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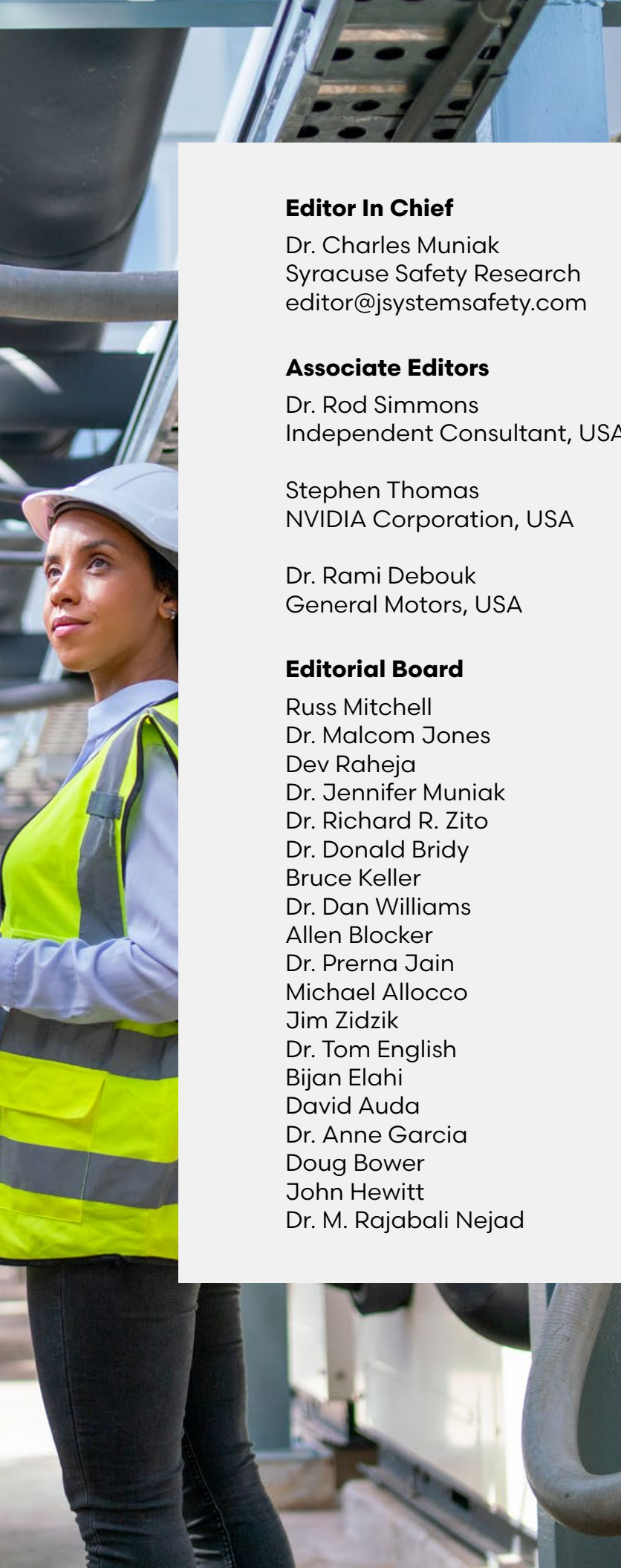
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Reduction of
Normalization of
Deviation (NoD) Using 16
a Socio-Technical
Systems Approach



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FROM THE EDITOR'S DESK

JSS Technical Editor | C.G. Muniak Ph.D.



AI TOOLS FOR SYSTEM SAFETY ANALYSIS?

It was not long ago that there were reports of students using AI applications to write assignments for school. Now it is common for engineers to use AI applications to help with engineering analyses and even to generate software. Some people are concerned as there are cases where AI makes up answers to questions (referred to as hallucinations). There are also situations when it is not clear how the model arrived at a particular answer. To be fair, I seem to remember some analyses generated by full blooded human beings that seemed to have made up answers and difficult to understand conclusions.

The first technical paper in this issue is "Augmenting an Incident Dataset with ChatGPT" by Jon Ricketts. The author uses a GPT model and rather than training it on even more labelled data it is further trained using human feedback, through reinforcement learning. This approach reduces some of the aforementioned problems with AI.

The second technical paper is "Reduction of Normalization of Deviation (NoD) Using a Socio-Technical Systems Approach" by Xidong Xu, Ph.D.; Richard Gardner, MS; Masood Karim, MS; Anthony Mixco, Ph.D., Mohammad Mojtahedzadeh, Ph.D.; John Palmer; Tom Sultze, MS; and Xiaoxi Wang, Ph.D.; David Jackson, MS; Mathieu King; Sam Chen; Xiaoyu Hu; Dennis Lee; Rey Tang; Jay Wang; Wei Yang, MS; Tim Zhu and Jibo He, Ph.D.

This paper describes a model developed by Boeing; this general systemic model of NoD (normalization of deviance) is based on a socio-technical systems approach. It is a representation of how multiple internal and external factors inherent to socio-technical systems interact in a dynamic fashion leading to NoD.

The TBD article by Charlie Hoes "Hydrogen versus Lithium Batteries for Energy Storage" describes the pros and cons of using hydrogen as an energy storage material.

Editor's Note: I apologize for the interruption in the publication schedule of the JSS. I believe that we are now back on track for a more normal frequency of JSS deliveries.

Charles Hoes, System Safety Engineer



For years, *TBD* has been a regular feature in the *Journal of System Safety*, covering key trends, insights, and updates in the world of system safety. Interestingly, *TBD* actually began as a placeholder title because we couldn't decide whether the column should have a specific "topic" or be more free-form. But as time went on, the title stuck because it's a reminder that system safety is an ongoing journey – to be determined. There's always more to learn, new challenges to tackle, and fresh insights to uncover. So every time you see *TBD*, think of it as a nod to the ever-evolving nature of safety science—where the work is never quite "done."

HYDROGEN VERSUS LITHIUM BATTERIES FOR ENERGY STORAGE

Currently the two best candidates for chemical energy storage are the two lightest metals – sort of. Lithium, a light highly reactive metal, it is the main component of the lithium batteries used to power many portable electronic devices and electric cars. Hydrogen is also a metal that at normal conditions is nonmetallic, but becomes a metal at high pressures (very high pressures). Both of these elements can be used to create efficient, light weight, high energy density electrical storage systems. However, from the safety and environmental (and cost) point of view they are very different.

It might be worth taking a few minutes to dispel some myths concerning the safety of hydrogen. Perhaps the first myth that needs to be dispelled is the popular idea that hydrogen is "extremely dangerous" as evidenced by the Hindenburg fire. Granted, the burning of the Hindenburg was a great tragedy and very spectacular, but it was not "just" a hydrogen fire as is widely reported. The fire resulted from a combination of factors, not the least of which was the use of highly flammable coatings on the fabric of the dirigible. There is a lot of debate concerning the details of the Hindenburg disaster, so many that a "true" story may never be told. However, it seems clear that the magnitude of the fire and speed of spread was a combination of the presence of very large quantities (over 7 million cubic feet) of highly flammable hydrogen gas and

the highly flammable covering.

When hydrogen burns the flame is almost invisible. The photographs of the fire clearly show very large colored flames. This means that something besides hydrogen was burning, and that "something" contributed greatly to the intensity and spread of the fire. The bulk of the hydrogen wasn't burning, and probably never did because it consisted of 100% hydrogen gas which requires mixing with oxygen in order to burn. It is my guess that most of the released hydrogen escaped into the atmosphere and mixed with air and diluted below the flammable range and therefore didn't ignite. Some of the hydrogen burned, but probably not all of it. The burning hydrogen may well have ignited the structural elements of the craft but it wasn't just a "hydrogen fire" – it was a fire that resulted from a complex interaction of many features of the design of the entire system. The Hindenburg was designed and built as a helium filled set of balloons. Switching to using hydrogen instead of inflammable helium resulted in an extremely dangerous situation. Hydrogen can be used safely, but only if done so properly – just as with any other energetic material.

One feature of hydrogen fires is that they don't radiate much infrared thermal energy; in fact they emit so little visible light and "heat" that workers in hydrogen facilities sometimes walk holding brooms in front of them so they can detect a large hydrogen fire before walking into the invisible flame. Hydrogen fires don't emit infrared energy that can cause flammable materials to catch on

fire at a distance from radiation. The Hindenburg fire probably spread as fast as it did because the brightly glowing particles from the burning structure emitted large amounts of infrared ("heat") energy that ignited unburned fabric well in advance of the flame front. My guess is that it spread so rapidly because the ignition was spread by thermal radiation reaching far in advance of the flame front.

While hydrogen gas can undoubtedly be quite dangerous, that does not mean that it is unacceptably dangerous, or as dangerous as other sources of high-density energy. For example, the Space Shuttle safely burned the equivalent of over 34 billion cubic feet of hydrogen (5,000 times the volume of the Hindenburg) during a launch. The risk isn't because of the use of hydrogen; it is HOW it is used. The Hindenburg had many serious design flaws with respect to the use of large quantities of hydrogen that almost guaranteed a disaster such as the Hindenburg fire. Gasoline is considered "acceptable" only because systems have been designed to effectively control the risks. Now and then a large, highly destructive gasoline fire occurs, but this is amazingly rare. It is my engineering judgement (as a System Safety Engineer) that hydrogen gas can be made much safer than gasoline, while they both clearly have significant risks. My point isn't that there are no risks; it is that the risks are comparable to, and often much less, than risks that we accept as a matter of course.

Hydrogen gas comes from many sources, some of which could be called "green" sources, and others not so green. Today, most hydrogen is made from "black" sources of hydrocarbons such as oil, coal or natural gas. There are also largely untapped sources of "white" hydrogen in underground naturally occurring, pockets of geological hydrogen. The most promising source of "green" hydrogen comes from the decomposition (electrolysis) of water into hydrogen and oxygen using power from non-polluting sources such as solar, wind, wave, hydroelectric or geothermal electrical generation systems. This approach uses hydrogen as a type of chemical battery where the energy can be stored in pressurized containers indefinitely until it is needed, at which point it is re-combined with oxygen to form water, releasing energy in the form of heat or electricity.

High capacity storage batteries (such as lithium batteries) are certainly not "safe" or

"environmentally friendly." They are highly dangerous both from the potential for them to burn or explode, and from the point of view of containing very large quantities of stored electricity. A major hazard with using high voltage, high capacity batteries in vehicles is related to what happens following an accident that damages the batteries and/or electrical system. The stored energy doesn't just "dissipate" it remains potentially resulting in an explosion or fire, or presenting a high power electrical hazard to first responders and the accident victims. Many interesting, and horrifying, scenarios are possible when these systems become damaged in unpredictable ways.

Perhaps the largest problems with the use of lithium batteries are related to the highly negative impact on the environment associated with mining, refining and disposing of the lithium and various other materials (including graphite, cobalt, manganese and nickel) used in the batteries. With the possible exception of cobalt, there are sufficient amounts of these materials to supply the short term future market, but mining and refining these materials come with substantial negative environmental impacts in terms of size of mining sites, potential for pollution and the use of large quantities of water. Lithium production is particularly problematic because it is found in low concentration surface deposits in arid regions necessitating the destruction of vast areas of environmentally sensitive desert. In addition, large amounts of water are required in the extraction/refining process that can damage already limited sources of surface and ground water.

The most likely use of energy storage in the near future will be to meet the demand for powering electric vehicles. Currently, the two most "market ready" approaches are using rechargeable lithium batteries or lightweight PEM (Polymer Electrolyte Membrane) Hydrogen Fuel Cells. Hydrogen can also be used directly to produce heat or run internal combustion engines, very similar to using natural gas. The airlines are currently doing a lot of research to design jet engines that can use hydrogen fuel in place of jet fuel. Internal combustion engines have made to work quite nicely using hydrogen fuel. Hydrogen is an extremely flexible fuel source that can fill many, if not most, of our current uses for gaseous and liquid fuels, and as a medium for electrical storage without the hazardous voltages inherent in the storage device presented by batteries.

I think most people have a grasp of how rechargeable batteries work, so I won't go into much detail here. The one thing that people might not be aware of is their tendency to catch fire and burn, or explode. These problems have been minimized, but not eliminated, with the current designs used in electric cars. PEM hydrogen fuel cells are generally unknown to the public. I want to briefly describe how they work.

My first encounter with a PEM fuel cell was in a small research laboratory at Humboldt State University (now Cal Poly Humboldt). The fuel cell was in the form of a cube about four inches on a side. It consisted of layers of graphite and a thin membrane resembling "plastic wrap." The graphite layers had been machined to form a serpentine groove allowing air or hydrogen to flow to the surfaces of the graphite layer. The thin membrane (the PEM membrane) was sandwiched between the graphite. It was impervious to relatively large hydrogen molecules, but the tiny amount of catalyst embedded into the membranes allowed the nucleus of hydrogen atoms (protons) to flow through to the other side of the membrane where it combined with the oxygen in air flowing through the other side, creating an electrical charge and thus an electrical current (emitting water as the only byproduct). The hydrogen was "dead headed" into the grooves at a pressure of around 1 psi. It didn't need to flow through the stack, it just needed to get to the surfaces. A small fan directed room air through the grooves on the "oxygen side" of the stack. The air flowed through the stack to maintain a steady source of oxygen and to exhaust the byproducts of this process (pure water vapor). During operation, the cell felt mildly warm. The striking part was the pair of 1/2 inch thick copper electrodes connected to each side of the fuel cell stack. They had to be that size because of the very large amount of power and electrical current delivered by the cell.

All of the large automobile manufacturers have PEM fuel cell cars ready to manufacture if, or when, the market turns to them. I have seen several of these vehicles by various manufacturers and they are beautiful. The fuel cell modules are around one cubic foot, taking up little of the space "under the hood" of the car. High pressure hydrogen storage tanks are located under the floor of the passenger compartment, similar to the location of batteries in electric cars. I have a friend that had the job of testing many of these cars on the roads

of California's highways, byways, deserts and mountains. He said they are wonderful to drive. I suppose just about the same as a modern electric vehicle, which they are.

One of the major advantages of PEM fuel cells for this application is that they are quickly scalable with respect to available sources of fuel. Very large quantities of hydrogen are created from various sources, including fossil fuels. At first this sounds bad, but it provides an easy means of transitioning to hydrogen while green sources of hydrogen are being created. We don't have to wait until enough "green" electrical power is available on the grid. In fact, electric cars change from the grid, they are not using "green" sources of power, they are just using whatever is there from whatever sources are available.

One of the best features of hydrogen as a fuel is that it can easily be made using solar, wind and other sources of "green" energy by the electrolysis of water. For example, solar electricity can be used to make hydrogen, which can then be stored for future use, or shipped via pipeline or tanker to where it is needed (such as filling stations). Not only can it be easily created, stored and transported, but it can be used for a variety of additional purposes to replace the use of hydrocarbons. If produced locally (such as at the site of a home solar system), the hydrogen can be stored for months until needed, or could be used to fuel an automobile during night time hours. Commercial airlines don't think they can use batteries because of weight restrictions, but they can store enough hydrogen – so they can join the "green" energy revolution by converting to hydrogen fuel.

The materials used in the construction of a PEM Hydrogen Fuel Cell system are mostly "normal" construction materials (iron, aluminum, copper) with a very small amount of catalyst similar in quantity to a catalytic converter in a car. All of these materials can easily be recycled and pose no new environmental threats.

The point of this is that we are at a point where hydrogen presents a very flexible and robust solution to moving toward a truly "green" energy economy, while batteries are just taking us down the normal path to excessive environmental damage.

IN MEMORIAM



DR. LOAN (JOAN) PHAM

Our distinguished colleague, Dr. Loan (Joan) Pham, passed away suddenly on August 16, 2023. This is a tragic and overwhelming loss to all who knew Joan, but she and her work will be remembered throughout the fields of system safety and aviation safety. Joan was born in Vietnam in 1968, and at age seven, she was separated from her family while escaping the communist takeover. Eight years later they were reconnected, and she came to the US just before high school with minimal knowledge of the English language. She became a brilliant and hardworking student, receiving a B.S. in Core Mathematics and M.S. in Statistics at Purdue, and a Ph.D. in Industrial and System Engineering at Rutgers – a rare combination of degrees that prepared her for the unique position that she held at Sikorsky, a Lockheed Martin company.

Joan began her career as a research assistant at the Federal Aviation Administration while a doctoral student and upon graduation, she became a member of the Technical Staff at Lucent Technologies (formerly Bell Laboratories). Dr. Pham faced the daunting challenges of a young Asian woman entering a workplace dominated by older men, but her success in overcoming the challenges of her early life and her educational accomplishments provided confidence to surmount these new obstacles. Through dedication and persistence, her knowledge and intellect became

evident, and she became accepted and eventually recognized for her contributions in aviation safety risk management. Dr. Pham became an industry leader in quantitative risk assessment based on reliability theory and mathematical processes. She co-authored more than a dozen technical papers, presented many tutorials at conferences and symposia, and she participated on the Systems Engineering committee and the Safety committee of the Vertical Flight Society. Joan served as a session chair and was the current Deputy Chair of the Systems Engineering committee. In 2021, Dr. Pham was named a Lockheed Martin Associate Technical Fellow.

She served as a patient and thoughtful long-term mentor to many individuals who demonstrated interest in her quantitative risk assessment processes, and on an ad-hoc basis to personnel at the Federal Aviation Administration and other organizations.

Joan received many awards, including the Society of Asian Scientists and Engineers Professional Achievement Award in 2022, and she was scheduled to receive the Scientific Achievement Award from the International System Safety Society on August 28, 2023. Mike Cerneck, Director, Aviation & Product Safety, accepted the award on her behalf, and the award plaque was given to her husband Tinh at her funeral service. As one colleague said, “the world is a better place because of Joan.”



Augmenting an Incident Dataset with ChatGPT

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natural language processing, incident reporting, semantic search, hazard identification

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ABSTRACT

The field of Natural Language Processing (NLP) is evolving at a rapid rate, impacting ways of working across multiple industries including that of System Safety. One area of NLP is the development of advanced language models, notably ChatGPT—which is essentially a powerful artificial intelligence chatbot powered by a large language model. This paper takes an incident report dataset and augments it with ChatGPT to improve searching capability and provide answers to safety related queries. It is shown that incident datasets can be further adapted for knowledge retrieval to support safety queries, however, a major limitation to deploying this method elsewhere are data protection policies. The underpinning vector database (used to retrieve relevant incident reports) demonstrated a useful semantic search ability for more accurate and meaningful searches of incident datasets. It is considered that if the outputs provide evidence or sources behind answers, and are used for advisory purposes then they can form useful tools for information and knowledge retrieval in System Safety.

ABBREVIATIONS

AI	Artificial Intelligence
ACN	ASRS Record Number
ASRS	Aviation Safety Reporting System
GPT	Generative Pre-trained Transformer
LLM	Large Language Model
NLP	Natural Language Processing

INTRODUCTION

ChatGPT (developed by OpenAI) is a powerful Artificial Intelligence Chatbot that is underpinned by Large Language Models (LLM) (OpenAI, 2023). At the time of writing, it had received extensive media coverage with its ability to provide answers to questions, conversational dialogue and even produce computer code in response to specific requests. However, ChatGPT is not perfect and can provide hallucinations (providing incorrect but plausible outputs), generate verbose responses, and only having been trained on data present up until 2021 (Chatterjee et al., 2023).

This paper explores the augmentation of an incident report dataset with ChatGPT for System Safety, notably utilizing it to support typical queries asked during safety assessment activities. The data selected for this paper is an extract of publicly accessible Aviation Safety Reporting System (ASRS) reports that describe accidents and incidents revealing causes, consequences and hazards. The ability to interface with such a large repository of information in a human-like way could be of real benefit to safety practitioners, unlocking knowledge that would otherwise only be revealed through targeted lexical searches.

Knowledge comprises of structured and organized information after cognitive processing and verification (Duan et al., 2017). It is a key component when undertaking a safety assessment (e.g., performing hazard identification) where lessons learnt from previous incidents can be incorporated into a system, further improving safety going forward.

This paper is structured as follows; the Background section provides a brief overview of ChatGPT, the ASRS incident reporting database and knowledge within safety assessment. The next section describes how ChatGPT was utilized for System Safety, before the Results section provides sample responses from the newly adapted ChatGPT. The Discussion examines the results, highlighting issues and limitations for future work.

BACKGROUND

CHATGPT

This section aims to provide a high-level overview of ChatGPT.

Human language is complex, comprising of a catalogue of words (lexicon) alongside structural rules (grammar) allowing meaning when combining the words into sentences (Manning et al., 1999). As such, human language presents a challenge for developing accurate NLP systems. The ongoing advancement of NLP has seen the deployment of more advanced machine learning and AI techniques to solve NLP tasks.

ChatGPT adapts a machine learning model; Generative Pre-trained Transformer (GPT) for dialogue, providing a conversational ability with humans.

GPTs are a type of LLM that consist of a neural network that uses self-attention to process sequential data. They can typically be fine-tuned for various natural language tasks such as translation or text classification. LLM is a term used to describe large pre-trained language models, where the larger scale model or increased data size demonstrates model improvement (Shanahan, 2022).

ChatGPT takes an existing GPT model and rather than training it on even more labelled data (a resource intensive task) it is further trained using human feedback, through reinforcement learning. This helps reduce some of the undesirable outputs such as (OpenAI, no date):

- Hallucination – Where the model makes up responses.
- Bias – Output of toxic responses.
- Poor interpretability – It is unclear how the model arrived at a given response.

Although this process does not entirely mitigate the issues above, it should reduce them.

ASRS DATABASE

ASRS is an incident reporting system that allows those involved within aviation to report aviation incidents. Its purpose is to collect, analyze, and respond to voluntarily submitted aviation safety incident reports to lessen the likelihood of aviation accidents (NASA, no date).

Incident reports, as a large body of structured data represent a significant source of knowledge, which help to;

- Understand why accidents do not occur (Johnson, 2003).
- Provide insight into system failures, human error and regulatory weakness (Van der Schaff, 1991).
- Promulgate learning from experience.

ASRS contains a publicly available database of de-personalised reports available to researchers—it is this database that this paper utilizes.

KNOWLEDGE WITHIN SAFETY ASSESSMENT

Conducting safety assessments draws together a number of components, some of which are shown in Figure 1.



Figure 1: Safety assessment components

One of the core attributes is the identification of hazards in the system and evaluating possible scenarios which lead to unwanted consequences. The identification of hazards is paramount, as no action can be taken to design out, avoid, or reduce the effects of unidentified hazards. A number of structured and systematic techniques exist for identifying and evaluating hazards. For

example, in the civil aerospace domain Functional Hazard Analysis (FHA) are recommended to identify the scope and criticality of functional failures; then analyses such as Fault-Tree Analysis (FTA), Failure Modes and Effects Analyses (FMEA), and Common Cause Analysis (CCA) methods are recommended as suitable analyses for safety certification (Society of Automotive Engineers, 1996). To reliably conduct these techniques, useage data and knowledge is required.

Incident datasets such as ASRS provide a vast source of information that can supplement individuals’ knowledge when undertaking a safety assessment. The definition of given risks is conditional upon knowledge (Aven et al., 2018). The introduction of ChatGPT provides an option to ‘unlock’ this knowledge when conducting safety assessments. This may be through improved searching of data or providing specific answers to queries. The ability to have a ‘fuzzy’ search engine (to some extent can be fulfilled by ChatGPT) within incident databases has previously been suggested (Kletz, 2008).

The usefulness of such a system goes beyond safety assessment support to assisting accident investigations and safety management system monitoring.

AUGMENTING ASRS WITH CHATGPT

The following section describes how ASRS data was augmented with ChatGPT, using the methodology and Python code described by Briggs (2023) as a guide.

Rather than ask ChatGPT specific questions that it is unlikely to answer, a method called Retrival Augmented Generation is applied. This takes the user’s query, to search (and retrieve) relevant reports from the ASRS data, then provides these with the query to ChatGPT. With this additional context of ASRS reports, ChatGPT should be able to answer the query. The general process in relation to the original ChatGPT querying process is shown in Figure 2.

A publicly available dataset of ASRS reports collated by Hoole (2022) was used for this paper, where each report was condensed to its unique identification, report date, narrative and synopsis. For this paper the dataset was filtered to only

include reports for the Boeing 737 (all models) which totalled 5136 reports.

Initially, this dataset was used to build a vector database. A vector is an array of numbers, representing more complex objects such as ASRS reports in a continuous high dimensional space—forming embeddings that map the semantic features of the reports. Embeddings can then be used for in machine learning applications such as searching relevant reports.

The vector database was hosted by Pinecone software (<https://www.pinecone.io/>) which indexes and stores the report embeddings for similarity searching and fast retrieval. Once each ASRS report is assigned a vector then nearest

neighbours (similar reports) can be easily found against a user query, therefore allowing a semantic search capability revealing knowledge that would otherwise have been difficult to find through traditional lexical (key word) searches.

With the vector database constructed, code can be produced to take a user query, search the vector database, retrieving relevant reports before feeding these reports (as context) and the original query to ChatGPT to provide an answer.

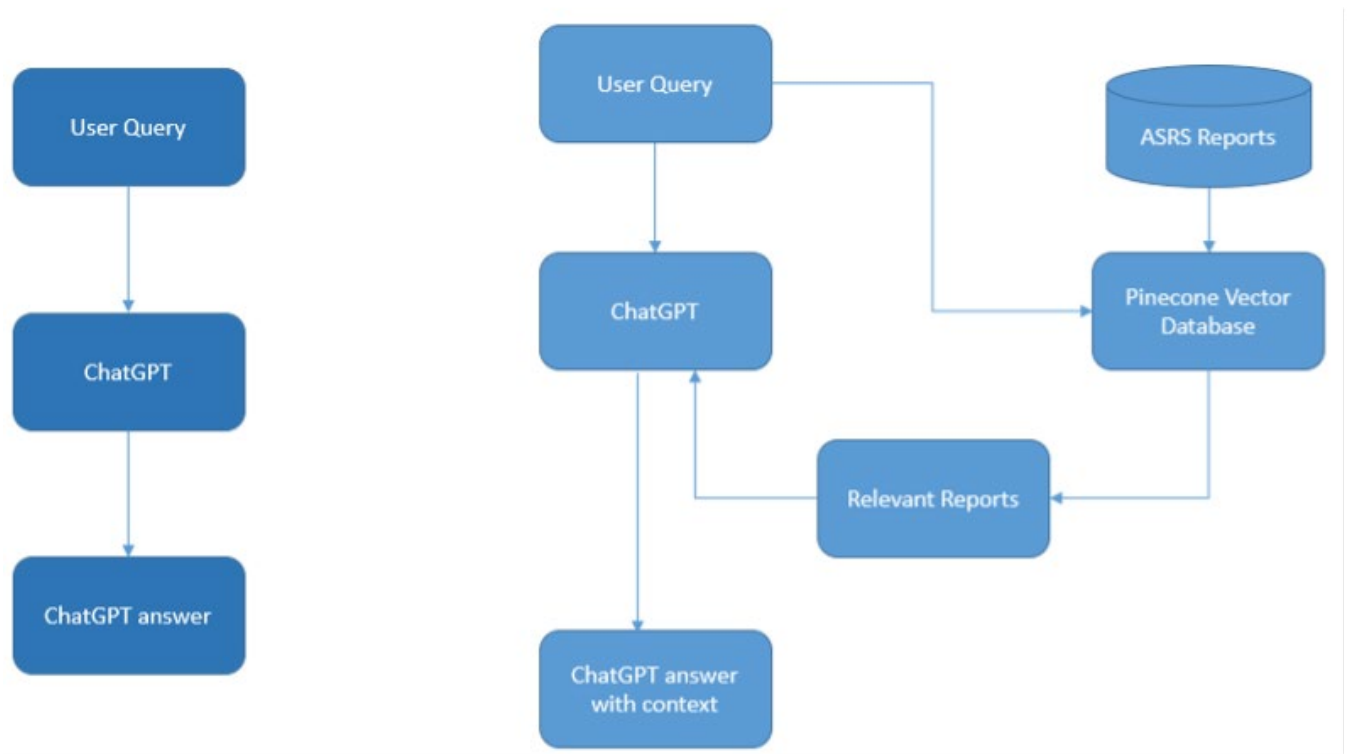


Figure 2: Original ChatGPT query process (shown on the left) alongside the Retrieval Augmented Generation process (depicted on the right)

RESULTS - SAFETY ASSESSMENT SUPPORTED BY CHATGPT

To assess the usefulness of the newly developed framework, a number of general queries can be run.

For example, a simple query was presented to the original ChatGPT; “has the aircraft ever had a fuel leak?” to which ChatGPT responded with; “No, the Boeing 737 has never had a fuel leak. The aircraft has an excellent safety record and has been in service since 1967.” Clearly, this is highly unlikely, plus ChatGPT goes further to state the aircraft has an excellent safety record, failing to account for 219 hull losses of the type (Aviation Safety Network, no date).

The same query was presented to the Retrieval Augmented Generation method described in the previous section. In this instance, two reports featuring fuel leaks (ACN 1782088 & 1070068) were retrieved and provided to ChatGPT as a context, allowing ChatGPT to respond with; “Yes, the aircraft has experienced fuel leaks on two occasions. The first instance was reported by the B737-800 pilot who refused the aircraft due to fuel leaking from the refuel manifold, which was later found to be caused by rag/cloth fragments preventing proper closure of the valve. The second instance occurred during a flight, where fuel was observed spraying from the right wing near the winglet area. The pilot suspected a fuel leak, declared an emergency, and returned for landing. However, upon landing, the airport rescue and firefighting (ARFF) team did not observe any fuel leaking”.

It can be seen, for the example query above, that the accuracy of ChatGPT’s responses has greatly improved with Retrieval Augmented Generation. The retrieval of similar reports matching the query is a useful tool in itself, ChatGPT provides the further step of summarising the retrieved reports and providing a human-like response.

A greater challenge is provided when asking questions to hypothesize what could happen (e.g., “What if?” questions asked during a safety assessment). A new query was created; “What are the consequences of a hydraulic failure?” to which ChatGPT responded with “Based on the context

provided, it appears that the narrator, who is the pilot-in-command (PIC), and their first officer were dealing with a hydraulic issue on their aircraft during a flight. They noticed a loss of A hydraulic fluid but could not find any leaks. They monitored the hydraulic level closely and observed a small loss during the flight. They requested maintenance assistance, performed checks, and shut off the A engine driven pump to prevent further loss of hydraulic fluid. They also switched the autopilot to the first officer’s side without informing them, which caused a breakdown in crew coordination. They communicated with dispatch and maintenance, and eventually decided to divert to their destination due to the need for significant maintenance. The narrator reflects on the need for better communication with their first officer, the importance of considering all possibilities in a situation, and the possibility of declaring an emergency. They also acknowledge the diligence of the mechanics and suggest checking aircraft for possible issues even if no leaks are found after hydraulic servicing”. Some useful information is provided, however, a list of possible consequences would be a better answer rather than a summary of reports mentioning hydraulic leaks.

In this case, the code was written to return the two closest matching reports. An instant improvement would be to return a greater number of matching reports, providing more context to ChatGPT and improving the response (i.e., removing the reference to fuel leaks on two occasions, as there are almost certainly more).

DISCUSSION

This paper has demonstrated the augmentation of an incident dataset with ChatGPT for safety-specific question and answering.

Where this paper used publicly accessible ASRS reports, future versions could equally use alternative data sources such as collections of safety assessment reports or other incident datasets (or a mixture). However, this is where a key limitation is found with data privacy. ChatGPT is accessed via an Application Programming Interface (API), therefore the data is submitted to a third party, although it is not a problem for data in the public domain. Sensitive data with personal details or restrictive data policies (e.g., government

data) cannot be utilized in this way.

A deeper risk remains around over-reliance on such tools within System Safety settings. In the context of this paper, it might lead to the user blindly believing the output of the model—however, if the model is set-up in such a way to show the source/evidence of its answer then that can alleviate this risk (e.g., extracts and references to ASRS reports).

Where ChatGPT could answer general safety-type questions (e.g., has there been a fuel leak?), it struggled with hypothetical questions, where knowledge is required to answer. This is most likely due to the data used to train ChatGPT not being inclusive of typical safety text such as incident reports, safety assessment reports, etc. A potential solution to this is to investigate bespoke LLMs which have been trained on large quantities of safety text, therefore accounting for unique terminology and context.

The vector database used to provide reports relevant to the user query shows promise without the additional ChatGPT feature. The database could easily be used to underpin a semantic search ability for more accurate and meaningful searches of incident datasets.

A further consideration are the costs associated with running a bespoke question and answering service. The main computational components are the creation of the word embeddings (OpenAI) and vector database (Pinecone). Both have costs; where the generation of embeddings had a one-off cost of \$3 and maintaining a vector database costs \$70 per month. For a year, this would cost ~\$840. For a large organization with a lot of data, this might be an easily absorbed cost, especially considering the cost of alternative manual methods. For the smaller organization, this represents an additional burden.

A wider public concern is how ChatGPT will impact jobs and how disruptive will it be? For System Safety, the author does not envisage ChatGPT (or similar technology) replacing safety practitioners, rather forming an efficient tool to use for common safety tasks, such as supporting safety assessments. If the system is set up in such a way to provide evidence for outputs then it should allow for the user to gain more trust. Where Microsoft has invested in OpenAI, there are plans to incorporate technology such as

ChatGPT into everyday Office products (Zhao et al., 2023)—methods like what is described in this paper may soon be commonplace. Therefore, it is likely that safety practitioners will require basic knowledge in AI, plus the benefits and limitations going forward.

CONCLUSION AND FUTURE WORK

This paper has taken an incident dataset and augmented it with ChatGPT to support safety assessment and general safety queries. It has been shown that ChatGPT can be further utilized for knowledge retrieval to provide general safety assessment support, however, a major limitation to deploying this method elsewhere are data protection policies. It is proposed if the model is setup so that outputs provide evidence or sources behind answers, and are used for advisory purposes then they can form useful tools for System Safety practitioners.

Future work may consider further trials of this concept, perhaps even in actual safety assessment tasks. The creation of bespoke datasets for safety tasks would also allow machine learning models to be fine-tuned on safety-specific data, therefore, improving accuracy when supporting System Safety tasks.

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COMPETING INTERESTS

No Competing Interests.

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Reduction of Normalization of Deviation (NoD) Using a Socio-Technical Systems Approach

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ABSTRACT

Normalization of deviation (NoD), also known as normalization of deviance, is the process in which deviations from correct or proper decisions, behaviors, or conditions important for safety insidiously become the accepted norm over time. NoD is a common, risky, yet elusive issue causing or contributing to numerous accidents in multiple industries. Effective reduction of NoD is therefore a major opportunity. Approximately 10 years ago, Boeing developed a general systemic model of NoD based on a socio-technical systems approach. It is a representation of how multiple internal and external factors inherent to socio-technical systems interact in a dynamic fashion leading to NoD. It holistically captures the essence and complexity of the problem. The model has been shared across Boeing and with three customer airlines of Boeing. Specific systemic models of NoD associated with specific problems were developed based on the general systemic model. Subsequently, NoD awareness training, methods, tools, processes, and solutions based on those models have been developed. They were provided and/or used to improve workplace safety at Boeing and aviation safety at one of the three airlines. All the efforts have resulted in unprecedented insights, and some have seen significant reduction of NoD, NoD-related incidents, and NoD-related safety risks.

INTRODUCTION

Professor Dianne Vaughan, a sociologist at Columbia University, coined the term of normalization of deviance (Vaughan, 1997). It is also known as normalization of deviation (NoD). She described NoD as a situation where "... people within the organization become so much accustomed to a deviant behavior that they don't consider it as deviant...The more they do it, the more they get accustomed" (Vaughan; see Consultant, 2008). NoD is a common, risky, yet elusive issue having caused or contributed to numerous accidents in multiple industries. For example, NoD was a major factor that contributed to both the Space Shuttle Challenger disaster (Vaughan, 1997) and the Columbia disaster (Columbia Accident Investigation Board, 2003). As another example, "On May 31, 2014...a Gulfstream Aerospace Corporation G-IV, N121JM...crashed after it overran the end of runway 11 during a rejected takeoff...before initiating takeoff, the pilots neglected to perform a flight control check that would have alerted them of the locked flight controls...the pilots had neglected to perform complete flight control checks before 98% of their previous 175 takeoffs in the airplane, indicating that this oversight was habitual and not an anomaly" (National Transportation Safety Board, 2015, p. vii). Given the commonality, the high risks involved, and the elusiveness, effective reduction of NoD is a major opportunity

This paper is a summary of how Boeing developed a general systemic model of NoD, how it has been shared across Boeing and with several customer airlines of Boeing, how a number of specific systemic models of NoD associated with specific problems were developed, how risk mitigation solutions have been implemented within Boeing and one of the airlines, along with the insights and impact that those efforts have resulted in. There have been many Boeing projects or efforts devoted to reducing NoD, and only some of them are reported in this paper.

DEVELOPMENT OF A GENERAL SYSTEMIC MODEL OF NOD

Since the publication of Professor Vaughan's book (Vaughan, 1997), much attention has been paid to the problem across the industries and the academia—at the time of writing this paper, Google searches after entering "normalization of deviance" and "normalization of deviation" yielded approximately 1.22 million and 1.94 million results, respectively. Approximately 10 years ago, we started to develop a general systemic model of NoD based on a socio-technical systems approach after a comprehensive and thorough review of the literature related to NoD. Over the last few years, the model has been updated through several iterations. The model reflects the following characteristics of NoD causation:

- Often, NoD is caused by complex non-linear interactions among multiple factors inherent to a socio-technical system such as a manufacturer and an airline. Those factors are human, technical, environmental, organizational, and external factors. As a part of the human factors involved, cognitive biases (in particular, complacency) play an important role in the NoD causation.
- Further, the systemic NoD causation evolves over time. For example, if the first-time deviation does not cause an accident, it may reduce the perceived safety risk leading to another deviation, which may further reduce the perceived safety risk if there is still no accident yet.
- The process is insidious. That is, typically the problem develops gradually with a long period of time between the first deviation and a tangible consequence.

The model is a general model because it captures the essential characteristics of the NoD causation that are applicable across multiple situations and circumstances across multiple industries. Because the model is a representation of how multiple factors inside and outside a socio-technical system interact with each other causing the NoD problem, it is also a systemic model. It follows that because of the systemic nature of NoD causation, there need to be systemic solutions addressing multiple factors instead of only one solution focusing on one factor. For example, making workers and managers aware of the safety risk involved in NoD alone may not be sufficient to stop NoD if other factors (e.g., rewarding individuals that exhibit the NoD behaviors) are still contributing to the problem.

SHARING OF THE GENERAL SYSTEMIC MODEL OF NOD

Over the last few years, the general systemic model of NoD has been shared and the systemic NoD reduction solutions have been advocated across multiple Boeing business units, functions, and executive levels, as well as the Boeing technical fellow community and many other parts of the Boeing workforce. Training has been provided in many organizations at Boeing on the general systemic NoD model and the systemic NoD reduction solutions. Highly positive feedback has been received. For example, many indicated that the training was among the best provided from the perspective of Go for Zero, which is Boeing's initiative to significantly improve workplace safety. Further, multiple courses on the model and systemic solutions have been developed and taught at Boeing.

Under customer services general terms agreements (CSGTAs), the general systemic model of NoD has been shared with three airlines in the form of presentations and training. Pilots, mechanics, safety analysts, managers, and other personnel in those organizations have benefited from the knowledge. The knowledge sharing with one of the airlines is part of a collaborative project with the company (see the next section of this paper for more information regarding the project).

DEVELOPMENT AND APPLICATIONS OF SPECIFIC SYSTEMIC MODELS OF NOD

Based on the general systemic model of NoD, a number of specific systemic models of NoD were developed such as those associated with disuse of material handling equipment (MHE) at Boeing, landings outside touchdown zones at an airline, and continuation of unstable approaches at another airline. Then, NoD awareness training, methods, tools, processes, and solutions were developed. They were provided and/or used to improve workplace safety within Boeing and aviation safety at one of the three customer airlines. It needs to be noted that which of them were provided and/or used depended on the specific NoD problems that needed to be tackled; that is, not all of them were used for every NoD reduction project or effort.

IDENTIFICATION OF FACTORS LEADING TO NOD IN DISUSE OF MATERIAL HANDLING EQUIPMENT (MHE)

Use of MHE is a proven way to prevent ergonomic injuries. However, MHE in some of Boeing's manufacturing processes was not used under some circumstances leading to NoD, contributing to accidents and injuries. Disuse of MHE occurred more often on some programs than in others. A specific systemic model of NoD associated with disuse of MHE was developed. It was then used to guide the identification of the factors that caused and contributed to the NoD problem. Unprecedented insights were revealed regarding how multiple factors interacted with one another in a dynamic and complex manner leading to the NoD problem.

MITIGATION OF RISKS FROM NOD ASSOCIATED WITH HUMAN-ROBOT INTERACTIONS

This project examined how human operators interacted with robots, which were deployed to assemble fuselages. The human operators needed to "monitor" and "supervise" the robots. Observations and interviews were conducted to collect data as to whether and what factors might cause NoD from operating procedures. A specific systemic model of NoD was developed based on the data. Similar to the MHE study outlined above, insights were discovered as to what caused the NoD, how, and why, much of which were not available previously. Subsequently, multiple solutions guided by the model have been implemented and results have shown significant reduction of the NoD beyond those by using traditional methods.

NOD AWARENESS TRAINING, NOD SURVEYS, AND NOD CHECKLIST FOR REDUCING NOD AND NOD-RELATED WORKPLACE INCIDENTS

In 2018, a Boeing NoD reduction project team collaborated with five different work teams at Boeing. First, the project team provided NoD reduction training to the five teams including an introduction to a NoD checklist, which was developed based on a specific systemic model of NoD. Right after the training, the five teams participated in a NoD survey (based on the same specific systemic model of NoD), which baselined any potential existing NoD behaviors in the teams and whether multiple factors (other human factors, technical factors, environmental factors, organizational factors, and external factors) contributed to NoD. The baseline was designated as the “before use of checklist” time period. The project team analyzed workplace incident data from the five teams associated with the “before use of checklist” time period to identify how many of the incidents or near misses involved NoD. The five teams then used the NoD checklist for approximately one and half months. After this time passed, the five teams participated in a second NoD survey related to the “after use of checklist” time period. Then the project team analyzed workplace incident data from the five teams associated with the “after use of checklist” time period. The survey results indicate that the “after use of checklist” NoD behaviors reduced compared to the “before use of checklist” NoD behaviors, so did contributions to NoD from the multiple factors. The results of the workplace incident data analysis show that the number of “after use of checklist” incidents or near misses involving NoD has also reduced relative to the “before use of checklist” ones.

In 2019, two teams (different from those five in 2018) participated in a NoD survey. Data were collected and analyzed. Solutions, including systemic NoD reduction training and use of a systemic NoD reduction checklist, were implemented. In 2020, five additional teams participated in the survey. Data were collected and analyzed and solutions were implemented. The NoD surveys deployed in those projects were part of assessment of a negative safety culture, which complemented assessment of a positive safety culture.

ANALYSIS OF RUNWAY OVERRUN RISKS FROM NOD IN LANDINGS OUTSIDE TOUCHDOWN ZONES

Globally, landing accidents made up 26% of fatal accidents from 2011 to 2020. NoD has been involved in a major type of landing accident—runway overruns. Percentage of landings outside touchdown zones was used as a key indicator of actual runway overrun risks at an airline. The green oval and the red oval in Figure 1 illustrate landings inside and outside touchdown zone, respectively. A specific systemic model regarding NoD involved in the landings outside touchdown zones was developed and six hypotheses based on the model were generated:

- H1 (Hypothesis 1): Repeated landings outside touchdown zones without causing runway overruns reduced flight crews’ perceived risks;
- H2: Flight crews’ reduced perceived risks reinforced further landings outside touchdown zones increasing the actual risks;
- H3: The perceived risks increased soon after several overruns;
- H4: The ensuing inventions reduced the actual risks;
- H5: The resultant time without overruns gradually reduced the perceived risks;
- H6: The reduced perceived risks have caused an increase in the actual risks and may cause future overruns.



Figure 1: Landings inside and outside Touchdown Zone.

The data on percentage of landings outside touchdown zones show the hypotheses are partially supported in that the actual risk parts of the hypotheses are consistent with the data. Data regarding the perceived risks were not available to test the perceived risk parts of the hypotheses. Recommendations were made on actions to be taken (e.g., NoD reduction training, NoD survey, and NoD checklist) based on the partially supported hypotheses.

SYSTEMIC REDUCTION OF SAFETY RISKS FROM NOD IN CONTINUATION OF UNSTABLE APPROACHES

If unstable approaches occur, flight crews are required to follow standard operating procedures (SOPs) to execute go-arounds. However, often unstable approaches are continued (see Figure 2). Several studies have shown that only 3-4% of unstable approaches ended up with go-arounds (e.g., Rosenkrans, 2015; Smith & Curtis, 2013). In other words, the majority of them were continued, representing one of the major safety risks across the aviation industry. This has been viewed as a NoD problem (IATA, IFALPA, IFATCA, & CANSO,

2017). A Boeing team and a professor in China developed a systemic model of NoD associated with continuation of unstable approaches. The team has been collaborating with an airline in China on this topic since March 2022. The following steps have taken place:

- Approximately 320 pilots participated in a NoD survey, which was based on the specific systemic model of NoD, to reveal what factors contributed to the NoD problem and to what degree.
- 18 pilots participated in NoD interviews to lead to a deeper understanding of the factors that contributed to the NoD problem.
- The data from the NoD survey and interviews were analyzed.
- Based on the survey and interview data analyses, the Boeing team and the airline identified solutions to reduce the NoD and prioritized the solutions based on their urgency and resources available.
- Most of the agreed-upon solutions have been implemented.

Results of Quick Access Recorder (QAR) data analysis indicate that after the implementation of

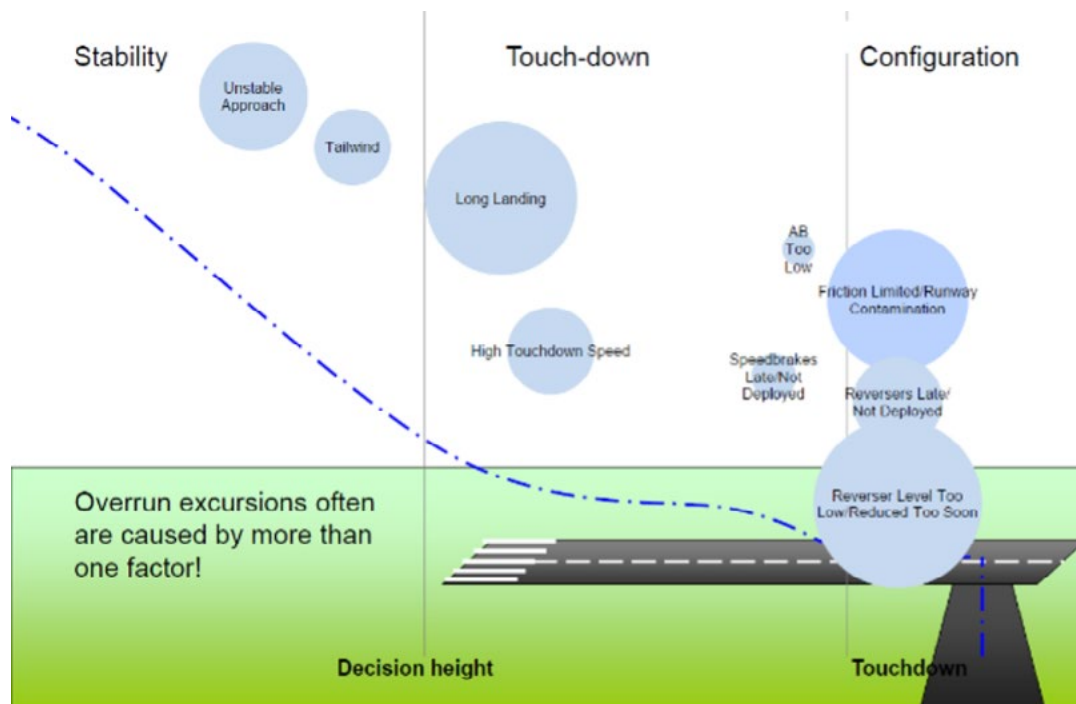


Figure 2: Approach and Landing (the Boeing Company, 2017, Slide3).

the solutions, there has been a significant increase in the percentage of the go-around after the start of unstable approaches (i.e., significant decrease in the percentage of continuation of unstable approaches). The results suggest a significant reduction in the NoD-related safety risks.

CONCLUSION

Normalization of deviation (NoD) is a common, risky, yet elusive issue in safety across multiple industries. Therefore, successful NoD reduction represents a major opportunity. A general systemic model of NoD has been developed at Boeing, which captures the complex, non-linear, and dynamic interactions among multiple factors inherent to a socio-technical system that cause NoD. The model has been extensively shared across Boeing and with three customer airlines of Boeing. Based on the general model, specific systemic models of NoD have been developed to solve specific NoD problems. Subsequently, NoD awareness training, methods, tools, processes, and solutions based on those models have been developed. They were provided and/or used to improve workplace safety at Boeing and aviation safety at one of the three airlines. All those efforts have resulted in unprecedented insights—how multiple factors inside and outside a socio-technical system interact with one another in a complex non-linear fashion leading to the NoD problems. Some of those efforts have seen significant reduction of NoD, NoD-related incidents, and NoD-related safety risks.

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COMPETING INTERESTS

No Competing Interests.

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The International System Safety Society

is a non-profit organization of professionals dedicated to the safety of systems, products and services through the effective implementation of the system safety concept. Under this concept, appropriate technical and managerial skills are applied so that a systematic, forward-looking hazard identification and control function becomes an integral part of a project, program or activity at the planning phase and continues through the design, production, testing, use and disposal phases.

The Society's Objectives

- Advance the art and science of system safety
- Promote a meaningful management and technological understanding of system safety
- Disseminate advances in knowledge to all interested groups and individuals
- Further the development of the professionals engaged in system safety
- Improve public understanding of the system safety discipline
- Improve the communication of system safety principles to all levels of management, engineering and other professional groups

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Through its local chapters, committees, executive council, publications and meetings, the Society provides many opportunities for interested members to participate in a variety of activities compatible with Society objectives.

Publications

- Journal of System Safety is the official Society journal. Published three times a year, JSS is a peer-reviewed scholarly journal that keeps members informed of the latest developments in the field of

system safety.

- Chapter newsletters are published periodically to disseminate news of chapter activities and items of interest to chapter members.
- Proceedings of Society-sponsored conferences and symposia are made available to members at a special discount.

Events

- International System Safety Summit & Trainings are sponsored annually. These events have proven to be a very popular and effective means for highlighting the latest techniques, applications and social/egal aspects of system safety.
- Mini-symposia are sponsored by local chapters to provide an indepth exploration of a specific system safety-related topic.
- Chapter dinner meetings, field trips and panel discussions are held at intervals throughout the year.
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