated Universal Time
Wi-Fi, Wireless Fidelity

Biographies of the Authors

Jim Weiss is an Assistant Manager in the Personal Automobile Actuarial Division at Insurance Services Office, Inc.. He works with ISO's Applied Informatix™ business unit in developing analytical tools to support telematics-based initiatives, and moderated and co-presented a session entitled "Effectively Utilizing Vehicle Telematics Data" at the Casualty Actuarial Society Special Interest Seminar on "Cutting Edge Tools for Pricing and Underwriting" in October 2011. Jim is a Fellow of the Casualty Actuarial Society, a Member of the American Academy of Actuaries, and a Chartered Property Casualty Underwriter.

Jared Smollik is a Manager in the Increased Limits & Rating Plans Division at Insurance Services Office, Inc.. He is responsible for increased limits for commercial and personal auto, as well as the development of increased limits and other rating factors for the management protection and e-commerce programs. He is also responsible for ISO's Enterprise Risk Management Service for Insurers and has been involved with ISO's telematics research and product development since 2005. Jared is a Fellow of the Casualty Actuarial Society, a Member of the American Academy of Actuaries and a Chartered Property Casualty Underwriter.