Adverse events, such as IT system failures at British Airways in May and August of 2017, or massive data breaches at Yahoo in 2013 and 2014, often bring significant damages to an organization or the society. In many situations, better efforts in maintaining and safeguarding a system can reduce the chance of such adverse events. The challenge is that these events may still occur, albeit less frequently, despite the best effort. And efforts are often hard to verify. Furthermore, people in charge of the effort (an agent) often cannot bear the full consequence of an adverse event due to limited liability. In practice, an agent is often a hired employee or subcontractor, who can be paid one way or another, but cannot compensate damages. In order to ensure efforts, a principal, be it a firm or a government, may decide to “keep an eye” on the agent, which ensures that adverse events occur at a lower rate, and are not due to lack of effort should they happen. For example, Accenture serves as an outside vendor to support the IT systems for Kasikornbank of Thailand (also known as the Kbank). According to our conversations with Accenture, once in a while, the in-house IT team at Kbank would show up to watch the Accenture team working. Such monitoring activities are often too costly to conduct at all the time. The principal can also schedule payments that are contingent on arrivals to motivate effort. How should a principal maintain efforts from the agent while minimizing the total payments and monitoring costs? In particular, in a dynamic setting where adverse events stochastically occur over time, what is the optimal schedule to pay and to monitor the agent?

To answer these questions, we study an optimal contract design problem in a dynamic setting, where a risk neutral principal faces a Poisson process of costly adverse events. The instantaneous
rate of the Poisson process can be reduced by a risk neutral agent, if the agent exerts effort at that moment. Effort is costly to the agent and observable to the principal only when the principal conducts costly monitoring. The principal, who can commit to a long term contract over an infinite horizon in continuous time, needs to trade-off direct payments to the agent, versus costly monitoring, in order to induce effort.

We formulate the optimal dynamic contract design problem as a continuous time stochastic optimal control model. The model identifies the optimal monitoring and payment schedule among general admissible policies that ensure continued effort from the agent. We are able to provide a complete characterization of the optimal control policy, which varies depending on the monitoring cost. As expected, if the monitoring cost is lower than a low threshold, the principal should monitor all the time, and only reimburses the agent’s effort cost. Therefore, the agent’s total future utility is always kept at 0. Interesting cases occur when the monitoring cost is higher than the low threshold. In these cases, the optimal monitoring and payment schedules depend critically on the agent’s promised utility, which can be thought of as a dynamically changing “score.”

If the monitoring cost is higher than a high threshold, the principal monitors the agent if and only if the “score” is below a “monitoring” threshold. As long as the score is at or above this threshold, and lower than an upper bound of promised utility, it always increases continuously between arrivals, with slope of increase determined by the current score. Upon reaching the upper bound, the score remains at the upper bound, while the principal pays the agent a flow payment, until the next arrival. Each arrival causes the score to take a downward jump of a fixed value, which is determined as the amount of the fine, should the principal be able to actually charge it, that would make the agent indifferent between exerting effort or not. If the score drops below the “monitoring” threshold, it continuously increases regardless of arrivals, because the agent is already being monitored. Therefore, the score approaches the threshold from below, along a continuous path in a deterministic fashion.

If the monitoring cost is between the lower and higher thresholds, the monitoring time under the optimal contract is no longer deterministically determined by the score. Instead, the principal
starts the contract by monitoring the agent for an exponentially distributed random time regardless of arrivals, while the score is kept at 0. The credit that the agent cumulates is not reflected in the continuous increase of the score as in the previous case, but a direct jump in “score” to a threshold occurs, marking the end of each monitoring episode. At or above this threshold, the score keeps increasing or takes downward jumps at arrivals, similar to the case with high monitoring discussed earlier, until it reaches an upper bound to trigger a flow payment. If a downward jump brings the score to be between 0 and the threshold, however, instead of automatically starting the monitoring, the principal randomizes the score to either 0 or the threshold. Only if the score lands at 0, another monitoring episode of exponentially distributed time would start.

The optimal monitoring and payment schedule, which only require the principal to keep track of a single score that moves in a predictable manner, are quite easy to implement. It is also intuitive that the contract structure induces effort. The agent’s effort reduces the chance of an arrival, which allows the score to reach the upper bound and the payment to start sooner. The increase of the score includes the credit cumulated from the costly effort, as well as the interest due to the agent’s time discount. These cumulated credits are paid as a flow when the score reaches the upper bound. While being paid, the agent still exerts effort continuously to delay the next arrival, which would pause payment for a period of time, the exact length of which depends on future arrivals. The downward jump in the score can be thought of as a fine for each arrival charged to the agent.

Optimal scheduling of monitoring in a dynamic environment is fundamentally an operations problem and we hope our study motivates more researcher to occupy this area.