Good afternoon ladies and gentlemen.

The next 30 minutes I would like to talk about safety matters, because safety matters.

I am sure that we all know that it matters, but I am also sure that it not always receives the attention it requires. This afternoon I will speak about safety and security to demonstrate how much it matters and how important it is that a renowned institute like the Delft University of Technology undertake systematic research on the matter.

The outline of my presentation is as follows:

I will start with a less cheerful introduction by reviewing some disasters which took place in 2013. Then I will give a simple analysis of safety and security. Before presenting some methodological remarks about safety and security studies, I may have to ‘frighten’ you a bit by sketching some possible undesired scenario’s involving the Aula, the place where we are sitting now. Such a scenario based analysis is an approach which is often used in safety and security science. I will close by looking into the future of safety and security research.

Let me take you to a brief selection of disasters which have happened last year. 2013 was marked by a number of major natural disasters. But people also had a hand in many disasters, intentionally or unintentionally. We had deadly train incidents in Spain and Canada. We had floods in Europe and the deadliest typhoon in the history of the Philippines, devastating forest fires in Australia, tornado’s in Oklahoma, terrorist attacks in Boston and Nairobi, cyber attacks to the banking system, the collapse of a clothing factory in Bangladesh, an explosion in a fertilizer plant in Texas, USA.

The year is only 10 days old and already new incidents have happened. Just yesterday, an explosion in a Shell refinery in Cologne, Germany and on Monday the identity fraud with DigiD in Amsterdam.

From these set of photo’s 3 types of undesired events can be distinguished. 1) natural hazards, 2) unintentional man-made hazards, and 3) intentional man-made hazards. The first two are safety related, the third one is security related; a division which was also just shown by the rector magnificus.

Safety and security science is about the scientific analysis of undesired events, disasters and accidents (both intentional and unintentional). Delft University of Technology is traditionally strong in modelling the probabilities and the consequences of these events. We aim to quantify safety and security, evidence based by numerical methods. But looking back to incidents retrospectively is not good enough in safety & security science! As engineers we also aim to optimize safety and security, by applying clever technical and socio-technical measures in the design phase; building higher dikes, stronger materials for airplanes, more redundancy in electronic networks, etc. The term “socio-technical” is used here to draw attention to the interaction between human behaviour, technology and organizations. Clearly, safety and security are not straightforward terms. Clearly, their analysis is not straightforward.

Let me put safety in perspective.

Our society is safer than ever, as can immediately be seen from the increase of our life expectancy. The average life time nowadays in the Netherlands is 78 years, and still increasing. At the start of our university, 172 years ago, life expectancy was only 40 years. Better food, clean drinking water and healthcare, but also better construction of buildings and sewerage systems have contributed significantly to the increase of life expectancy.

The Netherlands has a population of 16.8 million people. In 2012, a total of 140.000 people died. Hence, the overall probability of dying in the Netherlands is 8.3.10^{-3} per year; in other words 83 out of 10.000 people die each year.

The majority of these 83 people die of natural causes. Only 3.3 of these 83 people die of non-natural causes, which amounts to about 6000 casualties per year.
Of these 6000 casualties, 2800 took place by accidents at home, 1600 suicide, 650 traffic, 150 murder and assault, 60 work related, 750 other.

I am leaving out the delayed deaths because of asbestos and the preventable deaths in hospitals because of errors in surgery. I will come back to that later.

The mortality rate of non-natural causes shows a spatial fluctuation. The red areas on this map (Northern Netherlands, Amsterdam, South Limburg) show areas with a 50% higher mortality rate than average. Here in Delft, we are at the average.

Mortality rate also changes over time. The average mortality rate was 8.3.10^-3 per year, given by the horizontal red line. The figure, based on recent CBS data, shows that the lowest rates go as low as 10^-4 per year, for children in between 4 and 16 years. If they could stay in that condition, they would become 10,000 years old.

The influence of increasing the mortality rate with small probabilities, ranging from 10^-3 per year (the probability of dying because of smoking) to 10^-7 per year (the probability of dying after a bee sting), on the overall life expectancy, is shown in this table.

Currently the individual risk criterion in the Netherlands, posed by the Ministry of Infrastructure and Environment, is 10^-6 per year. It is not allowed to expose the people in which his or her probability of dying would increase by 10^-6 per year. There several accounts of how this number came into existence; one of them is that 10^-6 per year was taken as being 1% of the lowest mortality rate of people. According to the table on this slide, this corresponds to a decrease of expected lifetime of 1 day. Although this may seem not very much, we have to note that not just one life is involved in a disaster, but usually a large number. Therefore also criteria for group risk have also been formulated by the Ministry of Infrastructure and Environment.

The question which risk criterion should be applied, in other words “which safety level is safe enough?”, is a very important research question in safety and security science. And a very difficult one for that matter, since it also involves moral considerations.

Prof. van Dantzig showed in the 1950s that the problem of the acceptable level of risk can be formulated as an economic decision problem. The expenditure for a safer system is equated with the gain made by the decreasing present value of the risk. In this way optimal risk criteria could be derived for the flood protection system of the Netherlands, resulting in safety levels from once in 10,000 years for the coastal flood prone areas (shown by the red areas on this map) to once in 1250 years for the river flood prone areas (shown by the green areas on this map). Econometric models are very important in safety science; also expressed by the well known statement, if you think that safety is expensive, try an accident.

Prof. Vrijling, who recently retired as professor of Probabilistic Design and Hydraulic Engineering, also investigated the optimal allocation of investments in the safety chain of proaction, prevention, preparation, repression and after-care. He showed that the safety chain is not a series system, but in essence a parallel system. For the safety against flooding, he showed that from a rational point of view preventive measures are more cost effective than repressive measures, and in this way he could derive criteria not only for applying preventive measures but also for repressive measures.

There are many safety norms, not only in Dutch law, but also on EU level, NATO level, UN level, etc. Safety matters worldwide.

So far the overview of perspectives. Now, let us zoom in on some possible undesired events which could occur here in this building, the Aula. Since we were talking about flood risk, let us start with this event first.
Here we see a map of Delft and the campus on the south side. The legend on the right hand side shows the height of the buildings and the ground above mean sea level. This orange building is the Aula where the roof is about 20 m above mean sea level. You can also see the Mekelweg which has an average altitude of 1 m below mean sea level. The deepest points of the campus go as deep as 4 m below mean sea level.

Extreme flooding can occur from a number of possible scenarios, studied by the hydraulic engineering section at civil engineering, where I worked myself over the past 20 years, together with colleagues Professors Jonkman and Kok. One of the scenarios for flooding at the campus here in Delft would be a flooding caused by a breach at a weak spot in the embankment along the Schie Canal, for instance. Another scenario could be given by a coastal flooding by a breach in the dunes along the North Sea in Ter Heijde for instance. Although the probabilities of these scenarios are small (according to the previous figure less than once in 10.000 years), the consequences would be enormous.

In the unlikely event that we would have to evacuate the Delft campus we would face an enormous challenge. Even without an imminent flood disaster, it would take quite some time to leave the campus at the end of day around 17.00 to 17.30h. Prof. Hoogendoorn’s group creates insight into these problems. His section develops pedestrian flow and car flow models to predict how many people can safely evacuate an area within a certain time window. Without control measures and only limited time available, the proportion often turns out to be very low, depending on the circumstances. With an optimization, they can substantially increase this proportion - in some cases by a factor of 2 or 3 - by organizing a better distribution of the traffic over the campus road network and by regulating the inflow of the traffic in such a way that the number of vehicles remains below a critical level. It is necessary to retain some people (hoping that they would follow such advice) in order to minimize the overall total evacuation time.

During such crisis events, NL-Alert could be deployed. NL-alert is a novel way to do crisis communication, co-developed by staff of the safety and security science section. With NL-Alert the authorities can inform people in the immediate vicinity of an emergency with text messages to their mobile telephones. The message reports specifically what the problem is and what you can do best. Currently NL-Alert is used in life- or health-threatening situations, such as a major fire with toxic gases, explosion or flooding. For the last case the message would probably be, evacuate in vertical direction, stay high and dry in the Aula.

How about structural incidents, for instance caused by random or non-random vibrations? Let’s take a look at Feyenoord soccer stadium.

This is what happens after Feyenoord scores a goal. We clearly saw a resonance of the 2nd ring, caused by the simultaneous jumping of people. This can be quite frightening for people. During one of the concerts in the stadium, a person even fell down from the 2nd ring and died.

Delft University of Technology and TNO developed an ingenious way to reduce the resonance of the 2nd ring by using sound and video image manipulation. Zooming in and zooming out, freezing the video image, or slow motion of the goal help to reduce the symmetry of the movement of the crowd, and in this way the resonance of the ring. Although I don’t think we would need such a system here in the Aula.

Apart from safety related risks at the Aula, there can also be security related risks with respect to its structural integrity. One possible modus operandi is shown on this slide. This is a cross section of the Aula. The roof has a span of 32 m and hangs on two slender columns. If you would cut these columns, the roof would collapse on the audience. The lower tray stands on thick columns. In the original design of the building the thick columns were not there. To save costs and to decrease the vulnerability these columns were added to the design later on.

Security related risks are not only of this time, as we can see from this old painting in which the biblical figure Samson pushed the pillars of the temple of Dagon, killing 3000 Philistines and himself.
A large security threat nowadays comes from terrorist organizations, using terror at any time and place with the goal of undermining confidence in governments, social order and trust. Due to the changing nature of security issues, a new type of intelligence is needed, called network science or network sociology in which individual nodes (which, depending on the type of network, can be people, events, etc.) are connected by complex yet understandable relationships that form networks.

Network Analysis is a mathematical methodology for connecting the nodes, a way of using science to fight terrorism. Once we have a network map, we can measure parts of the network, using network metrics. The map on this slide used open source data to map the terrorist network of the 9/11 attacks. In the network map, the hijackers are color coded by the flight they were on. The dark grey nodes are people who were reported to have had direct, or indirect, interactions with the hijackers. The gray lines indicate the reported interactions -- a thicker line indicates a stronger tie between two nodes. An early warning system could have broken down this network before they attacked. Network metrics are studied by the group of professor Rob Kooij.

Though safety and security are traditionally separate working areas, many methods are being shared between the two fields today; so safety methods are used in security and vice versa in safety. Not only SAFETY MATTERS, but SECURITY MATTERS too.

To analyze safety and risks of different undesired events objectively, quantification and models are needed.

Some basic tools will be presented in this lecture:

Risk = Probability multiplied by consequences

A limit state function $Z = \text{resistance} - \text{stress}$

A systems analysis of components in a fault tree or Bowtie

Statistical distribution functions

Safety ladder

Risk can be modelled as the product of probability and impact. Risk can therefore be very well visualized in a risk matrix or a graph showing probability on the horizontal axis and impact on the vertical axis.

The Global Risks Report 2013 of the World Economic Forum for instance analysed 50 global risks in this way in terms of impact and likelihood, for the categories economy, environment, geopolitics, society and technology.

The report highlights wealth gaps (severe income disparity) followed by unsustainable government debt (chronic fiscal imbalances) as the top two most prevalent global risks. Following a year scarred by extreme weather, from Hurricane Sandy to flooding in China, respondents rated rising greenhouse gas emissions as the third most likely global risk overall.

In its most simple form, failure of a structure, system or process can be described by the equation $R - S$, in which $R$ stands for the resistance or strength of the structure and $S$ for the stress or load acting on the structure. As long as the difference $R - S$ is positive, we are in the safe domain. Failure will occur if the stress is larger than the resistance. There will always be some uncertainty around the exact value of the resistance and in particular around the value of the stress. They have to be modelled by probability distributions, based on fundamental physical-based studies, or based on empirical studies by fitting distributions to observations from the field.

An essential part of safety and security science is the methodology to estimate the exceedance probabilities of extreme events. A common approach is the annual maxima procedure, in which the
data is fitted with extreme value distributions by statistical parameter estimation methods. Still the extrapolation of the distribution functions to low probabilities is surrounded by large uncertainties, as can be seen from this figure, where 6 different estimation methods (shown by the coloured lines), applied to the annual maxima river discharges of the river Meuse (shown by the small circles, for which we have about 100 years of discharge observations), show a spread in the 10-4 quantile of almost a factor 2. Techniques are developed at the safety and security science group to reduce this uncertainty to smaller intervals.

**Failure can usually occur due to more than one single failure mechanism.** This is true for flood defence systems, which can fail by a whole set of possible mechanisms as shown in this fault tree. The fault tree is an essential tool in safety and security science to model the causes of possible failure with Boolean logic.

**The fault tree is the left part in the Bowtie model** which appeared so prominently on the invitation for this foundation day. The right part in the Bowtie model describes with forward logic the consequences appearing after the failure of a structure, system or process.

**The next step in safety and security science** is the development of Bayesian Belief Networks, also known as BBNs.

**My predecessor, prof. Ben Ale, and colleagues have** developed BBN’s in Air Transport Safety. Aviation processes now have reached such a degree of complexity that traditional analytical methods are no longer able to deal with the entire aviation system spectrum. A BBN model provides insight into cause-effect relationships in the event sequences leading up to potential incidents and accidents. These event sequences cover all potential failure modes of the operations during the different flight phases. The model enables quantitative risk assessments of existing and new operations to be carried out, while providing insight into the effectiveness and efficiency of risk-reducing measures. BBN’s are currently also introduced in the Chemical industry by researchers of the safety and security science group. And they represent a promising line of research with wide applications.

**Safety and security science is not only about technical and engineering issues,** but also about human behavior and safety culture in organisations. Human errors, knowledge-based, rule-based and skill-based errors have a large contribution to the occurrence of failures. But also the safety culture in organisations can contribute. The safety ladder distinguishes pathological organisations (where the organizational culture manages to escape the work of regulators) to generative organisations (where health and safety is how we do business here). Management priorities, training of employees, protocols, etc. are factors which help to describe the safety culture in organisations.

Pause

**In the last part of my presentation, I would like to share my views on safety and security for the future.**

Big data and multidisciplinarity is the new DNA for conducting safety studies. We are looking for cheaper solutions with higher efficiency, and my personal opinion is that the user generated data can help with this, although the problem of preventing privacy violations should be carefully addressed. I’ll come back to that later.

**Safety in traffic improved a lot 30 years ago** by the introduction of the safety belt. Still there are many casualties in traffic every year and traffic can be considered a high risk sector, although the risk perception amongst the general public is quite low. Traffic safety can be further improved by adding digital devices which measure the outside world continuously while driving. At Civil Engineering, Prof. Van Arem’s group, models are developed based on observed data from radar and ultrasonic sensors, GPS, lidar and video camera’s for self-driving cars.

**The potential benefits are enormous,** not only from a safety point of view, but also from an economic and environmental point of view. The risk perception by car drivers might decrease even further with these advanced sensors, which in itself could lead to an increase in traffic accidents again.
The Risk Hemeostasis Theory has been developed for this phenomenon (the preference of people to maintain a constant internal environment).

**Multifunctional radars are also examples of the big data trend**, very useful for safety and security applications. The MIMO-SAR based radar of prof. Yarovoy's group at the Electrical Engineering, added with neural network based detection systems can be used to detect concealed weapons, for instance at airports. The undesired electromagnetic fields of these types of radars is a factor 100 less than the field of a mobile telephone and they provide 3D scans of the human body, even when the person is in motion.

**Ultra wideband radars are developed for human being detection**, based on cardio or breathing spectrum analysis, very useful during recovery work after earthquakes or tornado's for instance, but also to detect human trafficking.

**Another example of obtaining big data** is by companies on industrial parks helping each other to deal with safety and security issues by exchanging information, successful policies, and collaborating re-actively as well as pro-actively. My colleague, Prof. Reniers, tackles these cooperation issues within the chemical and process industries.

**It is estimated that annually 1700 people die in Dutch** hospitals unnecessarily. This is below the international figures. Still the number should be further reduced. The 1-page safe surgery checklist of the World Health Organisation of 2008 had a high impact on avoidance of preventable deaths in operating rooms (in the Netherlands and worldwide). The safety checklist has its origin in aviation, and still, also at Delft University, much research is carried out to optimize the checklist further.

**Developments such as DORA** (the Digital Operating Room Assistant) developed at the faculty of mechanical engineering, by Prof. Dankelman and colleagues, in which a large number of variables are being measured, including video recordings of the doctors, may help to bring the numbers further down. Apart from improving the safety of patients it also helps to increase the efficiency of the surgical process.

Big data is collected in the offshore industry by techniques such as intelligent pigging, but also in an ‘old-fashioned” way by divers.

The results of these type of inspections can be used to update the safety and reliability of the offshore structures. The earlier mentioned Bayesian techniques can also be applied here, as done by Professors Kaminski and Huijsmans.

Especially for security studies, big data is a blessing. The first attempt to model big data was by the Frenchman Guerry already in 1833, who was particularly interested in uncovering the relation between social and moral variables. How are personal crime and property related to each other, donations to the poor, wealth, and so forth? Although this was not really big data, it was a big data study avant la lettre.

**Nowadays, we go from a descriptive analysis** (based on reporting), to real time monitoring (camera’s, the citizen as interactive sensor) to early warning and predictive analysis (extrapolation and self learning systems), in which very big data, exa bytes (which is a megabyte of a megabyte of a megabyte) even up to zetta bytes are being processed. A quantum computer really would help here.

Large-scale deployment of autonomous technology, sensors and robotics can gather data by a vast array of sensors including omnidirectional cameras, optical character recognition, thermal imaging, air quality, machines can collect significant quantities of real world data providing organizations with historic and real time information, behavioral analysis, and user-defined alerts enabling improvements in intelligence and analytics, and ultimately serving to make better decisions.

**Not only land-based machines**, but also unmanned aerial vehicles or drones, the very small ones being developed at Aerospace Engineering, can be used to improve safety and security, by collecting big data.
Mass data collection is very helpful for safety and security scientists, but it may scare people because of privacy violations. If we look at camera surveillance in city centres, the standard way of detecting faces is by identification with so-called eigenfaces (based on Principal Component Analysis). Privacy preserving signal processing is possible which allows for the detection of criminals, without leaving the faces of innocent people in the data base.

This is what it looks like recognizing a face. Who’s in this photo? You will only know it if you know this person, otherwise not. In other words, the NSA, or other intelligence services can learn nothing from innocent people. Privacy preserving signal processing methods are being developed by one of the previous foundation day lecturers, Prof. Lagendijk.

The very last part of my presentation is related to ethics with an application to nuclear safety. Nuclear technology is everywhere, not only in power plants but also in hospitals, industry, research institutions, food industry, sterilization facilities for medical equipment and the conservation of cultural heritage; in other words it is embedded in our society. The nuclear sector was, in fact, one of the first sectors which conducted scientific safety studies in the 1970’s with the famous WASH-1400, ‘Reactor Safety Study’.

Recently at a Canadian reactor at Chalk River there were some uncertainties about its safety during a regular inspection and maintenance schedule. The nuclear regulatory committee decided the plant had to be closed. An ethical issue however came up, since the plant provided half of all medical radio-isotopes for hospitals worldwide and thousands of scans for patients had to be postponed. The Canadian parliament adopted an emergency law to open the plant again.

All of the above has shown that safety and security science is very much a multidisciplinary research area. Apart from engineering knowledge, also psychological, economical, and ethical knowledge is required. The research of safety and security science should be conducted multidisciplinary; if not, try an accident.

Delft University of Technology has built valuable and solid expertise in the field of safety and security in the past decades, which makes evidence-based safety design possible. I am convinced that new technological developments both on the preventive and repressive sides of the Bowtie, intelligent monitoring and a more adequate system of systems approach (connecting human factors, technology, organization, ethics, economy and law) will improve the safety of our society further in the decades to come.

Dear ladies and gentlemen. If attention for safety fades away, accidents and disasters emerge. Therefore I can only conclude with my mantra for the Dies 2014: Safety matters!

Ik heb gezegd.