CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences

Department of Air Transport

Modelování situačního povědomí pilotů v událostech typu runway incursion

Modeling Pilot Situational Awareness in Runway Incursions

Bachelor's Thesis

Study Programme: Technology in Transportation and Telecommunications

Study Field: Professional Pilot

Thesis Supervisors: doc. Ing. Andrej Lališ, Ph.D., doc. Ing. Bc. Vladimír Socha,Ph.D

Joshua Nicholas Ramos

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Zásady pro vypracování

Při zpracování bakalářské práce se řiďte následujícími pokyny:

- Cíl práce: Analýza možností modelování situačního povědomí pilotů v událostech typu runway incursion s pomocí Interface Theory of Perception (ITP)
- Analyzujte události typu runway incursion a jejich faktory v letectví
- Vyberte a analyzujte konkrétní letovou proceduru na Pražském letišti, ve které se dějí události typu runway incursion
- Aplikujte ITP na konkrétní scénář runway incursion na Pražském letišti
- Dosažené výsledky vyhodnoťte a poduďte z pohledu jejich využití pro studium fenoménu runway incursion

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b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

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BACHELOR'S THESIS ASSIGNMENT

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Guides for elaboration

During the elaboration of the bachelor's thesis follow the outline below:

- Thesis goal: Analysis of the Modelling Possibilities for Pilot Situational Awareness in Runway Incursions with the Interface Theory of Perception (ITP)
- Analyze runway incursions and their contributory factors in the aviation
- Select and analyze flight procedure at Prague Airport where runway incursions occur
- Apply the ITP on selected runway incursion scenario at Prague Airport
- Evaluate the results and their usability for studying the runway incursion phenomenon

Graphical work range: according to the instructions of thesis supervisor

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Bibliography:

D. Hoffman, M. Singh, Ch. Prakash. The Interface Theory of Perception. Psychon Bull Rev 22, 2015.

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I confirm assumption of bachelor's thesis assignment.

Joshua Nicholas Ramos
Student's name and signature

Prague .... October 8, 2020

DECLARATION

I hereby submit for assessment and defense a bachelor's thesis, prepared at the end of my studies at the Czech Technical University in Prague, the Faculty of Transportation Sciences.

I do not have a compelling reason against the use of this school work within the intention of s. 60 of the Act No. 121/2000 Coll., on Copyright and Rights Related to Copyright and on Amendment to Certain Acts (Copyright Act).

I declare that I have elaborated this thesis independently using information sources listed in the bibliography in accordance with ethical guidelines for writing diploma thesis which are listed on the document Methodological Instruction No. 1/2009.

In Prague on 08.08.2021 ....

Joshua Nicholas Ramos

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ABSTRAKT

Teorie percepce rozhraní (Interface Theory of Perception) představuje nový způsob pohledu na lidskou percepci tím, že vnímání člověka odděluje od skutečné reality. Předložená práce se zabývá možností využití této teorie jako nástroje pro šetření událostí typu nepovolený vstup na vzletovou a přistávací dráhu (runway incursion) na letišti Václava Havla v Praze. Dělá to s využitím tzv. redukovaných vědomých agentů (reduced conscious agents) vytvořenými v souladu s teorií percepce rozhraní. V této práci byla vytvořena rozhodovací matice dvou takových agentů (pilotů). Toho bylo dosaženo prostřednictvím identifikace vjemů agenta pomocí sledování pohybu očí a jejich zaměření v letovém simulátoru s využitím virtuální reality, a rovněž propojením těchto vjemů s jednáním agenta s cílem porozumět pravděpodobnosti reakce na konkrétní vjemy. V rámci případové studie, kde bylo využito modelování dle teorie, se v rámci následného srovnání ukázalo, že teorie percepce rozhraní je využitelná při analýze nepovolených vstupů na vzletovou a přistávací dráhu. Takový závěr lze odvodit ze schopnosti výsledného modelu nabídnout kvalitativní popis situačního povědomí, jeho schopnosti ukázat tendence propojující vjemy s jednáním agentů, ze schopnosti ukázat výhody oddělení vjemů od skutečné reality a jeho potenciál pro více dynamické aplikace v oblastech, které nejsou v této studii zkoumány.

Klíčová slova: Percepce, Runway incursions, Letový simulátor, Virtuální realita, Teorie percepce rozhraní

ABSTRACT

The Interface Theory of Perception presents a novel means of looking at perception by uncoupling it from veridicality. This study looks at the possibility of using this theory as a tool in investigating runway incursion events in Vaclav Havel Airport Prague. It does this by the Reduced conscious Agents created in line with the Interface Theory. The decision matrix of two of these agents (pilots) were constructed in this study. This was done by means of finding the perceptions of the agent using eye tracking from a Virtual Reality Flight Simulator, and likewise linking these perceptions with the agent's actions as to understand the likelihoods of actions given certain perceptions. Through looking at a case study of this modeling, and comparing it to a second case, the theory was shown to have possibility for use in looking at runway incursions. This was due to the model's ability to show qualitative descriptions of situational awareness, its ability to show trends linking perceptions to actions, its ability to show the benefits of unlinking perceptions to veridicality, and its potential for more dynamic applications by implementing areas not investigated in this study.

Keywords: Perception, Runway Incursions, Virtual Reality, Flight Simulation, Interface Theory of Perception

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AIP	Aeronautical Information Publication
Ail	Aileron
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
CAA CZ	Civil Aviation Authority of the Czech Republic
Cpt Misc	Cockpit Miscellaneous
CA	Conscious Agent
Elv	Elevator
FOV	Field of View
HMD	Head-Mounted Display
HMI	Human-Machine Interface
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ITP	Interface Theory of Perception
ICAO	International Civil Aviation Organization
PDA	Perception, Decision and Action
PF	Pilot Flying
PNF	Pilot Not Flying
RCA	Reduced Conscious Agent

VREF	Reference Landing Speed
Rud	Rudder
R24 AP	Runway 24 Aiming Point
R24 ctr	Runway 24 Centerline
R24 ED	Runway 24 End
R24 LoC	Runway 24 Left of Centerline
R24 NB	Runway 24 Numbers
RIMCAS	Runway Incursion Monitoring and Collision Avoidance System
Twy C ctr	Taxiway C centerline
Twy C eg	Taxiway C Edge
Twy C LoC	Taxiway C Left of Centerline
Twy D ctr	Taxiway D centerline
Twy D LoC	Taxiway D Left of Centerline
Thr	Throttle
LKPR	Vaclav Havel Airport Prague
VR	Virtual Reality
VMC	Visual Meteorological Conditions
VRFS	VR Flight Simulation

INTRODUCTION

Runway incursion events are a significant danger in air operations due to the aircraft involved likely being in a high energy state as is the case in most runway operations. This danger has come to fruition multiple times in the past, most significantly during the catastrophe involving two Boeing 747s in Tenerife in 1977 (1). Since that time, many measures have been set in place to curb the danger of runway incursions. These measures have come from organizations such as Eurocontrol and the International Civil Aviation Organization (ICAO) and consist of many different means to reduce the risk of runway incursions (2) (3). Despite these measures in place dangerous runway incursion events still occur in the modern day.

One airport which has seen the dangers of runway incursion persist despite developments to stop the phenomenon is the Vaclav Havel Airport Prague. The airport had the highest number of runways incursions of any commercial airport in the Czech Republic in 2017, and has had an increase in runway incursions relative to fairly stable traffic rates since 2001 (4).This study investigates the specific case of runway incursions at this airport as detailed in the Aeronautical Information Publication, relating to runway incursion onto runway 12/30 from aircraft exiting runway 24 intending to vacate via taxiway D (5).

This study investigated this phenomenon by looking into pilot visual perceptions. Generally, this is modeled according to top-down and bottom-up theories. While many approaches exist to model perception, this study chose to use the top-down theory of the Interface Theory of Perception, as it presents a novel way to look at perception, by not linking it to veridicality. Likewise, it chose this theory as the theory was proven by means of evolutionary simulation. In these simulations, agents modeled according to the theory were constantly the ones to survive and not fall to extinction (6).

Along with the ITP the phenomenon was investigated using a VR flight simulator. This simulator allowed for eye tracking and flight data to be obtained from a subject non-obtrusively. By means of these data types, it was possible to model the basic agent from the Interface Theory (7).

Altogether, the study aimed to investigate runway incursions in Vaclav Havel Airport Prague, by means of modeling the agents from the Interface Theory of Perception using a VR flight simulator.

1. CURRENT STATE OF THE ART

The following chapter will provide further development to the topic by providing information regarding the main areas of runway incursions, theories of perception and virtual reality flight simulation.

1.1. Runway Incursions

Runway incursions are defined by the ICAO in the Manual for Prevention of Runway Incursions, from the definition in PANS-ATM, DOC 4444 as, “Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft.” (3)With this description in place, runway incursions are a highly dangerous matter, given they involve unintended entry to an area where there are typically aircraft in the critical phases of flight of takeoff and landing.

Due to the dangerous nature of runway incursion a manual has been developed by ICAO to aid its prevention. This can be said as runway incursion is a serious hazard that has led to significant loss of life in the past and may lead to more significant accidents and incidents in the future. The manual details ideas such as reasons why runway incursions occur as well as means to mitigate them. The manual also stated that for safety to be increased, there is a requirement for all stakeholders to increase awareness and make changes for the goal of reducing the phenomenon. This includes pilots, air traffic control (ATC), ground personnel, airport designers (3).

1.1.1. Causal Factors

According to a survey from Eurocontrol in 2011 (3) 50% of pilots report involvement in runway incursion. Thus, showing further the importance of reducing the phenomena (3).

Usually, from the pilot side, runway incursion occurs due to a breakdown in communications and loss of situational awareness, both of which may result in a failure to execute ATC instructions correctly (3). A report from Eurocontrol (2) found that breakdowns in communication occur mainly due to many reasons like, nonstandard phraseology, complicated instructions, fast speech, different languages in use, congestion on the frequency, wrong callsign, trouble with English, multiple frequencies in use, poor readbacks, and improper training (2).

Likewise, on the pilot side runway incursions have also been seen to be linked to other factors such as inability to understand complex airport design, lack of signage and markings, communication during high workloads, task saturation, lack of updated aerodrome information, last minute changes to clearances and head down tasks during taxi (3).

In terms of aerodrome design, the manual says that runway incursions are mainly caused by complex designs such as runway entries not being 90° to the runway, close proximity of parallel runways, uncertain or confusing intersections, and lack of end loop perimeter taxiways (3). These are all factors which are prevalent in many major airports across the globe.

1.1.2. Recommendations for the Reduction of Runways Incursions

To mitigate the risk of runway incursions the ICAO manual makes multiple recommendations and even dedicates a full appendix to mitigation of risk of runway incursions on the side of flight crews.

For flight crews it recommends briefings of all pertinent information as to be familiar with ATC instructions. It also recommends maintaining a sterile cockpit while taxiing. Likewise, the manual also recommends that pilots keep head down tasks while taxiing to a minimum as to maintain the best possible awareness over the situation. Also stated, was that pilots should never cross lighted stop bars. The manual also recommended to operate certain lights when on the runway as to make the aircraft‘s position better known (3).

Another recommendation made is to follow practices in communications such as using standard phraseology, using full callsigns, and using ICAO recommended speech rate and techniques when speaking with ATC. In line with communication recommendations, the manual also describes certain best practices, such as rejecting clearances to cross a runway from an oblique taxiway and informing ATC if lined up for 90 seconds more than expected (3).

On the side of the aerodrome operator, the manual details the means to create plans to mitigate runway incursion. This includes reporting all runway incursions and investigating them regardless of severity. Finally, the manual recommends detailing of hotspots for runway incursion within the Aeronautical Information Publication (AIP) and explaining these hotspots on a chart in detail (3).

All these recommendations are again reiterated by Eurocontrol in their own document for the prevention of runway incursions (2). However, Eurocontrol makes additional remarks to reduce runway incursions, which ICAO does not include in its manual.

One further recommendation by Eurocontrol is that single frequency be used for all operations on a single runway. They highlighted the potential as well to take this a step further with the example of Brussels wherein there is a rule of one runway, one language, and one frequency (2). This approach aims to make sure no miscommunications happen due to being on different frequencies, or due to not understanding the language of some transmissions.

Another recommendation from Eurocontrol is to develop a local runway safety team which is made up of individuals from the different backgrounds involved in runway safety. These include ground handling companies, pilots, air navigation service providers (ANSPs), air traffic controllers (ATCOs), aerodrome management. The goal of the team is to identify and assess current runway safety issues, and propose solutions to mitigate these issues, with the overall goal of runway safety (2).

While detailing the concept of a runway safety team, Eurocontrol also stated that such a team should understand what it is pilots want while on the ground. It stated that emphasis should be given in the area of communications. This includes the use of standard phraseology in a single language of aviation English, markings, and signs appropriate to all areas, shorter taxi instructions, less crowded frequencies, timely instructions, and accurate charting (2). It makes sense that these factors are wanted by pilots, as these are all steps which for the pilot mean less workload on taxi and increased likelihood to maintain situational awareness.

A third recommendation put forth by the Eurocontrol plans is to place a heavy emphasis on pilots being constantly aware of their situation. They reiterate ICAO's advice of reducing head down tasks during taxi and maintaining a sterile cockpit. In relation to this, Eurocontrol recommended that proper assessment be made before doing procedures such as single engine taxi out as to make sure that such procedures do not hinder the situational awareness. They also recommend briefings be done about all instructions, and caution be taken on accepting amended clearances if these do not allow adequate briefings (2).

1.1.3. Safety Performance Measurement of Runway Incursions

As part of the strategies to understand runway incursions and their causes, safety measurement is used. Specifically, this is done by using safety performance indicators. The aim of such modeling using the performance indicators is to allow for better understanding of the factors which contribute to the matter at hand. With this information, the goal is to understand these factors and use the information to stop the same issue from repeating itself in the future. Using such indicators, the understanding becomes better when a greater amount of data, and thus cooperation between stakeholders exists (8).

One limitation of this approach is that, despite the ability for performance indicators to provide a better understanding of the scenario, they have the requirement to cover all necessary areas. This is required as to capture all factors relevant to give a more complete picture. Despite this, performance indicators are still unable to present the entire picture of the situation, as they are unable to track secondary elements to the situation. One example of such would be the changing traffic situations at an airport across different months (8).

Along with the performance indicators, taxonomies can be used as to describe the events leading up to the runway incursion. This involves standardized wording to describe contributory factors such as those previously discussed (8).

One way of measuring the safety performance using the performance indicators together with taxonomies is by using a weighted network which involves summation of the weight of severity of each involved factor. By doing so, a measure of the severity of the runway incursion in question may be produced (8).

Overall, while not producing a full understanding of the runway incursion event, weighted taxonomies may be used to model the danger in runway incursion events. They have the main benefit of allowing for a better understanding of the situation without incurring significant costs to establish (8).

1.2. Major Runway Incursion Occurrences

Perhaps the best way to understand better the dangers of runway incursion, as well as its causal factors and prevention, would be by looking into an actual scenarios of runway incursions.

1.2.1. KLM 4805 and Pan Am 1736 crash in Tenerife

One of the most infamous cases of runway incursion would have to be the disaster resulting from the collision of KLM 4805 and Pan Am 1736 in Tenerife on March 27, 1977. The accident involved 2 Boeing 747s, which were on the runway in Tenerife Airport. The visibility on the day was significantly reduced due to clouds being blown over the airport. During the day as well, there was heavy traffic at the airport since many flights, including the two involved in the accident, were diverted to Tenerife due to a bomb blast in their original destination of Gran Canaria (1).

The accident played out with the starting situation of the Pan Am plane taxiing on the runway, and the KLM plane backtracking the runway. Upon completing the backtrack, the KLM plane then reported it was ready for take-off, to which the controller replied with instructions after departure, without an explicit take-off clearance. The KLM pilots then read this clearance back and said, "We are now at take-off". The controller then replied to this transmission with a request to standby for takeoff, which was not heard due to the transmission being garbled by a simultaneous transmission of the Pan Am plane. The KLM Plane then continued to roll down the runway for takeoff while the Pan Am plane was still on the runway, and eventually the KLM Plane crashed into the Pan Am 747 (1).

The accident's main causal factors are aligned with those causal factors relating to pilots detailed in the ICAO manual. The first of these factors is a breakdown in communications

(3). This was seen in the report on the accident by the conclusion that the KLM pilots failed to follow ATC instructions. This resulted from a garbled transmission due to two stations speaking simultaneously on the frequency, and the use of phraseologies outside of recommended standards (1). The other factor which aligned with the ICAO manual was the lack in situational awareness for the pilots (3). This can be seen in the report on the accident given the weather at Tenerife on that day. The airport had the wind blowing clouds over it, thus resulting in rapidly changing, and altogether low visibility. Due to this phenomenon, at the time of the crash the KLM pilots were unable to see the Pan Am plane which was still taxiing on the runway until they were about to hit it (1). Seeing these two factors, it gives a clear example of how the causal factors mentioned in the ICAO manual play out in an actual scenario.

Aside from these factors, certain other causal factors were seen in the accident which did not necessarily align directly with the ICAO manual. The first of which would be the conclusion of the pressure placed on the KLM pilot to depart as to not further delay the flight since he may reach duty limits should they be delayed further, and likewise should further delays occur the weather may have possibly deteriorated further thus disallowing the departure altogether. Another factor concluded was the traffic situation at the airport being unusual that day due to the increased traffic leading to odd taxi routings (1). Seeing these extra factors, they may have played a role in the overall severity of the accident.

The accident was also a driver for the current recommendations to reducing runway incursions. From the accident report 3 recommendations were made, and these align with the current recommendations to prevent runway incursions in the ICAO manual. The first recommendation was to follow instructions exactly as given. The second recommendation given from the accident was to use standard phraseology in all communications as to avoid misunderstanding. The third recommendation was to not use the term “take-off” when the statement made does not refer directly to a clearance for take-off (1). These all align with the ICAO recommendation to use standard techniques and phraseologies when communicating between pilots and ATC (3).

1.2.2. Runway incursion in LKPR

In Prague airport, in the year 2019 there has been a runway incursion which occurred between an A320 and Boeing 777. The event happened during the nighttime when visibility was lowered. The incident occurred with the Boeing 777 taking off, while the A320 was holding short of runway 24 from the CAT I holding point of taxiway B. The A320 crew were unable to positively identify the holding point markings and thought that they were just on the markings whereas in reality, they were significantly far past the markings. The investigation found that they overshot the markings to a point wherein their clearance with the B777 was 37m from the A320 fuselage to the 777 wingtip, and 34m between each other’s wingtips (9) as shown in the figure below. Given this distance, should the A320 have stopped a few seconds later than where they did, it would be likely that this would have become an accident situation with catastrophe like that of Tenerife in 1977.

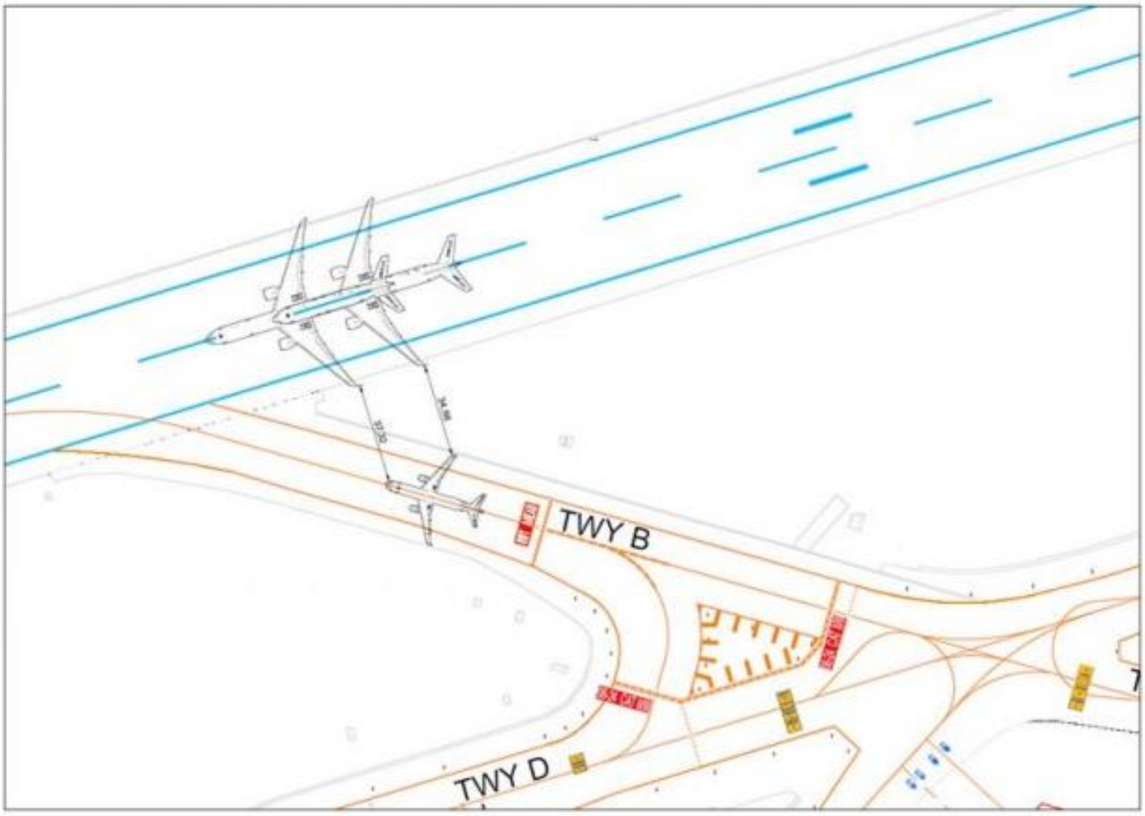

Figure 1. Distance between A320 and B777 involved (9)

The investigation team investigated the crew of the A320, the ATC, the Airport, and the Navdata available onboard.

In terms of the crew, it was found that multiple causal factors may have contributed to this incident. Firstly, it was found that the crew was likely in a rush since they had a delay due to weather on arrival. This can be inferred from the fact that they chose to takeoff from intersection B instead of using the full runway length. Secondly, it was found that the crew did not have familiarity with the area, and this was made even worse for them since they were using navigational information which was incorrect (9). These line up with the common causal factors stated in the ICAO manual with regards to runway incursion on the pilot side. Specifically, it shows a lack in situational awareness, and a lack of updated information on the aerodrome (3).

On the ATC side, the investigation found that an alert was sounded on the Runway Incursion Monitoring and Collision Avoidance System (RIMCAS) due to the occurrence. Due to this, the ATC asked the aircraft for their position, to which they confirmed that they did not see the CAT I holding point, but believed that it was just under their nosewheel. Because of this wrong information provided to the ATC, they deemed the situation to not be a hazard, and continued operations. Likewise, it was not possible for the ATC to verify the truth of the A320's position, since the surface movement radar screen did not possess a marking of the CAT I holding position (9).

On the Airport side, it was found that this occurrence happened despite the airport already having above-standard facilities relative to the regulations. The airport possessed both signage and markings at the holding point (9). Therefore, if the pilots were unable to see one, they would likely see the other, but in this case both the marking and the sign were missed by the crew.

Finally, in terms of navigational data, it was found that the data which was being used on the flight had a severely misplaced positioning of the CAT I holding point (9). This may have been part of why the crew thought that they were merely on the holding point, even if they were well past it already.

With all these factors coming together, this resulted in an occurrence which may have become overall a much more serious situation. It is alarming to see such a close call possible despite the many barriers in place today to avoid runway incursion relative to those back in 1977 when the Tenerife accident happened.

1.3. Situation in Vaclav Havel Airport Prague

This thesis focuses on the runway incursion situation at the Vaclav Havel Airport Prague (LKPR). According to a report from a safety conference of the Civil Aviation Authority of the Czech Republic (CAA CZ) in 2018 (4), LKPR had the highest number of runway incursions of any controlled commercial aerodrome in the Czech Republic in 2017. Likewise, the figure of number of runway incursions per year at the airport has risen since 2001 despite similar rates of aircraft movements across the years (4). This is a serious issue, since there is a trend of a continuous stable amount of runway incursions year on year despite improvements to stop them.

In LKPR it was found that 84% of all runway incursions from 2001-2017 were caused by pilot deviations. The report stated that these were mainly due to the following causal factors: unfamiliarity with the aerodrome, closures on the aerodrome, pilots rushing, the confusing layout between the crossing runways, complicated phrasing of instructions, and false assumptions by pilots of clearances being given (4).

Due to these runway incursions the following consequences were found: the need for more go arounds, delays to other aircraft arrivals and departures, violation of Instrument

Landing System (ILS) protected areas, crossing runways without permission, and entering the runway's protected area (4).

Majority of these runway incursions happen in two places in the aerodrome. These are described within the AIP of the Czech Republic in the aerodrome chart of LKPR (see figure 1). The first of these, HS1, details that Taxiways D, L and runway 12 may be confused for each other. In relation to this, the AIP stated that vacating runway 6/24 via runway 12 is strictly prohibited unless specifically instructed by ATC. The second hotspot HS2 details the crossing of runway 12 from taxiways F and D. This hotspot also informs pilots that there will be a delay between issuance of clearance and the switching off the stop bars on runway 12 (5).

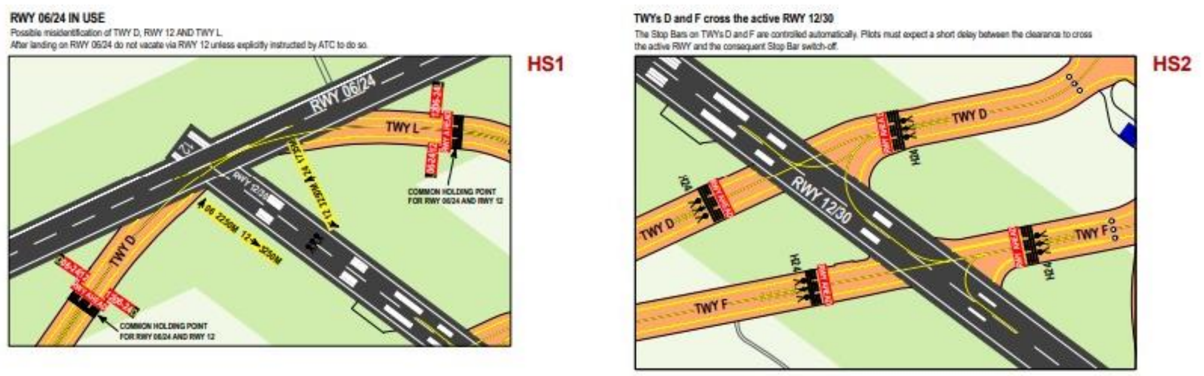

Figure 2. Details of HS1 and HS2 from AIP CZ (5)

Despite these measures taken to reduce runway incursions, the report from the 2018 safety conference of CAA CZ found that runway incursions on these two cases are still the most frequently occurring types in LKPR (4).

Due to this issue, the report from 2018 suggested the following barriers to prevent runway incursions further. For the ATC the main barrier to runway incursion is their systems, and visual watch when possible. It was recommended that surface movement radar may be used to help in the situation. Likewise, there is A-SMGCS which gives the ATC warnings and change of color to the aircraft icon to yellow or red depending on the hazard and its level. Also, on red level this system gives an audible alert to the ATC (4).

Despite such installations present these do not serve as well as a solution to the issue, as these still rely on a human-machine interface. Likewise, it is still dependent on ATC to decide how to act when a warning is issued. It was found by a study that such systems suffer from late or false predictions, lack of suggested solutions to ATC, lack in flexibility in detection, and frequently missed alerts. A potential mitigation to some of these issues was presented by the same study by means of an anticipatory runway incursion prevention system. This system would aim to have better accuracy, and prediction time as well as directly provide a solution to the ATC (10). Such a system could provide benefits as well if implemented in LKPR.

For pilots, the main barrier suggested was to maintain SOPs. This includes recommendations in communications such as clarifying uncertain instructions and clearances, as well as making evident the instructions such as taxiing followed by a hold short instruction (4).

1.4. Perception Theories

Across time, many models have been created as to describe human perception. Each model approaches the subject in different ways. These shall be explored withing the following section.

1.4.1. Types of Theories

Two main models of perception theories exist, top-down and bottom-up theories (11).

Bottom-up theories state that the perception is a result of the qualities of the matter being experienced. These sets of theories are based primarily on external data driving the results of what is experienced. The experiences of this type are known as data-driven perceptions. With this model, the outcomes are based on external inputs, and they match the inputs. These types of theories are also known as direct perception theories (11).

Top-down theories on the other hand define perception as being the result of sensory inputs coming in, then being processed as to create a model of what is being perceived. These are known as indirect perception theories. These theories can be divided as constructivist, computational and synthesizing theories (11).

1.4.2. Bottom Up-Theories

One movement in bottom-up theories is the Gestalt theory. Gestalt theory came up as a response against structuralism which stated that each aspect in a visual field corresponds to a part of perception, and all these together form the overall perception. This theory generally failed as upon testing; introspections made by trained observers led to different conclusions as to which aspects led to which parts of a precept (12). Due to this, Gestalt theory aimed to provide an alternative explanation.

The Gestalt theory focuses on why things appear as they do. Thus, it focuses on why things always stay as they are day-to-day. One principle established was figure-ground separation, which stated that there is a tendency for perceptions to organize themselves dynamically. The example was given by means of a 2D white circle in a black triangle which showed that one may perceive the circle on the triangle, or the circle as a hole through the triangle. Another principle established by the theory was that of grouping of individual unrelated objects to wholes, to which it gave the term ‘Gestalten’. Aside from this, Gestalt theory also established the concept of ‘Pragnanz’, or the tendency for perception to aim for simplicity, symmetry, and wholeness. Another principle stated in Gestalt theory, is that groups of stimuli lead to a precept, but that this precept is greater than the sum of its parts. The final principle given by the theory is that of constancy, which states that perception tends to be veridical since drastic changes do not occur in object color with change in illumination, and shapes maintain their shape despite a change in position of the perceiver. Gestalt theory became widely accepted as those who proposed it would usually demonstrate these qualities mentioned by means of image examples shown on a page as in Figure 3 demonstrating the figure ground separation claim. This led to many readers being highly convinced without further testing of the claims of the theory (12).

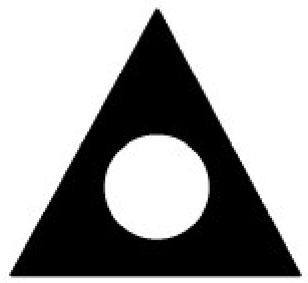

Figure 3. Gestalt Image Example of figure ground separation (12).

Another key bottom-up theory is that of JJ Gibson’s Theory of direct perception. This theory based on evolution, states that perceptions are from sensors which detect stimuli in the world. According to this theory perception is based on the relevant sensory apparatus picking up the information in packets coming from the environment (11). According to Gibson, perception is an act and not a response to the environment. The information in perception is taken from the environment, not built by factors in the environment (13).

The factors which are perceived in this theory are dependent upon position of the relevant sensory apparatus, although the reality which may be perceived from a specific object in the environment is preset and not affected by one’s perception (11). Gibson’s view was that his defined secondary qualities such as color and warmth come from actual factors in the environment. Likewise, he states that the environment lawfully has properties that allow for such perceptions. Due to this, in Gibson’s view the job of the perception theory is to explain the structures these come from and how the factors are perceived (13).

Experiments have contradicted the views presented by Gibson. To defend against these criticisms, which were demonstrated by tests showing that different inputs can lead to the same output perception, Gibson argued that the requirement of the theory applies to the normal ecology for the subject. Therefore, given this, the examples presented in studies go past the scope of normal ecology, since the tests were done using phenomena which do not occur naturally (13).

Given the requirement that perceptions come from ecology, for areas that deal with representations as words and numbers, Gibson described these as perceptions which are mediated. On top of this, in his views, the organism cannot have cartesian dualism, which means a separation of the mind and the body, wherein the body is merely a tool to the mind. Thus, the most basic unit for perception for him was the organism interacting with the environment.

1.4.3. Top-Down Theories

Top-down theories, which may be further divided in the form of computational, constructive, and synthesizing theories will be discussed in the next portion.

One approach to explaining perception as top-down is through computational theories such as Brunswik's probabilistic functionalism. The theory of Brunswik focused on how the brain acts when faced with distal and proximal events at the same time which do not normally match up. Within his theory, uncertainty exists for both the world and the perceiver. This was asserted by the evidence that environmental cues are mostly unreliable. Given the complexity of actual environments, then the perceiver must have a way to quickly form a valid perception from the uncertain information available. According to Brunswik, majority of times the brain can give a proper output to the perceiver, otherwise the perceiver would not survive. As to how this is possible, Brunswick asserted that it is required to study the perceiver in the context of the full complexity of its world, and not under a simple experiment. This means that, arriving at an end precept follows a probabilistic nature, meaning that given specific information from the environment, there is always a likelihood that the perception will come out with the wrong output (12).

Another top-down, computational approach is the Neurophysiological Approach. This approach to perception states that specific perceptions may be attributed to specific amounts and areas of stimulation in a physical portion of the brain. In this approach, neurons may work as logical gates which combine to lead to a precept. Specifically, the neurons may act as AND, OR, NOT, and AND-NOT gates. The approach also uses the principle of neurons responding to change as part of explaining the approach. Specifically, it refers to the finding that with change there is an increase in neuron firing, but with the same stimulation continuing, this firing then goes back down to close to resting values (12).

A final example of top-down, computational perception is Marr's model of perception, which states that perceptions can be modeled as levels of mathematical functions with multiple steps which lead to an outcome (11). Through his model, he explained that an information-processing system is required.

In Marr's information processing system three levels exist: the computational theory, the algorithm, and the hardware. The first level accounts for the goal of the processing and strategy to carry it out. The algorithm focuses on how the computation shall be carried out. Finally, the hardware defines what means shall be used to carry out the computation according to the algorithm (12).

According to Marr, visual perception happens by means of information processing in 3 stages. The primal sketch, the 2 ½ D sketch and the 3D model. In the first stage, spatial information is gathered and information on the distribution of intensities of changes, and organization is obtained. Next, in the 2 ½D sketch, further information on orientation and depth information is processed. In this stage, the information is not yet linked to the overall environment. Finally, in the 3D model representation, the shapes and orientations are made to represent specific 3D objects in an environment which the perceiver sees as the model of the external world (12).

In terms of constructive theories, the approach follows that of Empiricism, which is the idea that perception involves more than a direct process, that there are processes between the stimulation and the output precept. With the empiricist approach, cognitive processes are required as to gain the correct precept (12).

One empiricist approach was done by Helmholtz. He was the original person to suggest that processes are involved between perception and stimulation. He suggested that, based on the sensations, the brain must make inferences to get to the precept. These inferences must be from relations of association and experience. From his writings, perception was framed as indirect, constructive, and inferential (12).

Another proponent of these views is R.L. Gregory. Gregory described perception as like hypotheses formation and testing. This works in that from sensory signals arriving to the brain, interactions with previous knowledge happen, and based upon this a hypothesis is formed as to what is happening (12).

Due to the role of memory, the theory states that certain data may be overlooked by the brain due to a previous expected outcome of the perception. With this factor, the theory can explain optical illusions as being the result of multiple conflicting expected outputs of the perceived material. This is an area which Gibson's theory fails to explain since that theory states that perceptions are the deterministic result of the data presented (11) Given this, with Gregory's theory it is argued that previous experience is of more importance than the data, as it is possible to come to a false conclusion with incomplete data that comes from a previous expected outcome. An example of this is how an oval which is close to the shape of the circle, is perceived as a circle (11).

Certain properties exist with Gregory's approach. Firstly, precepts can be made of the same conclusion without complete data. Next, in familiar situations, perception can happen without delay. Further, perceptions may be ambiguous, such as that shown by the Necker cube. In line with this, perceptions may also be paradoxical. Also, perceptions can lift familiar objects from clutter of many stimuli. Likewise, perceptions can form unlikely objects given certain information. On top of this, one may also perceive something as representing another object. Further, perceptions do not necessarily reflect one's experience. Finally, certain perceptions may be completely unexplained, as is the case with hallucinations (12).

Moving onto synthesizing theories, an example is Neisser's Analysis by synthesis model. In this model firstly, receptors perceive the environment directly in preliminary sampling. From this, certain stimuli are found to be more important, and thus give where attention is directed to. Next, stimuli with little importance are gathered and processed based upon previous learning and experiences. In the third step, the model created by the mind is then compared to memory and potentially modified as needed to suit the inputs until a valid output is achieved (11).

1.5. Interface Theory of Perception

One more recent theory of perception which has synthesizing aspects related to several other theories is the Interface Theory of Perception (ITP). This theory has its basis in evolution by natural selection. The theory was proven by simulations of evolution showing that evolution favored fitness to environment over veridical perceptions. This means that species evolve to have perceptions which are beneficial to the survival of the species over having perceptions which show the true nature of reality. Therefore, the research creates the interface theory, in which perception is merely a beneficial means to interact with the world as opposed to a true representation of the world (6).

Based on the evolutionary games carried out comparing different perceptual strategies, the individuals who possessed the modeled interface theory of perception were the ones to prevail and survive. Based as well on the evolutionary games, it was seen that evolution indeed favored fitness over truth. Thus, the research was able to say that perceptions are indeed non-veridical, but instead based in fitness. Given this, despite a perception not taking the form of the true nature of something, it must be taken seriously, since the reason it is perceived that way is due to natural selection, which favors fitness. The researchers used the analogy of a venomous snake to emphasize this point. They stated that despite the situation veridically not match up with one's perception of the danger, the danger still does exist, and thus why perception has evolved to see such an item as dangerous (6).

The theory then goes on to model perception as a cycle of Perception, Decision and Action (PDA) loops which may be nested inside each other. It models perception by having 3 measurable spaces, W, X and G which connect by Markovian Kernels P, D and A. The space W has all the states of the world. The space X has all the possible perceptions, and the space G has all the possible actions. The P kernel (perception) links W to X and contains the probability of each state from W corresponding to each perception in X. The D Kernel (Decision) links X to G and contains the probability of each perception in X corresponding to each action in G. Finally, the A kernel (action) links G to W and contains the probability of each action in G corresponding to each state in W(6).

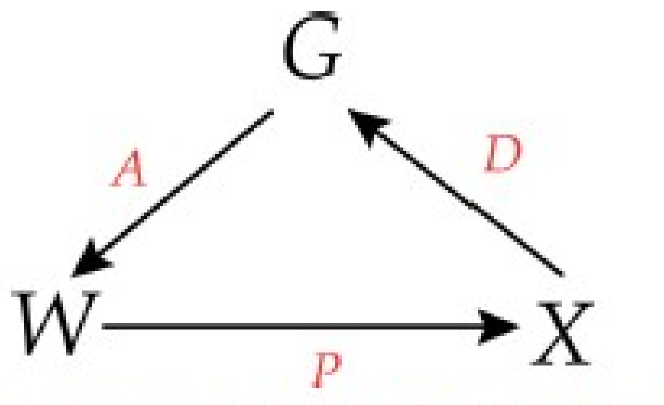

Figure 4.Graphic of the PDA loop from the ITP paper (6)

It is not possible for the observer working with a perception according to ITP definition to know the mechanics between G -> W and W -> X, since at present it is not possible to know how the actions change the true state of the world. Likewise, it is not possible to know how the change in true state of the world changes what is perceived. It is thus only possible to see the outcome of this process as the next perception (6).

1.6. Conscious Agents

From the PDA loop formed in the ITP, the conscious agent is then formed. The conscious agent is an individual who fulfils the properties of the PDA loop, and acts across time. The conscious agents are further developed in that they may interact with one another. This results in that the perceptions of one may directly be caused by the actions of another.

The research further places that the world may be defined as consisting in its entirety of conscious agents which are interacting and generating each other's perceptions (14).

The research also suggests a solution to the combination problem. The combination problem is the problem about how perceptions of a larger entity relate to entities which it is made of. ITP solves this problem by mathematically showing how multiple conscious agents can be combined without the destruction of any agent. This leads to the formation of a larger conscious agent which is made up of a directed or undirected join of other agents (14).

With the presentation of conscious agents, the research asserts the conscious agent thesis which states that "every property of consciousness can be represented by some property of a dynamical system of conscious agents." (14)

1.7. Conscious agent interactions

From the conscious agents (CA) theory, the further definition of a reduced conscious agent (RCA) is introduced. This is a CA which has limited abilities, more like that of an actual organism. The RCA is unable to access the true values of the world W. Also, it has no access to its own P, D, and A, as well as those of any other RCA. Likewise, the RCA cannot access another RCA's X (perceptions) and G (actions), therefore it gets all information strictly by its own perceptions only. Finally, the RCA cannot tell whether it is acting with just the world or with another RCA. The RCA can be defined mathematically as a 4-tuple [(X,x),(G,g),D,t] and it has an extrinsic W as well as A and P kernels. In this definition the variable t refers to time (7).

RCAs can then be made further complex by having memory built into their structure, Memory may be used to model why changes are made to how an RCA reacts to a perception due to past experiences with similar situations (7).

RCAs may interact with each other and form networks of interaction, but these networks need not have a two-way connection between RCAs, some RCAs may act on other RCAs without perceiving what they are acting upon (7).

1.8. Virtual Reality (VR) Simulation

VR flight simulation (VRFS) was found to be a middle ground between desktop simulation and full flight simulation for human factors studies. The main benefit with VRFS is that it is possible to show interaction in the human-machine interface (HMI) for a low cost. With a VRFS a 3D space is experienced by means of a head-mounted display (HMD) or 3D glasses. Further using VRFS, finger and head tracking can be made possible as to interact with the virtual environment (15).

With VRFS a few components are required for the system to function. Firstly, there is the flight simulator software. The next aspect is the tracking system. Further, there is the HMD. Finally, there is the hand tracking system (15).

An advantage with VRFS is the ability to obtain eye tracking data. With this data, indications may be seen about the pilot's perceptions. Using such data, such as fixations, glances, and transitions, information about pilot workload can be seen. VRFS also has the advantage that, it provides an opportunity to collect such data without obstructing one's view (15) (16). This tracking is done by a camera watching the pilot's eye. The data from eye tracking can then be time synchronized with the simulator and mapped to areas in the simulation (15).

With the eye tracking, there is the ability to take this data and process it as to generate a heat map for where the attention of the subject is. This works by means of a matrix wherein each row and column represent one pixel in the screen. The value of each entry then match up to a given intensity on the heatmap as seen in Figure 5 below (16).

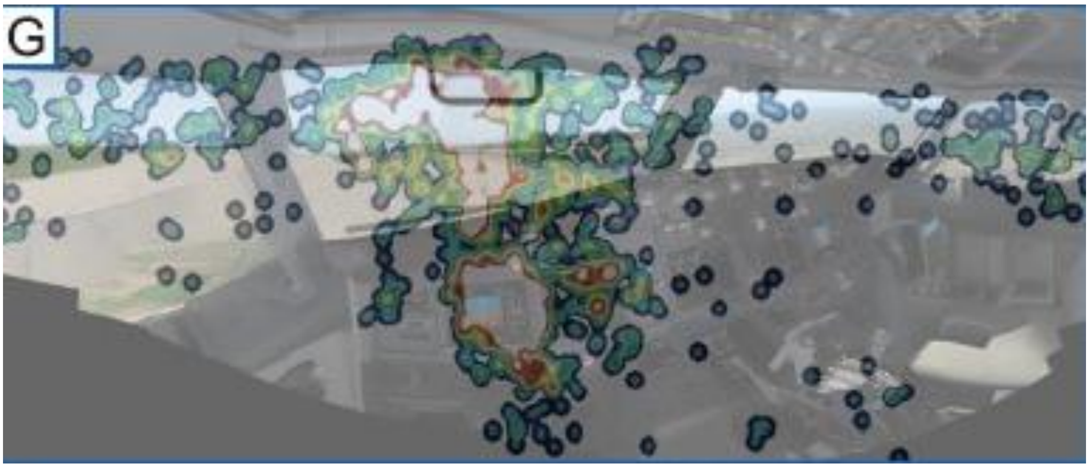

Figure 5. Sample eye tracking heatmap from Socha et. al. (16)

The eye tracking data can transform 2D information from the gaze to points in a 3D space. The tracking can even map this with the head tracking, to map out where in the area the gaze falls upon. This information can then be placed together across time to generate a heat map of where the pilot was looking at the most (15).

One downside with VRFS is that it is not the best solution for simulations involving multiple button interactions while also flying the plane. It was found that such tasks tend to be slower when done in VRFS compared to actual hardware. Despite these issues, it is nonetheless possible to carry out such tests with the VRFS. One means that will be adapted from a previous study as to combat this issue is by use of neodymium magnets as to represent positions of switches on the overhead panel of the cockpit (16).

Another downside comes with the VR equipment. One limiting factor with the HMD is in Field of View (FOV), since a higher FOV tends to result in lower pixel density, which makes it more difficult for the subject to read items in the simulation. Likewise, the VR equipment may eventually be uncomfortable to the user. Also, due to the VR, simulation sickness is a common phenomenon, which happens due to a mismatch of visuals and current head movement. Therefore, in such studies with a VRFS, it is necessary that times be limited as to reduce this phenomenon (15).

The main benefit of VRFS is that it provides a highly flexible simulation means, which is immersive, and provides high fidelity. Likewise, it has the advantage of non-obtrusive eye tracking. Altogether, VRFS is a means of simulation, which forms a middle ground between desktop simulation, and full flight simulation, while not entirely replacing either of the two ends (15). Finally, there are surely further ways to increase the immersion of the subject in a VRFS, one example would be by means of integration with a motion platform (16).

1.8.1. Further VRFS Studies

Aside from the aforementioned description of VRFS, other studies have been also conducted by both the same and other researchers.

One study, which is the precursor to the study mentioned above (15), was aimed at creating a generic VRFS which may be used for aerospace applications. This means, the aim was to develop a simulator not specifically linked to any products, aircraft, or software. The study found that there was an increased difficulty for participants to interact with virtual buttons and found a 77% hit rate for correct button presses in their trial. As a solution to this the study suggested the use of a physical mockup which would increase the haptic feedback to the subject (17).

A more recent study conducted with roots from references (15) and (17), was also conducted comparing pilot performance in VRFS and conventional flight simulation. It was found that with VRFS the subjects must take more time to complete actions such as setting landing configuration, and with rotation of knobs. In terms of piloting performance, the study found that there were greater deviations in heading and altitude with the VRFS compared to the conventional simulator. Likewise, the research also assessed the pilot workload by self-assessment by means of the NASA-Task Load Index (18). It was seen that the subjects found themselves to have a higher workload when operating the VRFS compared to the conventional simulator. Finally, the research investigated the subjects' simulator sickness by means of a questionnaire listing 27 symptoms. It was found by this self-assessment as well that there was increased simulator sickness in the VRFS due to the delays between head movement and visual output of the simulator (19).

Despite the deteriorations in performance most participants were able to safely complete the task of flying the aircraft in the VRFS. Given the results, the study recommended that future studies in VRFS account for the fact that actions take longer in VRFS when developing the study. The study reiterates the fact that in its current form VRFS is not a substitute for full flight simulation (19).

Another study conducted by a different group of researchers similarly compared pilots flying in VR to pilots flying in the real airplane. This study compared the cardiac activity of 4 pilots in a VRFS against when flying in a real airplane. This was done by making the 4 pilots perform the same flight activity in the VRFS and in a real airplane. A questionnaire was then used as to let the subjects self-assess the perceived difficulty of the phase of flight assessed. These were the phases of takeoff, downwind and landing (18).

Based on the self-assessment, the subjects found the downwind phase to have similar difficulty in both VR and real flight. Meanwhile both the takeoff and landing were perceived to be more difficult in VR. The study stated that this may be due to lack of experience with the VR simulator, or other limitations of VRFS such as graphic performance, and interaction with cockpit elements. Finally, despite the presence of a motion platform, the subjects found that the sensations of flight when close to the ground lacked realism (18).

In terms of cardiac data, the study found that heart rates were higher in real flights across all phases. The study attributed this potentially to a lack of immersion in the VRFS, and due to more challenging weather present in the real flight due to a crosswind on the day of testing, as opposed to the zero wind conditions in the VRFS (18).

1.9. Limitations of The Current State of the Art

From the State of the Art presented in the previous section multiple summarizations may be made about the different topics covered. This section will discuss a summary of the limitations in each area, and where this study will cover in terms of gaps.

In terms of runway incursions, much development has happened since the time of the most major accident regarding the issue in Tenerife in 1977. Despite many technologies and recommended practices from multiple entities the issue of runway incursion remains and is a pressing safety issue in modern aviation (3) (9) (4) (5). With this issue in the modern day, occurrences still lead to situations which may easily end in catastrophic outcomes, as evidenced by the runway incursion incident presented in Prague airport (9).

On the topic of human perception, multiple approaches have been taken, which all use different means to explain the phenomena. Each theory takes from different starting points to explain the process of getting to the final perception. Some claim that perceptions are the result of the outside world entirely, while others necessitate intermediate steps of different means as to explain the outcome (11) (12) (13).

Of these approaches, the interface theory of perception presents a novel way of approaching perception, by explaining it in the context of agents in interaction with one another whose experiences do not necessarily represent the veridical nature of the world they inhabit. Although, despite the non-veridical nature of the perceptions, the agents are still able to interact with the world in an evolutionarily viable way. These agents' perceptions work by means of the actions of one or more agents, explicitly defining the probability of certain perceptions, decisions and actions of other agents given certain inputs (6) (14) (7) .

Moving onto the topic of VRFS, multiple studies have been conducted to explore the viability of the VRFS. In general, it was found that VRFS forms a middle ground between desktop and full simulation and presents a limited degree of immersion compared to an actual flight. Likewise, it was found that VRFS limits the pilot in their actions, which take longer and are perceived to be more difficult than in a hardware-based cockpit environment. Despite these limitations, VRFS was found to be a cost-effective means to evaluate certain areas such as tracking and mapping the visual patterns of a subject. Currently, this has mainly been used to evaluate workload levels in human factors simulations (15) (16) (17) (18) (19).

Given what has been presented, this study aims to fill the gap wherein these three main areas intersect. This gap is that of evaluating pilot perceptions in runway incursion events using the VRFS. Currently, the VRFS has not been used to evaluate perception. This aim is a suitable use case for the VRFS since the main pilot interactions are done by means of physical hardware. This means that they are unlikely to be affected by the VRFS consequence of speed in actions when dealing with virtual buttons (19). Likewise, this goal benefits from the non-obtrusive eye tracking, and simulation data, which is possible to obtain from the VRFS, and which are usable as inputs for modelling the pilot perception in accordance with the ITP RCA (15). On top of allowing the RCA modeling, the non-obtrusive eye tracking also allows for an unobstructed view, which is otherwise mostly impossible in other simulator types. Any obstruction would likely have an influence in an accidental runway incursion in the simulation, thus why the non-obtrusive eye tracking is essential.

Currently, perception has not been studied in the case of runway incursion scenarios. To study this, multiple approaches are possible given the many theories of perception. By looking into pilot perceptions in runway incursions, it would be possible to then see which perceptions lead to which actions, that lead to the incursion. This would therefore allow the potential to learn new points about runway incursions.

Looking into runway incursions is important, as the data shows that despite many strategies to reduce runway incursions, the problem still prevails in modern aviation (4). Likewise, current runway incursion incidents still end in scenarios which only narrowly avoid a catastrophe like that of what happened in Tenerife (1) (9).

2. MATERIALS AND METHODS

This chapter details the information with regards to how the study carried out the application of the ITP in scenarios of runway incursion by using a VRFS.

The data used in this study are the same data as used from the concurrent study of Šudoma 2021 (20). Therefore, this study used it as a source for the profile of subjects and description of the procedure of measurements.

2.1. Application of ITP

The ITP is applied by evaluating pilot perceptions using the VRFS, in runway incursion events in LKPR relating to the accidental vacating to runway 12/30 after landing on runway 24 (5). Specifically, the study aimed to do this by using eye tracking data from the VRFS as to model a basic RCA. It did this by using the eye tracking data to form the X (perceptions) in the RCA. Further, it linked these through actions recorded from simulator outputs to be the G(actions). These two elements were then linked together to form the D (decision) kernel of the RCA (7). From this information, the study then aimed to investigate if the basic RCA of the ITP provides useful information to model pilot perceptions in runway incursions.

The RCA is a promising way to model the pilot perception given that this data from the VRFS allows for inputs towards the RCA's X and G, and in turn a means to construct its D kernel. Likewise, the study aimed to show which pilot perceptions showed the most likelihoods towards actions which lead to the specific RI event in question.

The RCA only used information from the X and G by its definition, and in turn only had the D kernel. In reverse this also meant that the RCA was defined in that it has no access to the true nature of its world W, and therefore likewise no access to its P and A kernels. Thus, this modeled that the RCA was unable to know how its perceptions were formed from the world W, and likewise how its action affects the world W (7).

In this study, the space X of the RCA was generated based on the data from the VRFS eye tracking, specifically by determining at what object the agent (pilot) is looking at. Meanwhile, G was generated based on the actions conducted by the pilot, signified by control position changes in the VRFS. By means of processing of these two streams of information in MATLAB, the D kernel of the RCA was constructed. The details on the specifics of the X, G and construction of the D kernel are detailed in further sections.

2.2. Participants

The participants in the study were captains and first officers from airlines who have experience on the Boeing 737NG/MAX airplanes. These plots came from two groups. The first group was of those who were not active pilots, group S1, meaning they lacked 3 takeoffs and landings on the type in the past 90 days. The second group of pilots were active pilots on 737NG/MAX. These individuals were placed into group S2. All pilots in the study had acted as first officers on the aircraft type in the past. They acted as Pilot flying (PF) in this experiment, with the person conducting the experiment as Pilot not Flying (PNF).

For Group S1, the average experience was 1380 hours, with an average age of 28.2 years. Meanwhile for the group S2 the average flying experience was 3030 hours, with an average age of 32.4 years old. Between the two groups, the pilots had experience on the 737NG/MAX of between 700-2240 hours. In total 34 pilots were used in the study, of which 10 were flight instructors on the 737NG.

Despite the presentation of the two groups of pilots, this information was included for the sole purpose of establishing the demographics of the subjects in use. Therefore, the difference between being in either group was not a variable to the study itself. This detail is included to merely provide context on who was evaluated.

2.3. Experimental Setup

Before starting on the experiment, different procedures applied to the groups S1 and S2. Due to not being current on the aircraft, the pilots in group S1 were asked to make 3 visual circuits on the VRFS 737NG in accordance with the 737NG Flight Crew Training Manual (FCTM). This exercise was not done by the S2 pilots due to having currency on the type. Despite this, the pilots in group S2 were given the opportunity still to test out the controls on the plane in the VRFS due to the difference in feel from the real 737 owing to simulator limitations.

For the purposes of uniformity, the simulated 737 was flown using the same configuration for all subjects. This configuration consisted of a Zero Fuel Mass of 48000kg, with 7000kg of fuel on board, thus resulting in a takeoff mass of 55000kg. Likewise, for uniformity, all takeoffs were done with flaps set to $5°$. Finally, the flights were all carried out with the PFD without navigation guidance, and the autothrottle set to off.

The experiment flight consisted of 2 phases. In the first phase the pilots were instructed to do specified maneuvers, while the second phase involved flying ILS approaches to runway 24 of LKPR. The first of which was in Visual Meteorological Conditions (VMC) while the second, and third were in Instrument Meteorological Conditions (IMC).

The following were the instructions to be flown by the pilots:

1. Climb to 4000ft on heading $240°$.
2. Fly at speed 210kt.
3. Turn right to heading $330°$.

4. Turn left heading $240°$ with bank $20°$.
5. Climb to 6000ft with vertical speed 1000ft/min.
6. Descend to 4000ft with vertical speed 1000ft/min.
7. Climb to 6000ft with vertical speed 1000ft/min and turn right heading $330°$.
8. Descend to 4000ft with vertical speed 1000ft/min and turn left heading $240°$.
9. Fly 1st ILS approach and land.
10. Fly 2nd ILS approach and land.
11. Fly 3rd ILS approach and land.

During all parts, over 600 parameters were recorded from the VRFS at a sampling rate of 5Hz. Likewise, the eye tracking recorded data of 1 datapoint per frame, with an average recording framerate of 30 frames per second.

Like the grouping of the pilots, portions 1-8 of the instructions do not play a direct role in the measurements of this study. These sections were there as part of concurrent measurements occurring at the same time as for this study. The detailing of these portions was included here in the interests of completeness as to provide a better context with regards to the whole flight which was asked of the subjects.

This study places its focus upon the three ILS approaches in steps 9-11. These were flown at a reference landing speed (VREF) for flaps $30°$ at 135KIAS. Likewise, all approaches were flown from a base position 15-24nm from runway threshold. The three approaches were flown one after the other, and between approaches the aircraft was repositioned to the base position on a heading of $270°$ to intercept the localizer at 4000ft. The first approach was flown with CAVOK weather and ISA atmosphere. Also, the autobrakes were set to setting 2. The second approach was flown with 3000m visibility, overcast clouds with a base of 1600AMSL and tops of 4300AMSL. On this approach the autobrakes were off, and an instruction to expedite vacating the runway was given after abeam taxiway L or below 30KIAS, whichever came first. The third and final approach was flown in the same conditions as the second approach but had the difference of an instruction to instead vacate runway 24 by taxiing via D, F then crossing runway 12. In the latter ILS approaches, worsened weather conditions, and specific instructions from ATC allowed for the simulation of factors increasing the workload of pilots, which have been linked to increased likelihood of the occurrence of runway incursions (3).

Before any of the data collection was done, the subject was also asked for their consent to have the data recorded, while maintaining their anonymity. Also, for the purposes of concurrent experiments run alongside this study using the same dataset, the pilots were asked to fill a postflight questionnaire, the details of which are not of relevance to this study.

2.4. Equipment and Data Collection

The experiment was run with the use of the simulation software of X-Plane 11 (Laminar Research, Columbia, South Carolina, United States), with a FOVE 0 (FOVE Co., Ltd, Tokyo, Japan) VR headset as the visual implementation in use. This device was chosen given its ability to allow for eye movement monitoring, and likewise its relative ease of use to program with for the purpose of eye tracking. The VR implementation was done using the Steam platform (Valve Corporation, Bellevue, Washington, United States), due to its abilities to work together with supporting software. With regards to the simulation software, it was chosen due to currently being natively capable of VR and being one of the better performing desktop-based simulators at the time. This latter claim can be made as it uses a physics simulation to work out the flight dynamics, as opposed to older simulations which use preset values. Likewise, the simulator was chosen given its ability to natively output flight data to a text document which may then be further processed (16).

For flight controls, a Logitech Flight Yoke System (Logitech International SA, Lausanne, Switzerland) was in use, along with a Logitech Throttle Quadrant (Logitech International SA, Lausanne, Switzerland) and Logitech Flight Rudder Pedals (Logitech International SA, Lausanne, Switzerland). Finally, for interaction with the rest of the VR environment, the hands of the pilot are tracked using VR Gloves (Sensoryx, Zurich, Switzerland). To further enhance this experience, neodymium magnetic beads were mounted to an overhead panel as to give tactile feedback to the pilot when interacting with the area (16).

The whole system was being run on a computer with high graphical capability due to the requirements of the flight simulator coupled with the VR headset. Specifically, the custom computer uses an Intel i7-9700K processor (Intel Corporation, Santa Clara, California, United States), a GeForce RTX 2080 Super graphics card (NVIDIA, Santa Clara, California, United States), 32GB of RAM (Corsair, Fremont, United States), and for storage a 512GB solid state drive (SSD) (Samsung, Seoul, Korea) (16).

On top of the mentioned hardware, biofeedback sensors are also used when running the simulation, specifically that of EEG and ECG. Although, these are mentioned, they played no role in this specific study, and were there for concurrent experiments which took place during the same measurement (16).

To collect all the data from the separate areas of the simulator, a custom software was created in a previous study using the simulator. This software allows for definition of the data to be collected, and synchronicity with the individual data streams, and the scene displayed. Specifically, the recording collected synchronized data from the flight simulation software, the scenes and tracking from the VR headset, and biological signals from EEG and ECG (16).

2.5. Data Processing

The data was processed by means of a script in MATLAB, combined with visual analysis of the Eye tracking frames. The process of this is described in the following section.

2.5.1. Eye Tracking Processing

The eye tracking data was processed starting from the video output from the VRFS with overlayed eye position. The mechanism for generation of this overlay was not part of the scope of this study, it was created as part of a different study. From the video, visual identification was used as to find what was being looked at by the subject during every 30th frame, therefore giving an input for every second. This timeframe is limited due to the manual processing, but at the same time it is great enough given it is above the required time for scene encoding for the human subject of 150ms. This figure of time was established by a research of Rayner et. al (21). The category of what was being perceived in that frame of time was then recorded as the X of the RCA, as described in section 2.1.

This study was unable to use heatmaps and opted instead to look at individual datapoints. This was due to issues in the video files complicating the creation of heatmaps.

Due to the inability of the VRFS do decipher between the subject looking at an area, and the subject seeing what is in that area, an assumption was made that the areas looked at were perceived by the subjects.

For the purposes of simplification, the possible visual perceptions and actions were condensed down to the items, and combinations thereof in Figure 6 . These are linked together by the D kernel which was constructed through the processing.

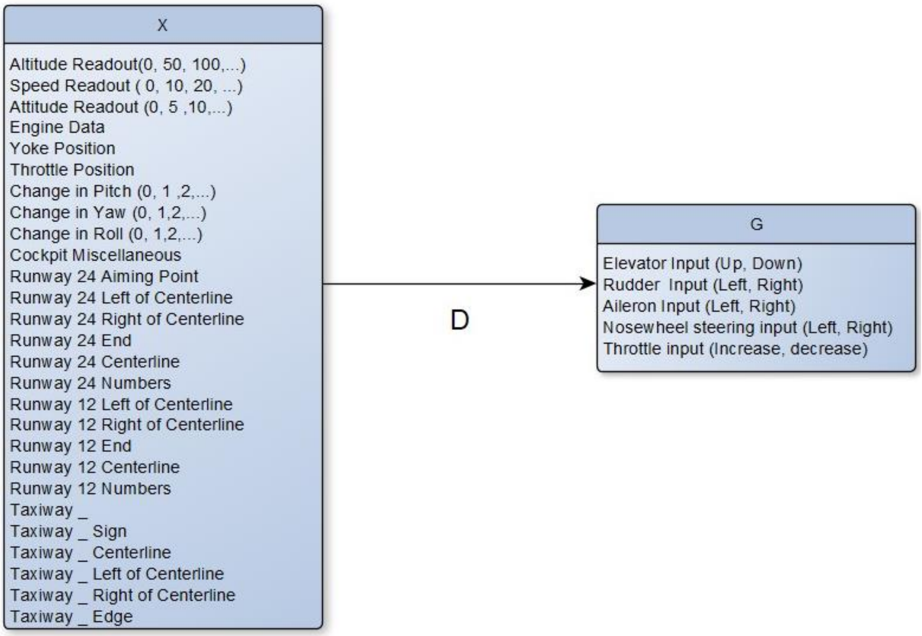

Figure 6. Possible Visual Perceptions and Actions

For areas wherein the perception contains a numerical value, the flight parameters from the VRFS were used to find this value, which was rounded according to the increments stated in the preceding figure.

2.5.2. MATLAB Processing

To process the raw output from the VRFS, which contained a higher resolution than necessary, and contained much unneeded information, the data was condensed down. Specifically, the data was condensed to take the mean value of the data points for every ~ 1 second. The exact second may not be in complete synchronicity with the eye tracking, given the different rates of data capture. However, this factor should not be of significant bias to the data given that the differences in timing were negligible in the order of <1s. Likewise, the data points in the table below were the only ones used from the VRFS simulator output due to many other parameters collected being of no significance to the measurement. These served the purpose of providing numerical values for some perceptions in X, and likewise control information for actions in G according to Figure 6. On top of this, the data outputs were provided for the contextual information regarding aircraft position.

Table 1. Data outputs to be used from X-Plane 11

Data Type	Name In X-Plane 11	Index in X-Plane 11	Name in Output .txt file
Time	Times	1	_real,_time
Top-down position	Latitude, Longitude &Altitude	20	__lat,__deg | ___lon,__deg |
Vertical Position	Latitude, Longitude &Altitude	20	__alt,ftmsl | ___alt,ftagl |
Altitude	Latitude, Longitude &Altitude	20	__alt,ftmsl |
Indicated Airspeed	Speeds	3	_Vind,_kias |
Aircraft attitude (Pitch, roll and yaw)	Pitch, roll and Headings	17	pitch,__deg | _roll,__deg | hding,_true |
Aircraft Heading	Pitch, roll and Headings	17	hding,_true | hding,__mag
Elevator Input	Joystick aileron/elevator/rudder and Flight Controls aileron/Elevator/Rudder	8 and 11	_elev,stick | _elev,_surf |
Aileron Input	Joystick aileron/elevator/rudder and Flight Controls aileron/Elevator/Rudder	8 and 11	ailrn,stick |ailrn,_surf |
Rudder Input	Joystick aileron/elevator/rudder and Flight Controls aileron/Elevator/Rudder	8 and 11	ruddr,stick |ruddr,_surf |
Throttle Input	Throttle (Commanded)	25	thro1,_part |

The data recorded at 5Hz was condensed down to the above-mentioned entries to one datapoint per second. This was done by taking the mean value of every 5 data points in MATLAB from the VRFS output text file. Likewise, only the columns with data relevant to the study were selected as to not need to deal with unnecessary inputs. The condensed data was then be placed into a new .txt file by MATLAB.

2.6. Data Analysis

From this .txt file in the processing the analysis started with the selection of the relevant dataset. This was done by means of placing the condensed .txt from each measurement into MATLAB and writing a .kml file using the latitude, longitude information. A .kml file was used as it was possible to open this file using Google Earth Pro to look at the ground track. This was done as to decipher if a runway incursion, or other wrong runway vacating had occurred during the measurement. From this information, it was then decided if the dataset was to be used or otherwise set aside.

Once all perceptions from the eye tracking were manually established, the flight data had been processed for use and the relevant dataset selected, all actions corresponding to each perception were placed into a single .txt file. This file was then read by MATLAB, and the percentage of each action for a given perception was calculated.

This process was then repeated until all perceptions had the output percentages of their corresponding actions. These percentages then represent the probability of a specific action given a certain perception.

For the possible actions of the subject, these were limited to inputs on the main control surfaces of the aircraft of elevator, rudder, throttle, and aileron movements. If no action was made with relation to these controls, or if an action was done relating to another element in the cockpit, they were listed as no action being conducted. This was done in the interests of simplification, as the interaction with other elements was not expected during the relevant phases. Also, this was done for the practicality in processing, and due to the aim of the study to focus mainly on main interactions, as opposed to secondary details.

With regards to the mentioned control inputs possible, the rudder input also signified steering inputs which were the most important inputs in case of accidental runway incursion. This was the case as the VRFS in use did not incorporate a separate steering tiller, thus the steering inputs were done through the rudder pedals.

Each run of the MATLAB script created one row for the output Markov Kernel from the data, meaning that the probability of all items in each row sums to 100% (6). One column represents a given perception, and one row represents the possible actions and the probability of such an action given a certain perception. The final Markov Kernel was then outputted to a .Csv file. The complete kernel may be seen in the results section.

A sample of the output of a single column of the kernel from the processed data is shown on the right in Figure 7. The left side describes the actions corresponding to their probability of execution on the single column on the right.

81×2 table

Unique Actions				Occurence [%]
{'No Thr inp'}	{'No Rud inp'}	{'No Ail inp'}	{'No Elv inp'}	0
{'No Thr inp'}	{'No Rud inp'}	{'No Ail inp'}	{'Elv UP' }	0
{'No Thr inp'}	{'No Rud inp'}	{'No Ail inp'}	{'Elv DN' }	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail R' }	{'No Elv inp'}	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail R' }	{'Elv UP' }	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail R' }	{'Elv DN' }	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail L' }	{'No Elv inp'}	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail L' }	{'Elv UP' }	0
{'No Thr inp'}	{'No Rud inp'}	{'Ail L' }	{'Elv DN' }	0
{'No Thr inp'}	{'Rud R' }	{'No Ail inp'}	{'No Elv inp'}	0
{'No Thr inp'}	{'Rud R' }	{'No Ail inp'}	{'Elv UP' }	23.529
{'No Thr inp'}	{'Rud R' }	{'No Ail inp'}	{'Elv DN' }	23.529
{'No Thr inp'}	{'Rud R' }	{'Ail R' }	{'No Elv inp'}	0
{'No Thr inp'}	{'Rud R' }	{'Ail R' }	{'Elv UP' }	0
{'No Thr inp'}	{'Rud R' }	{'Ail R' }	{'Elv DN' }	0
{'No Thr inp'}	{'Rud R' }	{'Ail L' }	{'No Elv inp'}	0
{'No Thr inp'}	{'Rud R' }	{'Ail L' }	{'Elv UP' }	0
{'No Thr inp'}	{'Rud R' }	{'Ail L' }	{'Elv DN' }	0
{'No Thr inp'}	{'Rud L' }	{'No Ail inp'}	{'No Elv inp'}	0
{'No Thr inp'}	{'Rud L' }	{'No Ail inp'}	{'Elv UP' }	11.765
{'No Thr inp'}	{'Rud L' }	{'No Ail inp'}	{'Elv DN' }	41.176

Figure 7. Sample of MATLAB Output (table continues further beyond shown)

To calculate the output, from the relevant .txt file corresponding to a specific perception, the aileron, elevator, rudder, and throttle data were selected. With this data, the difference was then taken between the datapoint at the time of perception, and the datapoint directly following the perception. This timeframe between perceptions and action was sufficient given that it is greater than both the simple reaction time, and scene encoding time found by previous studies (21) (22). From there, the action was classified as any of the 81 combinations of actions possible. This number of 81 possible actions was constructed by finding all possible combinations of actions between the 4 control surfaces with 3 possible states each.

To calculate such combinations, the data was codified by having a positive output from a control surface map to a value of 1, a negative output map to the value 2, and no input mapped to 0. For elevators, a positive output refers to movement up, while a negative refers to a movement down. For ailerons and rudder, a positive output was to the right, while a negative was to the left. For throttle, a positive output was an increase in power, while a negative was for a decrease. For the purposes of simplicity, the reaction of the relevant part on the plane was not accounted for and was taken as instantaneous.

To differentiate actions between the 4 different control surfaces, the data from each surface involved was multiplied by an exponent of 10 starting with 10^0 multiplied to the elevator data, 10^1 for the aileron input, and in order further for the rudder then throttle inputs. This was done as to be able to know which surfaces were being moved together in a single datapoint. For example, following the logic, an output of 1210 mapped to throttle up, rudder left, aileron right, and no elevator input.

From the constructed combinations, the number of times a specific combination came up was counted. Then, this was divided by the total number of actions taken for the given perception. This resulted in the construction of each column of the Markov Kernel.

3. RESULTS

From the 34 measurements conducted, each corresponding to a single individual, none ended in the intended runway incursion of accidental vacating to runway 12/30. Although, across the measurements, there were indeed 5 cases of the aircraft vacating to the wrong position relative to instructed. Of these 5 cases, a single case presented the possibility to be investigated. This was due to issues regarding the video recording on 4 of the 5 cases. The case investigated involved the pilots vacating the runway to taxiway C, whereas the aircraft was instructed to specifically vacate via D. This occurred during the last approach of the measurement. In this approach the pilot flew an ILS in IMC conditions down to 1600ft AMSL. The raw data of this measurement can be seen in Appendix 1.

3.1. Data Presentation

Through the processing of the selected case's data, the actions for each perception were established and the D kernel was created.

3.1.1. Approach with wrong Vacating

The part of flight analyzed is shown on the ground track in Figure 8. This starts at approximately the point when the minimums were reached.

Figure 8. Ground Track of 3rd approach and landing

The Table 2 lists on the left-hand side the individual combinations of actions taken. It does not show all possible combinations of actions, but only those which were done by the pilot. All the actions in each row were taken at the same time. From left to right, it specifies the type of action taken with the relevant control surface going from throttle (Thr), rudder (Rud), aileron (Ail), then elevator (Elv). For throttle, an UP input signifies an increase in engine power in the forward and reverse range, while a DN input signifies a decrease in engine power. In the data used, only one input for throttle UP was related to an increase in forward thrust, and this was marked in the table in orange. All other inputs for throttle UP corresponded to an increase in reverse thrust. This was the case, given the limitation of the flight data recording showing throttle inputs (both forward and reverse), as values from 0-1.

Table 2. Output D Kernel From 3rd Approach Conducted (Runway 24 End - R24 ED, Runway 24 Numbers (Identifier) - R24 NB, Runway 24 Centerline – R24 ctr, Runway 24 Left of Centerline – R24 LoC, Runway 24 Aiming Point – R24 AP, Taxiway C centerline – Twy C ctr, Taxiway C Left of Centerline – Twy C LoC)

Unique Actions Conducted				**Probability of Action given Perception (%of Occurrence)**						
				R24 ED	**R24 NB**	**R24 ctr**	**R24 LoC**	**R24 AP**	**Twy C ctr**	**Twy C LoC**
No Thr inp	No Rud inp	No Ail inp	Elv UP	0.00	0.00	0.00	0.00	0.00	10.00	0.00
No Thr inp	No Rud inp	No Ail inp	Elv DN	0.00	0.00	0.00	4.00	0.00	0.00	0.00
No Thr inp	Rud R	No Ail inp	Elv UP	0.00	0.00	0.00	0.00	0.00	10.00	23.53
No Thr inp	Rud R	No Ail inp	Elv DN	0.00	0.00	0.00	8.00	0.00	30.00	23.53
No Thr inp	Rud R	Ail R	Elv UP	0.00	0.00	0.00	8.00	0.00	0.00	0.00
No Thr inp	Rud R	Ail R	Elv DN	0.00	0.00	33.33	4.00	0.00	0.00	0.00
No Thr inp	Rud R	Ail L	Elv UP	0.00	0.00	0.00	4.00	0.00	0.00	0.00
No Thr inp	Rud R	Ail L	Elv DN	0.00	0.00	0.00	4.00	0.00	0.00	0.00
No Thr inp	Rud L	No Ail inp	Elv UP	0.00	0.00	0.00	8.00	0.00	10.00	11.76
No Thr inp	Rud L	No Ail inp	Elv DN	0.00	0.00	0.00	0.00	0.00	20.00	41.18
No Thr inp	Rud L	Ail R	Elv UP	0.00	100.00	33.33	0.00	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv UP	50.00	0.00	0.00	8.00	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv DN	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr UP	Rud R	No Ail inp	Elv DN	0.00	0.00	0.00	0.00	0.00	10.00	0.00
Thr UP	Rud R	Ail L	Elv UP	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr UP	Rud L	Ail R	Elv UP	50.00	0.00	0.00	0.00	0.00	0.00	0.00
Thr UP	Rud L	Ail R	Elv DN	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr UP	Rud L	Ail L	Elv UP	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr UP	Rud L	Ail L	Elv DN	0.00	0.00	0.00	8.00	0.00	0.00	0.00
Thr DN	No Rud inp	No Ail inp	Elv UP	0.00	0.00	0.00	0.00	0.00	10.00	0.00
Thr DN	Rud R	Ail R	Elv UP	0.00	0.00	33.33	0.00	100.00	0.00	0.00
Thr DN	Rud R	Ail R	Elv DN	0.00	0.00	0.00	8.00	0.00	0.00	0.00
Thr DN	Rud R	Ail L	Elv UP	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr DN	Rud R	Ail L	Elv DN	0.00	0.00	0.00	8.00	0.00	0.00	0.00
Thr DN	Rud L	No Ail inp	Elv DN	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Thr DN	Rud L	Ail L	Elv UP	0.00	0.00	0.00	4.00	0.00	0.00	0.00

For rudder and aileron, the logic goes that an R input is to the right and an L input is to the left. For elevators, an UP input is for elevator up and a DN input is for elevator down. For no input made “No X inp” was stated, where X is the abbreviation for the relevant control surface.

On the right-hand side of the table are the perceptions which were observed by looking at the eye tracking data. Below each perception observed is the likelihood of each of the actions taken.

A visualization of the data seen in Table 2 can be seen in Figure 9.

In the timeframe observed, between minimums and fully vacating the runway past the holding point, the pilot did not ever look to the instruments. The pilot was only seen to have looked to 7 areas, relating to different points on runway 24 and taxiway C. The pilot spent the greatest amount of time looking to a spot on runway 24 left of the centerline. This was followed second in frequency by looking at miscellaneous points on taxiway C left of the centerline.

One detail not shown in the output kernel, but of valuable information, is that for the time observed, the pilot maintained a forward-facing position, and did not tend to turn or nod their head often. This was suggested by the video constantly showing a scene just above the primary flight display. This can be said as the video was centered around the central position of field of view of the pilot. An example of the view which prevailed during the measurement is shown in Figure 10.

Looking further into the details of the kernel, different actions were seen for each perception. In the perception of runway 24 end which had 2 data points, there was always an action of increase in up elevator, and left rudder. While half the time the ailerons were moved in one direction, and in the other half they were moved in the opposite. Likewise, in half the time the throttle was increased. Although, this increase was numerically small at a value of only 0.1% of throttle lever range of movement.

Looking at the perceptions of runway 24 number, and runway 24 aiming point, a deterministic behavior in the kernel was seen with only one combination of actions resulting from each perception. In both cases elevator up was seen, as well as right aileron. Although different actions occurred in the areas of throttle and rudder, with the former showing left rudder and no throttle inputs, while the latter showed right rudder, and throttle down inputs. The deterministic behavior was due to only a single datapoint mapping in each case.

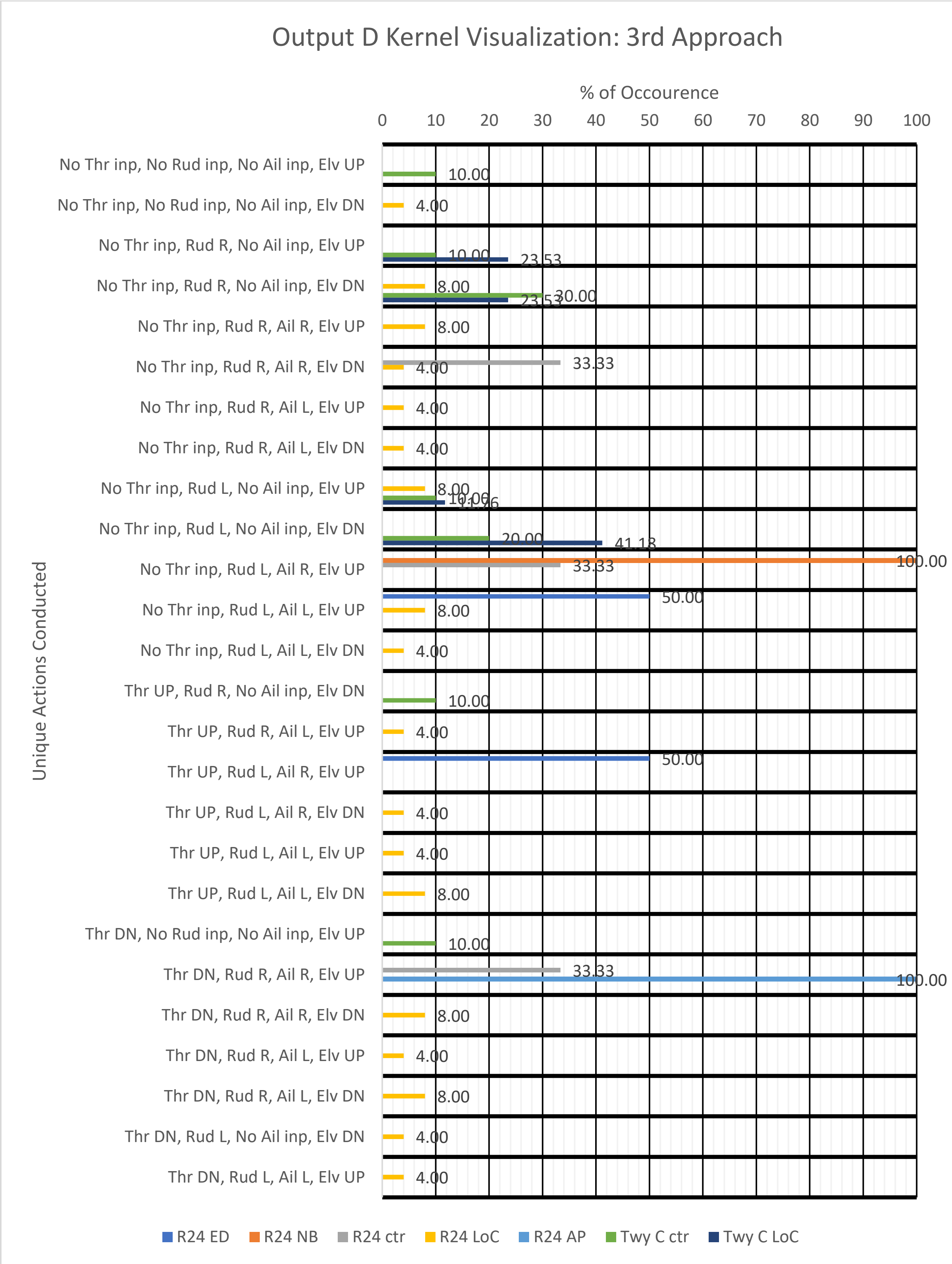

Figure 9. Data Visualization of 3rd Approach (Runway 24 End - R24 ED, Runway 24 Numbers (Identifier) - R24 NB, Runway 24 Centerline – R24 ctr, Runway 24 Left of Centerline – R24 LoC, Runway 24 Aiming Point – R24 AP, Taxiway C centerline – Twy C ctr, Taxiway C Left of Centerline – Twy C LoC)

Figure 10. Primary Field of View in Measurement Video with Eye tracking Overlay (Blue – Left Eye, Red – Right Eye)

In the case of the perception of runway centerline, which occurred 3 times, 3 different actions were seen. In all cases the ailerons were placed towards the right, and in two of these times the rudder was likewise deflected toward the right, while in one it was deflected left. Elevator up was also seen in 2/3 cases, meanwhile a down deflection was seen in 1/3 cases. Finally, for throttle no input was seen in 2/3 cases, and a decrease was seen in 1/3 cases.

With the most common perception of left of centerline on runway 24, which had 25 datapoints, a large variety of actions were seen, which each occurred once or twice each. Once being signified by an action which had 4% probability, and twice by 8% probability. The most common control surface movement was elevator down at 56% of datapoints, followed by rudder right and aileron left equally at 52%. This was then followed by rudder left and elevator up equally at 44%.

Moving onto the taxiway C perceptions, starting on the centerline perception, which had 10 datapoints, 50% of the time right rudder inputs were seen. left rudder inputs were seen 30% of the time, and 20% without rudder inputs. A wide variety of elevator and aileron inputs were also seen in this time. Finally, an increase in reverse thrust was also seen in one case. For the perception meanwhile of points left of centerline on taxiway C, it was largely centered close to the centerline and had 17 datapoints. The most common action was involved left rudder inputs, while the rest involved inputs of the rudder to the right. No throttle or aileron inputs were seen with this perception, while the elevator was once again seen moved multiple times in both directions.

3.1.2. Second Approach for Comparison

As a point of comparison to the landing wherein the pilot vacated the runway wrongly, a second approach and landing was also evaluated from the same subject. Although in this approach the instructions were rightly followed, it contained its own issue of a landing with two bounces. This approach and landing analyzed was the second approach conducted in the measurement. This was chosen since the first approach did not end in a landing and vacating, but instead a go-around due to the pilot failing to touchdown in time. Aside from the issue of a bounced landing, this approach also contained multiple ground proximity, and glideslope warnings. The ground track of this approach is shown in Figure 11.

Table 3. Output Kernel From 2nd Approach Conducted (Runway 24 Centerline – R24 ctr, Runway 24 Left of Centerline – R24 LoC, Cockpit Miscellaneous – Cpt Misc, Taxiway D Centerline – Twy D ctr, Taxiway D Left of Centerline – Twy D LoC).

Unique Actions Conducted				Probability of Action given Perception (%of Occurrence)				
				R24 ctr	**R24 LoC**	**Cpt Misc**	**Twy D ctr**	**Twy D LoC**
No Thr inp	No Rud inp	Ail L	Elv UP	0.00	5.26	0.00	0.00	0.00
No Thr inp	Rud R	No Ail inp	No Elv inp	16.13	10.53	50.00	8.70	0.00
No Thr inp	Rud R	No Ail inp	Elv DN	0.00	15.79	0.00	0.00	0.00
No Thr inp	Rud R	Ail R	No Elv inp	3.23	0.00	0.00	0.00	0.00
No Thr inp	Rud R	Ail R	Elv DN	3.23	0.00	0.00	0.00	0.00
No Thr inp	Rud R	Ail L	Elv UP	6.45	5.26	0.00	0.00	0.00
No Thr inp	Rud R	Ail L	Elv DN	6.45	5.26	0.00	0.00	0.00
No Thr inp	Rud L	No Ail inp	No Elv inp	9.68	5.26	0.00	21.74	0.00
No Thr inp	Rud L	Ail R	Elv UP	3.23	0.00	0.00	0.00	0.00
No Thr inp	Rud L	Ail R	Elv DN	3.23	5.26	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv UP	6.45	0.00	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv DN	6.45	5.26	0.00	0.00	0.00
Thr UP	Rud R	No Ail inp	No Elv inp	0.00	5.26	0.00	26.09	0.00
Thr UP	Rud R	Ail R	Elv DN	0.00	5.26	0.00	0.00	0.00
Thr UP	Rud R	Ail L	Elv UP	0.00	5.26	0.00	0.00	0.00
Thr UP	Rud L	No Ail inp	No Elv inp	0.00	5.26	0.00	8.70	100.00
Thr UP	Rud L	Ail R	No Elv inp	3.23	0.00	0.00	0.00	0.00
Thr UP	Rud L	Ail R	Elv DN	3.23	0.00	0.00	0.00	0.00
Thr UP	Rud L	Ail L	No Elv inp	3.23	5.26	0.00	0.00	0.00
Thr UP	Rud L	Ail L	Elv UP	0.00	5.26	0.00	0.00	0.00
Thr DN	Rud R	No Ail inp	No Elv inp	3.23	5.26	0.00	13.04	0.00
Thr DN	Rud R	Ail R	No Elv inp	0.00	0.00	50.00	0.00	0.00
Thr DN	Rud R	Ail R	Elv DN	3.23	0.00	0.00	0.00	0.00
Thr DN	Rud R	Ail L	Elv DN	3.23	0.00	0.00	0.00	0.00
Thr DN	Rud L	No Ail inp	No Elv inp	9.68	5.26	0.00	21.74	0.00
Thr DN	Rud L	Ail L	No Elv inp	6.45	0.00	0.00	0.00	0.00

From the processing of the second approach and landing, the D kernel in Table 3 was created. Like the previous Kernel, throttle UP inputs refer to an increase in engine power in both forward and reverse thrust. The inputs referring to an increase in forward thrust are marked in orange.

Like the 3rd approach, a visualization of the processed kernel from the 2nd approach can be seen in Figure 12.

In this approach, the pilot once again never looked towards the instruments between minimums and vacating the runway. During this approach, they only looked to five areas, the runway 24 centerline, left of the runway centerline, miscellaneous spots in the flight deck, the taxiway D centerline, and left of the taxiway D centerline.

The most common area looked at in this approach was the centerline of runway 24. This area was viewed across multiple points starting from before touchdown, until before exiting the runway via taxiway D. From looking to this area, again a wide variety of actions were seen ranging from one occurrence, up to 5 on an input of only right rudder.

Figure 11. Ground track of 2nd approach and landing

The next most common occurrence was that the subject was looking at the taxiway D centerline. This happened for 23 datapoints. The most common action taken by the pilot, seen in 52.2% of datapoints, was input of left rudder. Across the entire time with this perception, no actions were seen with regards to the elevators and ailerons. Finally, looking at throttle inputs, there was an equal split of time wherein forward thrust was increased and decreased, at 34.8% of the time each.

In this measurement, the third most common perception was to look left of centerline on runway 24. This also showed a large variety of actions referring to it, ranging from one to three occurrences each. Within these actions, the most common movement was to increase right rudder, which was seen in 57.9% of datapoints.

The two least common perceptions were miscellaneous areas in the cockpit, and left of taxiway C. With the former, 2 cases were seen, and in both the subject was seen to have made right rudder inputs. While in the latter, 1 case was seen, and it involved left rudder inputs and increase in throttle.

3.1.3. Comparison of Approaches

Looking to the two kernels generated from the two approaches processed, multiple areas can be compared.

Starting from the big picture, in terms of areas the pilot was looking, the two approaches were similar in that the attention was primarily outside. Likewise, in both cases, no datapoints showed the pilot ever checking their instruments. With the perceptions outside, these were primarily on, or left of the centerlines of the runway and relevant taxiway. Given the data, it was likely that these points were looked at as a means of judging the relative lateral position of the aircraft to the taxiway or runway. The same can also be said about with regards to height above the runway in these areas, as well as in the areas of the runway numbers, runway end, and runway aiming point. The claim of using the area of centerline and left of centerline to judge the lateral position is further supported by the datapoints showing a great amount of rudder inputs in these perceptions. Similarly, the variety of elevator, aileron and rudder inputs seen while looking to the runway centerline and left thereof suggest the use was for judging height and lateral position during the last moments of flight.

Looking to the probabilities of actions for a given perception, it was seen in both that there were entries with deterministic actions due to only having one datapoint. Similarly, both approaches had perceptions with only 2 options available due to again having only 2 datapoints related to the perceptions. Finally, in both approaches the perceptions which were widespread across the measurement likewise had a wide spread of actions relating to them.

Altogether, looking between the two output kernels from the approaches investigated, they showed similar behaviors in actions relating to perceptions. This was seen in all areas from before touchdown, during rollout, and after vacating. Looking to the kernels, no drastically striking differences were seen between them.

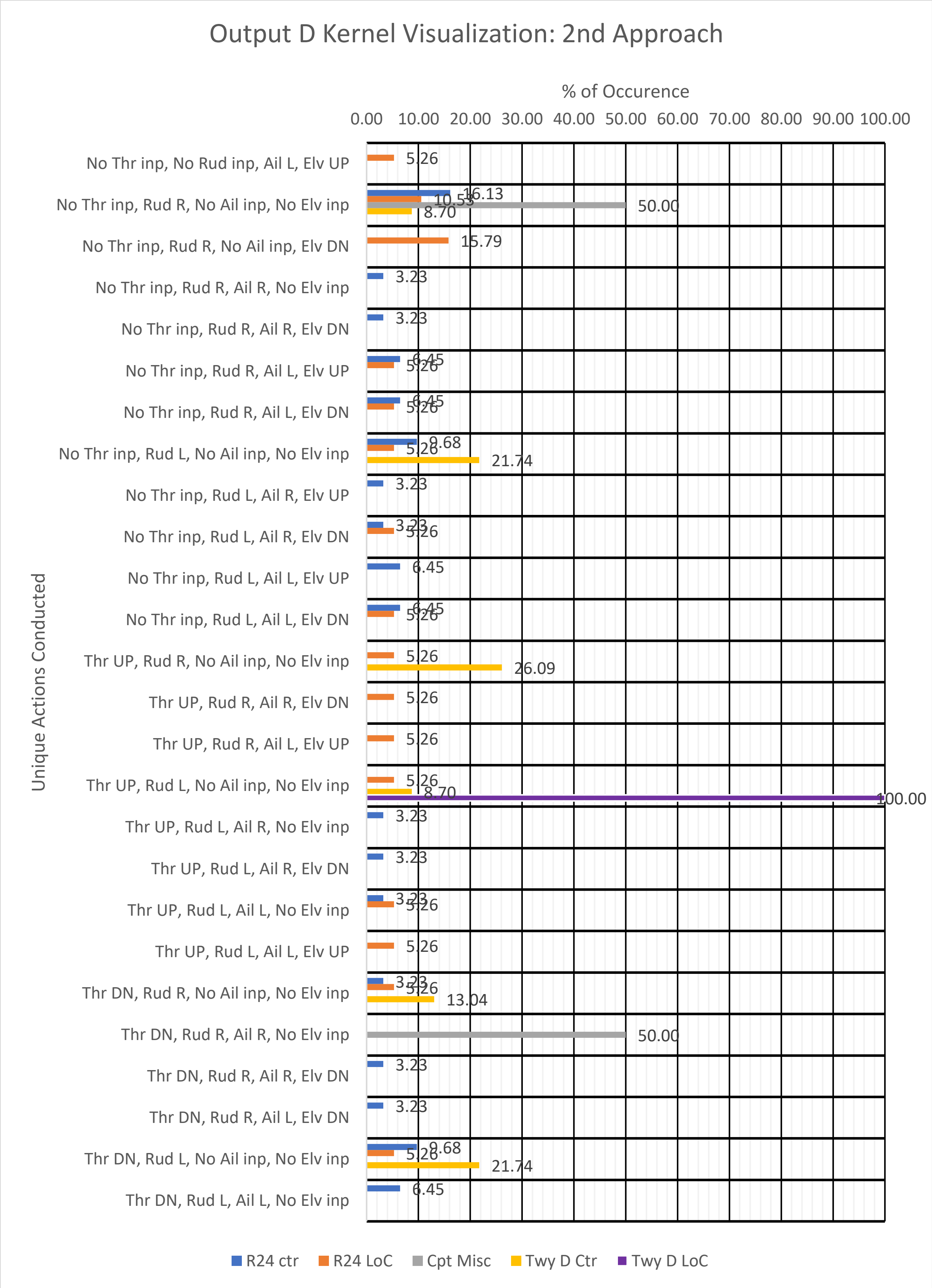

Figure 12. Data Visualization of 2nd Approach (Runway 24 Centerline – R24 ctr, Runway 24 Left of Centerline – R24 LoC, Cockpit Miscellaneous – Cpt Misc, Taxiway D Centerline – Twy D ctr, Taxiway D Left of Centerline – Twy D LoC).

4. DISCUSSION

This section will detail the information which was collected from the results shown in the previous chapter.

4.1. Case Information

Investigating the case of the vacating to the wrong taxiway, certain similarities can be seen with the contributory factors to a runway incursion. The total reasoning behind the wrong vacating was likely due to a mix in these factors. Looking first at the overall situation in the 3rd approach, it was flown close to minimums in IMC, and at minimums the aircraft was to the left of the centerline. Next, the approach was the last approach after an hour of flight involving two previous approaches and other non-standard maneuvers. Further, the two previous approaches were also not altogether normal, with the first one ending in a go-around, and the second having a double bounced landing. These are conditions which were likely to contribute to the risk factors in runway incursions of task saturation, and limited situational awareness (2) (3). Although, due to not looking into the task load index presented to the pilot, this study is unable to confirm the level of saturation of the individual.

One thing this study was able to establish in the case investigated in the 3rd approach, was that overarching situational awareness was not presented by the individual. Quite contrary to the causal factors in a runway incursion (2), this was due to the individual having a constant “head-up” position in the cockpit during the landing roll. This made it so that there was no possibility for the pilot to have been monitoring their deceleration quantitatively. This was supported by the eye tracking data only showing perceptions involving elements external to the cockpit for the duration of the landing roll. This behavior was seen in the two approaches compared. As to why specifically the pilot decided to not monitor the deceleration, despite being instructed to vacate specifically on taxiway D remains unknown. This may have been due to a multitude of factors aside from those already mentioned, which may include but are not limited to, difficulty experienced with looking downward while wearing the VR HMD, the pilot forgetting the instruction, the pilot normally conducting landings in this manner, familiarity with the aircraft or airport, accidental overapplication of deceleration, and so on.

From the comparison of the data of the two approaches, it suggested that the focus of the pilot was on maintaining the position on the runway. This was suggested by the pilot constantly looking to an area which would potentially help them determine lateral position, and these perceptions often being associated with rudder inputs.

4.2. ITP RCA Modeling

Looking more generally at the data, as to see what the ITP and its RCA can provide, it was able to accomplish its task of showing the likelihood of actions for a given perception.

Likewise, the kernel generated was able to show trends in actions conducted for specific perceptions. This was evident especially in the perceptual areas seen relating to taxiways. These showed the behavior inclined towards rudder inputs to vacate to the taxiway, and further to stay on it. This was seen in 96% of the datapoints relating to taxiway perceptions in both approaches. This could also be seen in the behavior of the pilot in the 3rd approach with the perceptions relating to the runway end, centerline, aiming point and runway numbers, which were all perceived while still airborne. With these perceptions, there was an affinity towards actions to increase the elevator pitch, which match up with the action of flaring the airplane. This was the case in 85.7% of relevant datapoints. Seeing that the kernel generated according to the ITP reflects the behaviors in a normal situation, it is likely that in an actual runway incursion it would possibly likewise confirm certain causal factors, such as that of showing if awareness is lacking in a situation, as was the case with the landing roll previously discussed.

The actual details of what the RCA's kernel could show unfortunately remains unknown, due to the inability to forcibly create a runway incursion scenario without creating bias in the actions conducted by the pilots. Perhaps this accidental runway incursion would be possible with the scenarios used in this study, but it unfortunately was not the case in the 34 measurements which were conducted.

Despite not knowing exactly what the ITP would provide in an actual runway incursion, by comparing an approach where instructions were followed, with one where they were not, it was seen that the ITP could provide contextual information about what the pilot was doing given what they were seeing. In the cases compared, this was seen firstly with how the pilot behaved on a normal approach, versus one that ended in error. In both cases the pilot was seen constantly paying attention to external factors, and in turn making inputs to stay on the runway or taxiway. Also, the area looked at on the runway, being on the left could suggest the possibility that the pilot was also looking to see for taxiway lines to vacate the runway. By comparing both approaches, the ITP also showed that in the case of wrong vacating, no increases in throttle were made after landing, as to vacate further down the runway. Such a point could suggest a precursor factor as misunderstood instructions. Therefore, the ITP was able to show the ability to help detect certain precursors to runway incursion.

This means that the ITP could help detect precursors could be seen in multiple ways. One such way was showing where a pilot was looking and linking that to their actions. This allowed the potential to link erroneous actions with where the individual was looking. Another way the ITP was seen to help detect precursors to runway incursion was by allowing a comparison of actions between flights. This let one see if significant differences occurred between a normal, and non-normal situation by comparing the actions for given perceptions.

Finally, the ITP showed the possibility to give insight to the precursor to runway incursion of a lack of situational awareness, as seen by the output kernel showing missing perceptions otherwise relevant to proper execution of instructions.

4.3. Interface Theory

In the modeling of the RCA, it could also be seen that the world often acted as an interface which was not necessarily perceived literally. This could be seen in the areas where the pilot chose to look during both approaches. Often, the pilot was looking towards areas on the runway and taxiway centerline markings, or close to their position. While the pilot was literally looking either to concrete, or marks on concrete, based on the actions, it was likely that the pilot was perceiving their relative position to such markings. This was likewise suggested regarding vertical position when the subject was looking at the runway end, aiming point and runway numbers. This follows in line with the theory's claim that perceptions need not be literal as to be useful to an individual (6) (an example of a literal perception being seeing something directly for what it is, e.g., seeing the lines of paint on the ground as lines of paint, without deriving any meaning further).

Although such derived meaning was suggested by the eye tracking and actions, the study chose to write perceptions in the context of the kernel referring to the literal spots looked at. This was done, as the manual processing would likely introduce unnecessary bias to the matching of eye tracking to a specific factor such as "being on centerline". An example can be seen in Figure 13 wherein the aircraft is clearly on centerline, but the processor is unable to tell whether this was indeed known to the pilot given when they were looking.

Figure 13. Example of Ambiguous Frame if listing percepts directly

4.4. Modeling Consequences

For some perceptions, deterministic behavior was seen in the Markov Kernel. This is likely due to the limits in the modeling used. This may have been caused by the lack in possible resolution creating perceptions wherein only one datapoint could have been used. It is possible that an increased resolution of the data would allow more detail to be seen by zooming into what was one data point in this study, and taking it as separate points by decreasing the time step of the flight and eye tracking data.

The consequences of limited resolution were also seen in the perceptions which occurred across different portions of the approach. Compared to those other perceptions that showed clear trends in actions, they were occurring in a similar timeframe wherein a similar part of the flight was happening. Meanwhile, these perceptions were seen across times ranging from before touchdown, up to right before leaving the runway. This suggests that a single kernel is not applicable across the whole timeframe, and there could be benefits of clearer behavior patterns should the kernel be generated per each specific subset of time. Another possibility is due to the general nature of the definition of the perceptions, they may not have given as much definition to the actions linked, and this may be fixed by changing the perceptions to be more specific than defined. The final means to potentially fix this would be by modeling the memory of the RCA, as the information stored in its memory changes the D kernel itself in accordance with what the RCA had remembered in the past (7). This would therefore mean that the probability of the actions for a given perception would then be changing according to the context of the perception.

Another consequence of the limited resolution chosen was seen in the results in control inputs. Due to not specifying actions based on the specific amount of control deflection, it was impossible to decipher whether certain inputs were of significance. This could be seen in the perceptions relating to movement on the taxiway. During the whole-time elevator inputs were being made. This is since an elevator input is recorded anytime there is a difference in control position, regardless of degree. It is possible, that during this portion of the flight the inputs were merely a result of the pilot's hand on the yoke registering as a miniscule movement of the controls. This issue may be omitted by setting a threshold as to when an input will be registered. Despite this, the study has decided against setting such a threshold due to being unable to decipher at what value this threshold should be set while at the same time not missing any actual inputs.

4.5. Further Consequence Investigation

Unfortunately, this study was unable to address majority of these modeling limitations stated due to the lack of a sufficient timeframe between discovering the limitations, and completion of the study. Although, the study was able to investigate further the consequences of initially processing the data at a time interval of 1 second. This was done by reprocessing a portion of the approach with wrong vacating. Specifically, the reprocessing was done on the 3rd approach between the point of reaching 60kts, and completely vacating the runway. This was reprocessed at the data capture rate of 5Hz. The output kernel from this reprocessing is seen in Table 4, and its visualization is seen in *Figure 14.*

Table 4. Output D Kernel: Reprocessed 3rd Approach at 5Hz (Runway 24 Left of Centerline – R24 LoC, Taxiway C centerline – Twy C ctr, Taxiway C Left of Centerline – Twy C LoC, Taxiway C edge – Twx C eg)

Unique Actions Conducted				**Probability of Action Given Perception (% of Occurrence)**			
				R24 LoC	**Twy C ctr**	**Twy C LoC**	**Twy C eg**
No Thr inp	No Rud inp	No Ail inp	No Elv inp	2.70	0.00	4.49	0.00
No Thr inp	No Rud inp	No Ail inp	Elv UP	10.81	28.57	17.98	0.00
No Thr inp	No Rud inp	No Ail inp	Elv DN	16.22	21.43	17.98	0.00
No Thr inp	Rud R	No Ail inp	No Elv inp	0.00	4.76	1.12	0.00
No Thr inp	Rud R	No Ail inp	Elv UP	0.00	9.52	8.99	0.00
No Thr inp	Rud R	No Ail inp	Elv DN	5.41	7.14	14.61	0.00
No Thr inp	Rud R	Ail R	Elv DN	2.70	0.00	0.00	0.00
No Thr inp	Rud R	Ail L	Elv DN	5.41	0.00	0.00	0.00
No Thr inp	Rud L	No Ail inp	No Elv inp	0.00	2.38	3.37	0.00
No Thr inp	Rud L	No Ail inp	Elv UP	10.81	7.14	15.73	66.67
No Thr inp	Rud L	No Ail inp	Elv DN	2.70	0.00	15.73	33.33
No Thr inp	Rud L	Ail R	Elv DN	2.70	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	No Elv inp	2.70	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv UP	5.41	0.00	0.00	0.00
No Thr inp	Rud L	Ail L	Elv DN	2.70	0.00	0.00	0.00
Thr UP	No Rud inp	No Ail inp	Elv UP	0.00	7.14	0.00	0.00
Thr UP	No Rud inp	No Ail inp	Elv DN	0.00	4.76	0.00	0.00
Thr UP	Rud L	Ail L	Elv DN	2.70	0.00	0.00	0.00
Thr DN	No Rud inp	No Ail inp	Elv UP	0.00	4.76	0.00	0.00
Thr DN	No Rud inp	No Ail inp	Elv DN	2.70	2.38	0.00	0.00
Thr DN	No Rud inp	Ail L	No Elv inp	5.41	0.00	0.00	0.00
Thr DN	No Rud inp	Ail L	Elv UP	2.70	0.00	0.00	0.00
Thr DN	Rud R	Ail R	Elv UP	5.41	0.00	0.00	0.00
Thr DN	Rud R	Ail R	Elv DN	8.11	0.00	0.00	0.00
Thr DN	Rud R	Ail L	Elv DN	2.70	0.00	0.00	0.00

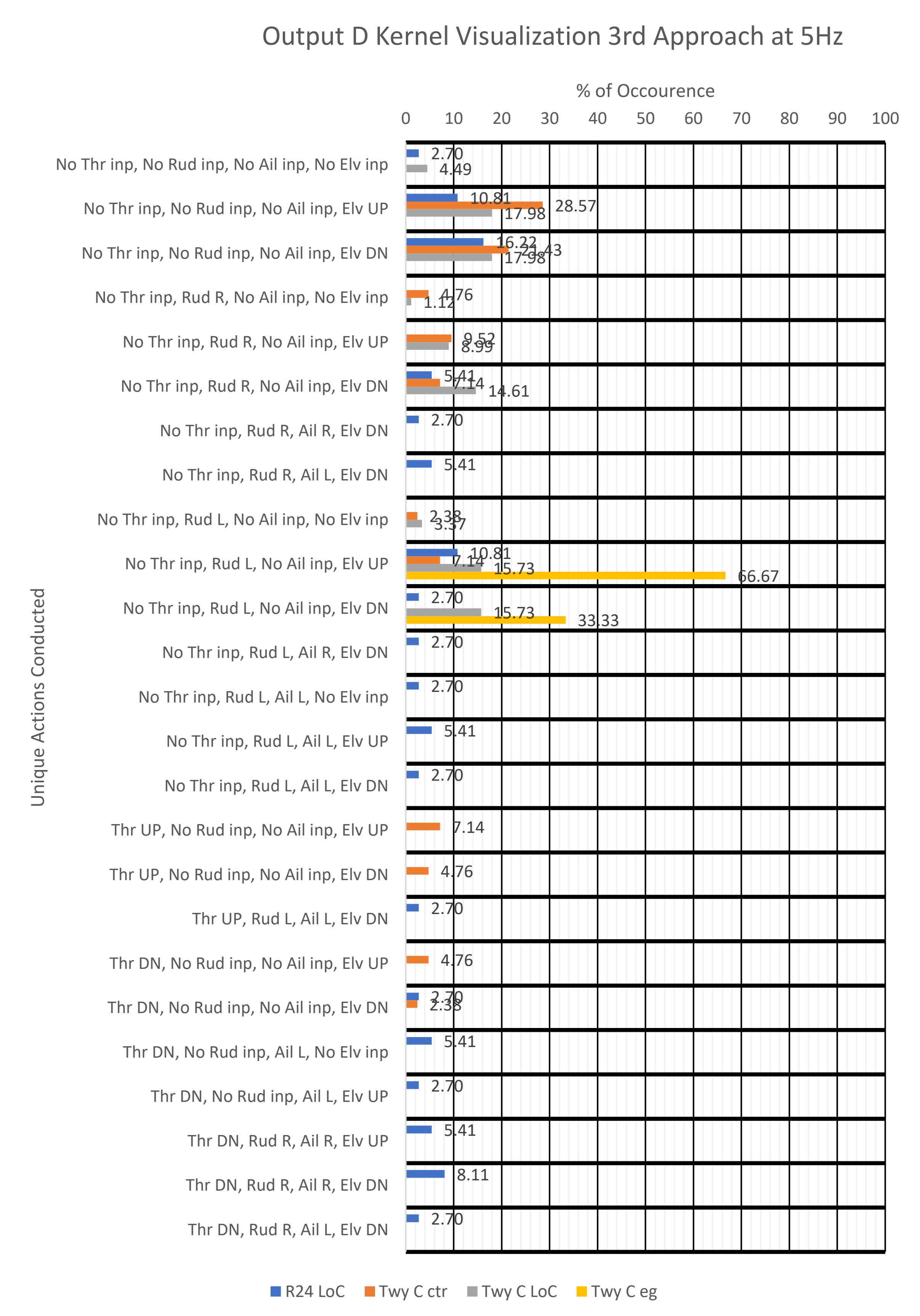

Figure 14. Data Visualization of Reprocessed D Kernel: 3rd Approach at 5Hz (Runway 24 Left of Centerline – R24 LoC, Taxiway C centerline – Twy C ctr, Taxiway C Left of Centerline – Twy C LoC, Taxiway C edge – Twx C eg)

From reprocessing the kernel for the part of the 3rd approach, multiple consequences were seen. Firstly, given the increased resolution, the time to process a given amount of time increased. Secondly, due to the smaller time interval, frame rate sensitivity became more significant. This was seen in that when a frame drop occurred, the time on the flight data did not match the video with eye tracking overlay. To compensate for this, an extra 2-3 frames were skipped in such cases as to be viewing a frame with a matching time stamp as flight data.

Looking at the reprocessed kernel, there were no major missed phenomena seen between processing at 1Hz and 5Hz. Although, there was definite information loss when looking only at 1Hz. Firstly, this may be seen given the perception of the taxiway C edge. This perception occurred in 3 cases across 1 second, but all three cases were in between the interval of 30 frames in the initial 1Hz processing. Secondly, a loss of information from the 1Hz processing may be seen in the actions conducted. The most significant difference was seen in that, with the 5Hz processing, there were instances recorded where no actions occurred. Additionally, in the reprocessed kernel, there were entries wherein no elevator inputs were seen. This consequence in the 1Hz initial output was due to taking the average of every 5 datapoints. This in turn masked those datapoints wherein no inputs occurred.

Comparing specific percepts, would best be done on the areas relating to the taxiway, as the full timeframe of being on the taxiway was present in both the initial processing, and the reprocessing. Firstly, data loss was seen in the 1Hz processing, just like with the overall kernel. One example of this would be that the inputs with only down elevator were completely lost in the 1Hz version of perceptions of taxiway C centerline and left of centerline. Another example of data loss was that in the 1Hz processing of left of taxiway C center line, the perceptions were split across 4 actions, whereas in the 5Hz, they were across 9. The same was the case with the taxiway C centerline, where the 1Hz captured 7 actions, while the 5Hz captured 11. Data change was also seen in the higher resolution reprocessing. With the centerline perceptions, the most common at 1Hz was for elevator down with right rudder, meanwhile at 5Hz the most common action was elevator up alone, followed by elevator down alone. Despite these differences though, the data on the taxiway C precepts still maintained its overall trend of showing much rudder inputs to maintain lateral position. Therefore, the reprocessing did not change the big-picture conclusions from the data.

Altogether, a sure benefit could be seen with reprocessing at a higher frequency. Although processing at lower frequency did not create any major changes in the data trends, certain details were indeed lost. Firstly, certain perceptions were lost, such as those of the taxiway edge. Secondly, certain actions were lost or gained due to combining datapoints.

Thirdly, percentages of actions were mixed up due to this mixing. All in all, a higher frequency of processing, while having its own challenges, would be beneficial to future works as it allows a truer image of reality of the RCA, as well as better accuracy on the details of its actions given a perception. Although, processing at 1Hz still allowed for a more general image of the RCA's reality to be created.

4.6. Data Validation

To ensure the integrity of the data processed, validation was done in multiple ways. Firstly, this was done by having the processing be according to the Interface Theory of Perception. Secondly, this was done by testing of the scripts used in processing multiple times before the actual data input. Third, the validity of the kernels was ensured by manually checking datapoints from the flight data and comparing it with the result in the output kernel. Fourthly, data validation was ensured on the eye tracking by confirming the simulator timestamp of the image matched with the timestamp on the flight data it was to relate to. Finally, the data was validated through expert evaluation from experience as a pilot and showed no apparent issues. These methods together were used as to ensure the data in this study reflected the reality of the measurement conducted.

5. CONCLUSION

Runway incursions present a continuous challenge in safety in the aviation industry, and thus tools to investigate them are of great importance. This study investigated a potential means for another possible tool to understand the phenomenon by means of the RCA from the ITP. While the study was unable to use this theory directly in a runway incursion scenario, overall, from the information presented conclusions may be made regarding the specific scenario looked at, the ITP RCA and the consequences of the modeling.

5.1. Summary and Contribution

This thesis investigated the ITP RCA in runway incursion events in LKPR using the VRFS. This was done with a selected measurement by looking at ground tracks to find one in error. From this, two approaches were processed for comparison by linking their eye tracking data with actions established based on the VRFS flight data. Once these were linked, for every perception, the percent of occurrence of each action was calculated. These were then placed together and then gave 2 output D kernels which were analyzed and compared.

Regarding the scenario selected from the measurements in the 3rd approach, it was qualitatively clear that by looking at the eye tracking data, the subject involved in the specific case evaluated lacked full awareness over their situation with regards to deceleration to vacate the runway correctly. It was also seen, that based on previous analyses of runway incursions, certain external factors relating to the approach could have been reasons contributing to why no attention was paid to the airspeed. This scenario showed how identifying the perceptions of the RCA, by means of the eye tracking in the VRFS, allowed for information to be drawn regarding the qualitative situational awareness in relation to the deceleration.

Moving on, with regards to the modeling of the RCA, it was seen that the basic model alone was able to show trends in actions relating to perceptions which reflect the normal reality. This was seen across multiple occasions in the case investigated, and was clearest shortly before touchdown, and during the runway vacating. Given this, the modeling was able to provide insight as to what was most likely to be done given a certain percept. This would likely prove useful in analyzing an actual runway incursion, as to allow one to understand what actions came about due to specific perceptions.

Further, the evaluation based on the ITP was able to show the claim of the ITP that perceptions need not be veridical to be useful, as suggested by the output kernel showing the pilot looking to areas of concrete and paint as to form references of aircraft position. Given this information, it shows that it is therefore unlikely to say directly what meaning was derived by an individual directly from where they were looking. Nonetheless, as suggested by the data, the actions associated with where and individual was looking, are likely to give context to the meaning derived by an individual. In the context of runway incursions, this information is of value as it allows one to see that actions conducted by an individual do not necessarily agree with what is literally being looked at by that individual, and these actions could suggest what meaning was derived by that individual given their perception.

Finally, with regards to the consequences of the modeling, it was clear that improvements could definitely be made as to how this was carried out. Firstly, in terms of automation of the processing to allow more resolution. Secondly, by having time specific kernels. Finally, by having thresholds or more definition in actions conducted. Through these changes, it is likely that future modeling would be able to show clearer relationships between the perceptions and actions.

All in all, this study was able to show that with modeling the RCA from the ITP by means of eye tracking using a VRFS, a useful tool could be developed for the evaluation of runway incursions. Firstly, this may be said as the modeling was able to provide qualitative information regarding pilot situational awareness. Secondly, this is the case as the RCA showed a clear linking of perceptions to their actions in certain cases, which may be used to better understand the chain of actions in a scenario. Thirdly, because the concept of non-veridically linking perceptions to actions allows the potential for meaning to be derived from trends in actions seen resulting from a perception. Fourthly, because by enriching this model, further information may be gathered to produce a more concise relationship between the perceptions and actions, to potentially create a model with a dynamically acting kernel.

5.2. Limitations and Recommendations

The study was limited in multiple areas in terms of how it approached looking into runway incursions using ITP. Firstly, the study aimed to only model the basic RCA from the ITP. From doing this it was only able to investigate the basic relationship between the perceptions and resulting actions. The study did not investigate the effects of memory being modeled into this RCA. In line with this as well, the study greatly limited the RCA in terms of its possible perceptions, and actions. Secondly, in relation to this, the modeled RCA was likewise limited in terms of its resolution. Due to the data being processed primarily by visual assessment, and a lack of available time to assess more datapoints, it was not possible to specify use with a higher degree of resolution in terms of time across the entire case evaluated. A third area of limitation in the study was regarding the flight simulation. While the VRFS provided a means to see where the pilots were looking, it was not a true 1:1 analogue of reality. This can be said especially given the difference in controls, lack of motion simulation, and visual representation of the real world in the simulator.

Given the limitations stated, certain recommendations can be made for future studies. First would be to investigate a more thorough RCA, which has its memory modeled, and has a higher degree or resolution. Likewise, future studies could further enrich the RCA by addressing the limitations on the possible actions and perceptions, as to get an output closer to reality. Likewise, future studies could benefit from processing of the data by means of an automated system which will link a perception in one point of time, to an action in the next point in time. Although, such a system would still be limited to a fixed interval as with this study, unless it would be able to account for changing reaction time. This would allow for an output kernel which presents more completely the likelihood of actions given a perception of the RCA. Future studies could also look at modeling an RCA based on multiple data points of different instances of the same perception across many different measurements and individuals and recording the resulting action each time from this perception.

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APPENDIX

Appendix 1. Raw Flight Data Used for Processing Eye Tracking: 3rd Approach

x_real__time	x_Vind__kias	x_elev_stick	ailrn_stick	ruddr_stick	pitch___deg	x_roll___deg	hding___mag	x__alt__ind	thro1__part
3855	140	-0.03068	-0.09055	0.000624	5	2	242	1350	0.198432
3856	140	-0.00583	-0.04118	0.0006	3	1	242	1350	0.2
3857	140	0.040438	-0.24174	0.000186	2	-1	242	1350	0.2
3858	140	0.29822	0.000996	4.80E-05	1	-4	242	1300	0.2
3859	140	0.067194	0.034866	0.000192	2	-4	241	1300	0.2
3860	140	0.154266	0.12921	0.00033	3	-2	241	1300	0.182744
3861	140	0.880752	0	0.00042	4	-1	240	1300	0.08706
3862	140	-0.47233	-0.00032	0.00076	8	-1	240	1250	0.03137
3863	140	0.031978	0.029206	0.005426	7	0	240	1250	0
3864	140	0.044654	0.018528	0.044278	3	0	240	1250	0.425814
3865	140	0.799254	0.003234	0.042248	2	1	241	1250	0.89016
3866	130	0.151898	-0.13648	-0.03629	4	0	241	1250	0.98347
3867	130	0.121574	0.117914	-0.0797	4	-1	241	1250	1
3868	130	0.652932	0.128622	-0.02978	1	1	240	1250	1
3869	120	0.785728	0.097986	-0.01043	0	0	239	1250	1
3870	120	0.353962	0.241364	0.17068	0	0	239	1250	1
3871	110	0.348906	0.121584	0.370718	-1	0	241	1250	1
3873	110	0.467676	0	-0.22531	-1	-1	244	1250	1
3874	100	0.49832	0	-0.73629	-1	0	245	1250	1
3875	90	0.497848	0	-0.31033	-1	2	241	1250	1
3876	80	0.497856	0.000708	0.779058	-1	1	237	1250	1
3877	80	0.497848	0.000138	0.549974	-1	-1	239	1250	1
3878	70	0.500178	0	-0.87632	-1	-1	245	1250	1
3879	70	0.491376	0	-1	-1	0	246	1250	0.828048
3880	60	0.408388	0.019882	-0.55542	-1	1	242	1250	0.213882
3881	60	0.384158	0.149866	0.484004	0	1	238	1250	0.043902
3882	50	0.375716	0.102932	0.763038	0	0	237	1250	0
3883	50	0.287688	0.062616	0.731246	0	-1	239	1250	0.008628
3884	50	0.335208	0	0.006972	0	-1	243	1250	0
3885	50	0.35387	0	-1	-1	0	245	1250	0
3886	50	0.355952	0	-1	0	1	244	1250	0
3887	50	0.352622	0	-1	-1	2	239	1250	0
3888	40	0.20943	0	-0.67174	-1	2	230	1250	0
3889	40	0.139078	0	0.752386	0	2	222	1250	0
3890	40	0.139076	0	0.996502	-1	0	218	1250	0
3891	40	0.079364	0	0.766944	-1	0	219	1250	0
3892	40	0.05604	0	-0.88184	0	0	221	1250	0
3893	40	0.056038	0	-0.91438	0	0	221	1250	0
3894	30	0.056938	0	0.005044	0	1	218	1250	0

3895	30	0.05492	0	-0.20697	0	0	216	1250	0
3896	30	0.054708	0	-0.75677	0	1	214	1250	0
3897	30	0.034022	0	-0.67923	0	1	210	1250	0
3898	30	0.031406	0	-0.13551	0	1	207	1250	0
3899	30	0.031596	0	-0.92247	-1	1	203	1250	0
3900	30	0.031188	0	-0.15546	-1	1	199	1250	0
3901	30	0.030164	0	-0.42077	-1	1	195	1250	0
3902	30	0.03055	0	-0.79865	-1	1	192	1250	0
3903	30	0.034366	0	-0.1989	-1	1	189	1250	0
3904	20	0.031512	0	-0.20873	0	0	187	1250	0
3905	20	0.03141	0	-0.63282	0	0	186	1250	0
3906	20	0.029658	0	-0.91618	0	0	183	1250	0
3907	20	0.033766	0	-0.9139	0	1	180	1250	0
3908	20	0.031266	0	-0.50223	-1	1	177	1250	0
3909	20	0.033778	0	-0.34939	-1	0	175	1250	0
3910	20	0.034394	0	-0.34856	-1	0	175	1250	0
3911	10	0.03154	0	-0.34523	-1	0	175	1250	0
3912	10	0.034194	0	-0.34606	0	0	175	1250	0
3913	0	0.034108	0	-0.34523	0	0	175	1250	0.424472
3914	0	0.034474	0	-0.34523	0	0	175	1250	0.275524

Appendix 2. Raw Flight Data Used for Processing Eye Tracking: 2nd Approach

x_real__time	x_Vind__kias	x_elev_stick	ailrn_stick	ruddr_stick	pitch__deg	x_roll__deg	hding__mag	x__lat__deg	x__lon__deg	x__alt__ind	thro1__part
3376	150	0.000008	0.186558	0.001396	1	0	240	50.11665	14.27554	1350	0.2549
3377	150	0.006642	-0.01151	0.001532	0	3	240	50.11633	14.2745	1350	0.2549
3378	150	0.078502	-0.11169	0.001804	-1	2	241	50.11601	14.27346	1350	0.2549
3379	150	0.275834	-0.2852	0.001668	-1	-2	241	50.1157	14.27241	1350	0.2549
3380	150	0.253952	0.157074	0.001532	1	-5	240	50.11538	14.27137	1300	0.2549
3381	150	0.245858	0.027192	0.001804	3	-1	240	50.11506	14.27032	1300	0.2549
3382	150	0.213566	0.011566	0.003072	3	-1	239	50.11473	14.26928	1300	0.050196
3383	150	0.000008	0.105336	0.01029	2	-1	239	50.1144	14.26825	1250	0
3384	150	0	0.054758	0.01271	1	1	240	50.11409	14.26724	1250	0
3385	150	0.737796	0	0.013544	0	3	240	50.11377	14.26625	1250	0
3386	150	0.118162	-0.01391	0.012988	3	1	240	50.11347	14.26527	1250	0
3387	150	-0.53135	0.019742	0.01271	3	0	240	50.11317	14.2643	1250	0
3388	150	0.3282	0	0.01271	-1	1	240	50.11288	14.26335	1250	0
3389	140	0.3208	0	0.015534	0	1	241	50.11259	14.26242	1250	0
3390	140	0.005664	0	0.02854	5	0	241	50.11231	14.2615	1250	0
3391	140	0	0	0.040646	7	1	241	50.11204	14.2606	1250	0
3392	140	-0.1165	0.038882	0.097086	4	1	241	50.11177	14.25971	1250	0.265576

3393	140	0.726094	0.016486	0.128966	-1	3	242	50.11151	14.25884	1250	0.826314
3394	130	0.73672	-0.19506	0.066994	0	2	243	50.11126	14.25798	1250	0.962798
3395	130	-0.30132	0	0.027478	3	0	244	50.11103	14.25714	1250	1
3396	130	0	-0.27776	0.00042	2	-1	244	50.11081	14.25635	1250	1
3397	120	0.081644	-0.15308	-0.01233	-2	0	243	50.11061	14.2556	1250	1
3398	120	0.000962	-0.19551	-0.06701	-1	0	242	50.11043	14.25491	1250	1
3399	110	0.000368	-0.2165	-0.10575	-1	0	241	50.11026	14.25428	1250	1
3400	100	0.000004	0.0005	0.066466	-1	1	240	50.11009	14.25371	1250	1
3401	90	0	0	0.463002	-1	0	239	50.10993	14.25321	1250	1
3402	80	0	0	-0.11332	-1	-1	242	50.1098	14.25277	1250	1
3403	80	0	0	-0.3137	-1	0	243	50.10968	14.25237	1250	1
3404	70	0	0	-0.35902	-1	0	242	50.10958	14.25202	1250	1
3405	60	0	0	-0.01984	-1	1	239	50.1095	14.25173	1250	1
3406	50	0	0	0.172712	-1	0	237	50.10942	14.25149	1250	1
3407	40	0	0	0.590494	-1	0	238	50.10936	14.25131	1250	0.634734
3408	40	0	0	0.152802	-1	0	240	50.10931	14.25118	1250	0.140594
3409	30	0	0	0.014016	0	0	241	50.10928	14.25105	1250	0.027236
3410	20	0	0	0.000156	0	0	242	50.10924	14.25093	1250	0.141176
3411	20	0	-0.19963	-0.00122	0	0	242	50.1092	14.25079	1250	0.32549
3412	20	0	-0.59026	-0.42595	0	0	242	50.10916	14.25065	1250	0.39608
3413	20	0	-0.1053	-0.70897	0	0	241	50.10912	14.25051	1250	0.397648
3414	20	0	0.013562	-0.17647	0	0	239	50.10908	14.25037	1250	0.38431
3415	20	0	0.036496	0.972368	0	0	238	50.10903	14.25022	1250	0.38431
3416	20	0	0.009364	0.435172	0	0	238	50.10897	14.25004	1250	0.302746
3417	20	0	0	-0.13488	0	0	240	50.10891	14.24986	1250	0.26353
3418	30	0	0	-0.01054	0	0	240	50.10884	14.24965	1250	0.381962
3419	30	0	0	-0.02167	0	0	241	50.10878	14.24943	1250	0.30588
3420	30	0	0	-0.11714	0	0	241	50.10871	14.2492	1250	0.173332
3421	30	0	0	-0.0742	0	0	241	50.10863	14.24895	1250	0
3422	30	0	0	-0.01878	0	0	241	50.10856	14.24869	1250	0
3423	40	0	0	-0.00645	0	0	240	50.10848	14.24844	1250	0
3424	40	0	0	-0.00104	0	0	240	50.1084	14.24817	1250	0
3425	40	0	0	0.00051	0	0	240	50.10831	14.2479	1250	0
3426	40	0	0	0.116886	0	0	240	50.10823	14.24763	1250	0
3427	40	0	0	0.186238	0	0	240	50.10815	14.24737	1250	0
3428	40	0	0	-0.05578	0	0	241	50.10807	14.2471	1250	0
3429	40	0	0	-0.36058	-1	0	241	50.10799	14.24684	1250	0
3430	40	0	0	-0.96264	-1	1	240	50.10792	14.24661	1250	0
3431	40	0	0	-0.22874	-1	1	236	50.10786	14.24642	1250	0
3432	30	0	0	0.08229	0	0	233	50.10779	14.24625	1250	0.013334
3433	30	0	0	0.089694	0	0	231	50.10772	14.24609	1250	0.043138
3434	30	0	0	-0.46938	0	0	230	50.10765	14.24592	1250	0.033726
3435	30	0	0	-0.19107	0	0	228	50.10757	14.24576	1250	0.08627
3436	30	0	0	-0.00269	0	0	226	50.10749	14.2456	1250	0.173332
3437	30	0	0	-0.03273	0	0	225	50.1074	14.24544	1250	0.232154
3438	30	0	0	-0.33429	0	0	225	50.10731	14.24528	1250	0.122354

3439	30	0	0	-0.49813	0	0	223	50.10722	14.24511	1250	0.07451
3440	30	0	0	-0.19452	0	1	221	50.10712	14.24495	1250	0.031372
3441	30	0	0	-0.08533	0	0	219	50.10701	14.24478	1250	0
3442	30	0	0	-0.23597	0	0	218	50.1069	14.24462	1250	0
3443	30	0	0	-0.50936	0	1	216	50.10678	14.24447	1250	0.009606
3444	30	0	0	-0.14086	0	1	213	50.10667	14.24432	1250	0.586554
3445	30	0	0	0.728534	0	0	211	50.10654	14.24418	1250	0.912104
3446	30	0	0	0.263338	0	0	212	50.10643	14.24404	1250	0.956558
3447	30	0	0	-0.41908	-1	0	214	50.10631	14.24391	1250	0.37158
3448	30	0	0	-0.58169	-1	0	213	50.1062	14.24377	1250	0.079658
3449	30	0	0	-0.00982	-1	0	212	50.1061	14.24366	1250	0.010064
3450	30	0	0	-0.51537	-1	0	213	50.10602	14.24356	1250	0
3451	30	0	0	-0.8282	-1	0	213	50.10595	14.24348	1250	0
3452	20	0	0	-0.02158	-1	0	212	50.10588	14.24341	1250	0
3453	20	0	0	-0.29389	-1	0	212	50.10583	14.24335	1250	0