



# **BEng Project Interim Report**

## **Dynamic Modelling of a Continuum Robotic Snake-arm and its Performance Evaluation by Analysing Robustness**

**Student Name:** Arundathi Shaji Shanthini  
**Contact e-mail:** arundathi.shanthini.16@ucl.ac.uk  
**Student number:** 16018351

**Project Supervisor:** Prof. Sarah Spurgeon  
**Contact e-mail:** s.spurgeon@ucl.ac.uk  
**Department:** Department of Electronic and Electrical Engineering


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# DECLARATION

I have read and understood the College and Department's statements and guidelines concerning plagiarism.

I declare that all material described in this report is all my own work except where explicitly and individually indicated in the text. This includes ideas described in the text, figures and computer programs.

Name: Arundathi Shaji Shanthini .....

Signature:  .....

Date: 09.12.2019 .....

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## **Abstract**

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# Chapter 1

## Introduction

### 1.1 Description and Motivations for the work

(Advantages if this robot): - can access remote areas (slender or heavier payload) - has no electronics in the robot itself makes it access hazardous environments with no issues (easy risk assessment) benign - high data quality

### 1.2 Aims and Objectives

The aim of the project is to contribute to the modelling and control effort around the snake-arm at Here East by developing and implementing a mathematical model and testing a control system configuration suitable for the task. For this the first objective would be to develop a model that best represents the system. This model will then be implemented in Simulink and will be tested to ensure that the behaviour is as expected and represents the physical snake-arm well. The next objective is to define control requirements for the automation of the optical metrology process and design control strategies that performs the operation with the required accuracy. Through iterative testing, the model will be improved over the course of the project till satisfactory results are obtained. Finally, the project also aims to investigate the robustness of the system since it is expected to work in environments with varied conditions where external disturbances affecting the arm's propagation might be considerable. It is also expected that depending on the technique adopted for the optical metrology different payloads may be attached to the head of the snakebot. The payload may also change in mass especially in occasions when improvements have

been made to the same metrology technique under consideration. Therefore, the robustness of the system under the influence of change of mass of the head and the external disturbances will be investigated through experiments in the simulation software. The summary of the main objectives of the project as mentioned above are: • Develop and implement a mathematical model that best represents the snake-arm at Here East. • Design and test control strategies that will help control the path followed by the arm during the metrology task. • Analyse the robustness of the control system configuration developed by running experiments with varied physical parameters.

### **1.3 Literature Review**

This section discusses the primary sources identified from the literature explored for this project. Since, the system under consideration is specifically that of the OC Robotics snake arm, material published by the founders Graham A. and Buckingham R. were of immense interest. Even though material directly related to the robot or its technology could not be found, [1-3] by these authors were a good introduction to their work on snake arms and the bigger context of the varied applications of such robots. The slides in [3], also discussed the main features of snake arm robots. Given that the system was identified as a wire rope driven, hollow core structure with passive revolute joints connecting the links to each other, attempts were made to identify literature around modelling of a similar system. The work of Jones B. et al. [4] (dated 2006) has been cited in most papers. His work on kinematics for multi-section continuum robots seems to be the inspiration for most of the work around continuum snake arm robots. The works of Li Z. et al. [5-10] discusses how the skeleton of the robot is inspired from the skeleton of a snake and the idea of a the cable driven structure is inspired from the muscle arrangement in the tentacle of an octopus. Even though across various papers their work discusses the kinematic model of the snake arm robot, they do not discuss much about the dynamic model and control of the system. The references [11-14] represents the OC robotics snake arm the most. The system described by these papers uses a cable-driven snake arm in which the cables are controlled at the base with maxon motors exactly like the snake arm at Here East. The papers published by Tang L. et al. [11, 12] describes the design, motion planning and path tracking of the snake-arm. The work of Tang J. et al. [13] describes the design of this hyper-redundant manipulator. However, the work of Xu W. et al [14] dated 2018, remains the most suitable reference found so far as it discusses the

dynamic model and control of the cable-driven snake arm in great detail.

## **1.4 Approach**

# Chapter 2

## Mathematical Modelling

### 2.1 Understanding the system

To find the most suitable mathematical model that suits the snake-arm, a clear understanding of the system itself was to be established. Understanding the actuators that drive the system and understanding what parameters can be controlled was also essential to determine what terms should be used to represent the mathematical model.

The videos that have been made available by OC Robotics specially [15, 16], helped understand the snake-arm and its capabilities to an extent. In the video for Maxon Motors [16], Graham A. talks about the unique nose following property of the snake arm robot and how it is easily controlled using a proprietary software. The robot is driven by the wire ropes [17] that run in parallel on the surface outside the link (as can be seen in the picture on the top-right of Fig 1) casing and the cables are controlled 30 or more motors [16] in the base (as can be seen in the picture on the left and bottom-right of Fig. 1) using maxon motors as it offers higher power density. The nose of the snake arm can accommodate different payloads and the snake arm also has a hollow core thus allowing cables, hoses or any other equipment required by the specific payload to be routed through the centre of the snake arm.

From these information, currently work of Xu, W et. al. [14] looks like the most suitable model.



**2.2 Kinematic Modelling**

**2.3 Dynamic Modelling**

**2.4 Testing the model behaviour**

**2.5 Discussion**

## **Chapter 3**

### **Initial Simulation Results**

# Chapter 4

## Conclusions

### 4.1 Discussion of Progress

### 4.2 Failure Risk Assessment

The project mainly involves modelling of a dynamic system and analysing its behaviour under control system configurations. Therefore, with respect to this project, failure can be mainly thought of as not being able to simulate the behaviour of the real dynamic system using the mathematical model chosen or not being able to obtain expected tracking of the reference parameters. Several factors can cause these failures, therefore to tackle such unexpected behaviour and/or arbitrary results, an iterative method is used for testing and improvement of the results. From a very early stage (as can be seen in the Gantt Chart), the results will be compiled, understood and analysed to understand how improvements can be made. Necessary changes will be then incorporated, and this process will be repeated till desired tracking of parameters is achieved. Each iteration may involve improvements made through educated trial and error methods and/or experiments. Iterations may also involve major changes to the simulation model. If after several attempts desired results could not be obtained, then different control system configurations will be attempted and changes supporting improved results will be adopted. The mathematical model representing the snake-arm may also be replaced to use simpler or more complex. To make it easier if the mathematical model fails to behave as expected, during literature review possible variations of the mathematical model will be noted and recorded. Currently, the robotic snake-arm has been identified as a continuum robot however, if this approach fails to represent the behaviour of the model, then an alternative model that

represents the system will be identified or else the last resort would be fall back on the simplified option for the mathematical model which is the approach of a simplifying the snake-arm as a modular robotic arm with several rigid links of a fixed length. The modular “vertebrae-like” model would still simulate the behaviour of the arm even though the number of degrees of freedom of the system might reduce significantly. Additionally, the weekly project tutorials with the project supervisor will also help give new perspectives and ideas on how the results can be improved.

### 4.3 Safety Risk Assessment

Since the project does not include any tasks involving hardware or use of laboratory equipment and machinery, the risks associated are only those around working on a computer. Some of the main safety risks associated to working on a computer have been identified as:

- **Eyestrain:** Long hours of looking into a screen especially with incorrect screen settings and in a room with poor/intrusive lighting conditions can lead to eyestrain and headache related to it. Control measures:
  - Ensure that the screen settings are suitable for the lighting conditions of the room. The contrast, brightness and colours of the screen must be easy on the eyes.
  - Face your screen away from intrusive light or glare. This can be avoided by facing it away from windows, bulbs and bright light in the room.
  - Ensure that the screen is clean.
  - Make sure that while reading, the screen is zoomed in sufficiently so that the letters are large enough to be read from a comfortable position.
  - Ensure that the text on the screen is sharp and in focus. The screen shouldn't flicker, and the text must not appear to be moving.
  - Give your eyes a break from looking into the screen by looking into the distance from time to time.
- **Poor Posture:** Poor posture while sitting at a work station can lead to discomfort from aches, backpain etc. and may even cause injury. Poor posture may even be caused due to poor workstation set up. Control measures:
  - Ensure that you are sitting upright with your back positioned comfortably on the backrest of the chair. Sit close to the desk to prevent leaning forward uncomfortably.
  - Ensure that your eyes are at the same height as the top of the screen.
  - Take short and frequent breaks and change position if possible.
- **Repetitive movements:** Poorly designed workstations or uncomfortable working postures might lead to repetitive strained movements and can cause repetitive strain injuries. Control measures:
  - Take short and frequent breaks and if possible, stretch and change position.
  - Make sure there is space under the desk to move legs.
  - Ensure that the workstation layout does not con-

tribute to repetitive strained movements. Choose a comfortable space. □ Position the mouse such that it is within easy reach and can be held with a straight wrist □ When not typing use the space in front of keyboard to rest your wrists and hands. □ Do not overstrain muscles by overstretching fingers when typing or holding onto the mouse with a tight grip. □ Sit upright and close to the desk to reduce working with the mouse with your arm stretched. • Tripping: When working in computer labs or study spaces there is a risk of tripping over objects or slipping on spillages. Control measures: □ Be mindful and careful of obstructions on the floor/walkways even in rooms that you are used to working in. Avoid walking around carelessly or looking into the screen of the computer. □ Inform the responsible management if any major obstruction with potential risk is noticed. This may include damaged floors, trailing cables, inadequate housekeeping, incorrect lighting levels etc. • Poor lighting conditions: Poor lighting conditions refers to both insufficient lighting as well as excessive lighting of a room. Poor lighting conditions may cause headaches or sore eyes. Control measures: □ Control the lighting in the room suitably. □ Adjust the blinds to control natural light levels or to avoid glare on screens. • Lone working: When working alone in the office there is risk of injuries, emergencies etc. with inadequate provision for help. Control measures: □ Avoid non-routine working. □ Be aware of the risks and precaution associated to the work undertaken. □ Have the information and knowledge of how to deal with emergencies The above-mentioned risks are the main risks associated to working on a computer. A more exhaustive list of risks, including ones that are very unlikely, were submitted via RiskNET.

## **4.4 Additional Work to complete goals**

# Appendix A

## Project Gantt Chart

The following page contains the Project Gantt Chart. The project will mainly have four phases - Preparatory phase, Simulation and Modelling, Testing and Improving results and Analysis and Compilation of Results

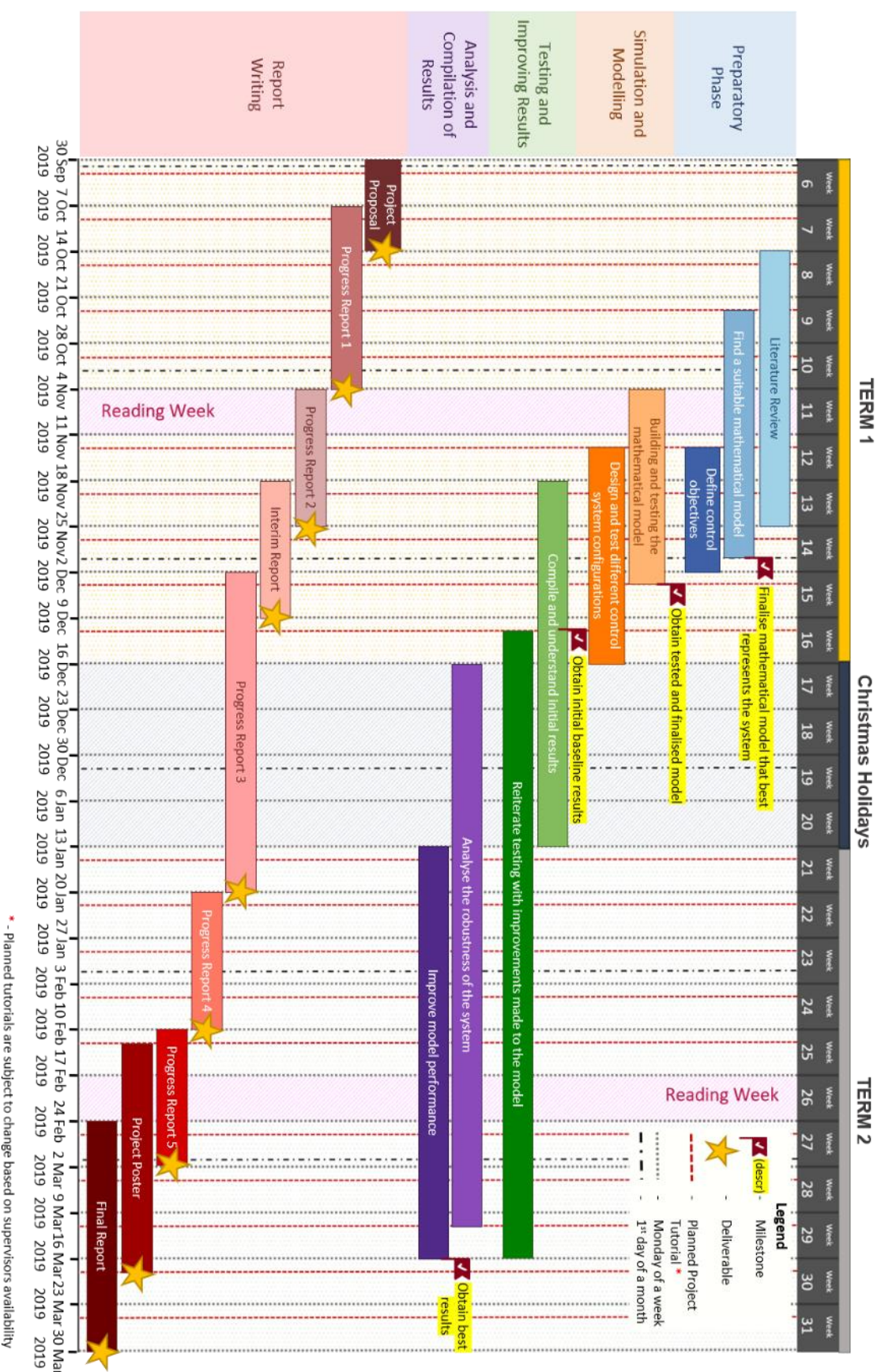
**Preparatory Phase:** The first month and a half will involve preparatory phase during which through literature review several suitable mathematical models will be identified and the model that best represents the physical snake-arm will be implemented. During this phase the control objectives of the snake arm will also be clearly investigated and will be defined mathematically. Work undertaken over summer proved that the approach of mimicking a biological snakebot to improve reach and span of the robot will not be suitable, as controlling such a snakebot poses a lot of challenges. Even though extensive research over the years have led to improved results, the level of accuracy of the tracking of the controlled variable is lower than what is required for a task like air wing inspection. The risk of a snake-arm making contact with the structures due to incorrect path following can be very unsuitable for this scenario. Also, given that the OC Robotics snake-arm is more like a tethered continuum robot moving in free space, the viscous friction model adopted by most authors to describe the dynamic model of a wheel-less ground-hugging robot snakebot won't be suitable. Therefore, the initial approach when modelling the snake-arm the concept of continuum robots may be used the most.

**Simulation and Modelling:** The next phase of the project will then involve implementing the mathematical model, simulating the control system on Simulink and obtaining the initial results. The tracking error of the parameters (specially speed, position and orientation) will be analysed and efforts will be made to improve these results. It is expected that at this stage, an iterative testing method would be adopted to improve the model until desired tracking accuracy is obtained.

**Testing and Improving Results:** From the start of the second phase to the end of the

project, results will be improved and tested iteratively until desired results are achieved. Although this has been specified as a separate phase it represents the steps that are part of the second and the last phase. Analysis and Compilation of Results: Once satisfactory results are obtained; the final phase of the project will focus on testing the robustness of the system in varied conditions. It is expected that the payload attached to the head will change depending on the optical metrology technique for which it is being used. Further, it might be performing measurements in environments where external disturbances are no longer negligible. So, for these scenarios, tests will be performed to analyse the robustness of the system to these disturbances. Results obtained will be reported systematically and periodically through progress reports that are roughly due once in every three weeks since the start of the project.

# Project Gantt Chart





## **Appendix B**

### **Risk Assessment**

The following pages includes a summary of the approved risk assessment generated using RiskNET. (Add a short table of risks and its effect like a summary table here)



## Risk Assessment

### Summary

Reference: RA030578/1

Sign-off Status: Author

Date Created:	05/10/2019	Confidential?	No
Assessment Title:	ELEC0036: Third Year Project - Arundathi Shaji Shanthini		
Assessment Outline:	This risk assessment is being carried out prior to the third year individual project (Module code: ELEC0036) undertaken as part of my undergraduate course.		
Area Responsible (for management of risks)		Location of Risks	
Division, School, Faculty, Institute:	Faculty of Engineering Science	Building:	Roberts Building
Department:	Dept of Electronic & Electrical Eng	Area:	Ground and Above
Group/Unit:	All Groups/Units	Sub Area:	Laboratory
Further Location Information:			
RISK_HE_FORMA_COUNTRYLABEL:	RISK_HE_FORMA_COUNTRY_HEADER		
	UNITED KINGDOM		
Assessment Start Date:	05/10/2019	Review or End Date:	05/10/2020
Relevant Attachments:			
Description of attachments:			
Location of non-electronic documents:			
Assessor(s): SHAJI SHANTHINI, ARUNDATHI			
Approver(s): SARAH SPURGEON			
Signed Off: SARAH SPURGEON (16/10/2019 12:07)			
Distribution List:			
PEOPLE AT RISK (from the Activities covered by this Risk Assessment)			

Reference: RA030578/1

Sign-off Status: Authorised

1. Working in Computer Lab / Study Spaces	
Description of Activity:	The project undertaken mainly involves working on a computer and the following are the risks associated to working in computer labs or study spaces.
<b>Hazard 1. Eyestrain</b>  Long continuous hours of looking at the screen, poor DSE workstation and lack of suitable corrective eyewear can lead to eyestrain.	<b>Existing Control Measures</b>  Ensure the screen colours are easy to look at, and that the characters are sharp and legible. Ensure that the contrast and brightness settings are suitable for the room lighting conditions. Reposition the screen to avoid glare/bright intrusive light from lights or windows. Look away from the screen into the distance for a few moments to relax your eyes; focus on something 30 metres away for 30 seconds every 30 minutes.  Keep the screen clean and use a desk lamp to make it easier to see. Zoom into the text file being read such that the text is large enough to read easily on screen when sitting in a normal comfortable working position. Utilise eye test provisions (if required)
<b>Hazard 2. Poor posture</b>  Postural issues may give rise to discomfort or injury and can arise through a poor or inadequate workstation set up.	<b>Existing Control Measures</b>  Ensure that sit upright with your back positioned comfortably on the backrest of the chair. Sit close to the desk to prevent leaning forward uncomfortably. Ensure that your eyes are at the same height as the top of the screen. Take short and frequent breaks and change position if possible.

## Risk Assessment

<b>Hazard 3. Repetitive movements involved with working on a computer</b>	
Poorly designed workstations or uncomfortable working postures might cause repetitive strain injuries or problems like carpal tunnel syndrome	<p><b>Existing Control Measures</b></p> <p>Sit upright and close to the desk to reduce working with the mouse with your arm stretched.</p> <p>When typing stretch use the space in front of the keyboard can help you rest your hands and wrists not keying.</p> <p>Position the mouse within easy reach, so it can be used with a straight wrist. Sit upright and close to the desk to reduce working with the mouse arm stretched.</p> <p>Stretch and change position. Take short, frequent breaks. Look into the distance from time to time, and blink often.</p> <p>Do not overstrain muscles by overstretching fingers when typing or holding onto the mouse with a tight grip.</p> <p>Make sure there is space under the desk to move legs.</p>
<b>Hazard 4. Tripping over objects</b>	
Congested layout of room, temporary obstructions, trailing wires near printing equipment etc. can be reasons that can cause tripping over objects and cause injury	<p><b>Existing Control Measures</b></p> <p>Be mindful and careful of obstructions on the floor/walkways even in rooms that you are used to working in. Avoid walking around looking into the screen of the computer.</p> <p>Report the responsible management if any major obstruction with potential risk is noticed. This may include damaged floors, trailing cables, inadequate housekeeping, incorrect lighting levels etc.</p>
<b>Hazard 5. Poor lighting conditions</b>	
This refers to both insufficient lighting as well as excessive lighting of a room. Poor lighting conditions may cause headaches or sore eyes.	<p><b>Existing Control Measures</b></p> <p>Control the lighting in the room suitably.</p> <p>Adjust the blinds to control natural light levels or to avoid glare on screens.</p> <p>Inform responsible management of insufficient lighting or broken lights in the room .</p>
<b>Hazard 6. Lone working</b>	
When working alone in the office there is risk of injuries, emergencies etc. with inadequate provision of help.	<p><b>Existing Control Measures</b></p> <p>Avoid non-routine working.</p> <p>Be aware of the risks and precaution associated to the work undertaken especially when working alone.</p> <p>Have the information and knowledge of how to deal with emergencies</p>

## Risk Assessment

<b>Hazard 7. Fire</b>	
<p>If trapped in the event of a fire, one could suffer fatal injury from smoke inhalation or burns.</p>	<p><b>Existing Control Measures</b></p> <p>Make sure that when working in a room you are aware of the nearest emergency exit and assembly point.</p> <p>Be aware of the instructions on the notices or information boards in the room installed by the management for such events.</p> <p>Inform the responsible management if any obstructions are noticed near emergency exits.</p>
<b>Hazard 8. Contact with electricity</b>	
<p>Exposed electrical conductors in general office / computer lab equipment can cause electric shocks, burns and injuries.</p>	<p><b>Existing Control Measures</b></p> <p>Be mindful and careful of exposed electrical conductors which may be live on the floor/walkways even in rooms that you are used to working in. Avoid walking around looking into the screen of the computer.</p> <p>Report any exposed electrical conductors or damaged equipment that can cause electric shock.</p>
<b>Hazard 9. General Welfare</b>	
<p>Inadequate facilities or unplanned work can affect the general welfare of a person.</p>	<p><b>Existing Control Measures</b></p> <p>Report any problems with basic facilities in the building like lack of source for potable water, toilet and hygiene facilities, heating and lighting provision etc.</p> <p>In case of unlikely extreme situations like stress, bullying or disturbances from another student/staff, use university services provided like Student Support and Wellbeing to report and to receive help.</p> <p>To avoid stress ensure that a plan for the work is in place and avoid working long hours. Ensure that the regular discussions take place with the supervisor and raise any issues with him/her.</p>

<b>Risk Level</b>
With Existing Controls:
<div> <div> <div>A -</div> <div>Risk Level</div> </div> <div> <div>Very Low / Trivial</div> <div></div> </div> </div>