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Selection of Project:

The chosen project will be the same as from Individual Assignment 1, namely my Fourth Year Design Project on automatic urban delivery.

Statement of Contributions:

Out of all my team members for the FYDP, none of them are in the SYDE 543 Winter 2021 class. This project is done individually.

PART A: Situation of Concern as a Sociotechnical System

1) The motivation of this project is that delivery companies now, more than ever, are looking for ways to save on costs, especially in the midst of this pandemic. One way they can save on costs is by automating the delivery process, as this can save the company money by not having to pay for the various expenses that pertain to normal delivery (ex. paying employees, having liabilities, etc.). Thus, we identified a need for the development of an automatic delivery system for companies to autonomously deliver their packages. Stakeholders for this project include companies who have services focused on the delivery of general payloads and packages such as Uber Eats, Amazon, and FedEx. Target users consist of the employees present at the source of the delivery site, as they are the ones who will prepare the payloads, such as food or mail, and then place them in the delivery system. As a result, this requires extensive training for the employees to ensure not only that the packages are situated properly, but also that the robot is setup to successfully deliver the packages and return safe and sound.

2) Many of the delivery systems in the works today are either wheeled robots such as cars and small automobiles, or tread-based robots such as tanks. However, our design is a new proposed solution in this space of autonomous delivery, which is that of a hexapod robot:

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Figure 1: Our FYDP of an urban delivery system carrying a sample payload.

We are at the point where we can control the robot and get it to traverse simple paths such as straight-line deliveries and small stairs. The strength of this design over wheeled and tread-based robots is that this one is capable of performing more complex movements which will allow it to avoid more obstacles that are typically present in dense urban environments (ex. people walking by, signs, curbs, etc.). Although hexapod-based robots already exist, they are typically only used for other applications such as for hobbyists, security, and the army. Thus, the design itself is an existing solution, however, the problem we are applying it to is brand new and turns into a proposed solution.

3) This solution should be considered a sociotechnical system, both in terms of how it interacts with the environment during its deliveries, as well as how it might impact the job market with respect to delivery. As it is intended to operate in dense urban environments, it is important that the robot be aware of its surroundings and avoid any contact or harm with other humans. Nonetheless, it would take a while for a city of humans to get used to seeing robots drive around on a daily basis, which may impact their general behaviour and how they view technology and automation. Some people may feel uncomfortable or even threatened being around these robots, even if they are designed to pose no harm to humans. With respect to the job market, people who work in the delivery sector may lose their jobs to such a system and fight back against it as a result. Overall, it would take a while for humans to assimilate themselves to living in a city full of delivery robots, and this may slow down further development and integration of such systems on a wider scale.

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PART B: Literature Search on Cognitive Academic Disciplines

1) The cognitive capabilities of the robot are very important, as it needs to autonomously get from its source to its destination all on its own. The cognitive architecture of the robot must plan the most optimal path it needs to take, as well as effectively re-route and reconfigure itself if any issues arise. Therefore, the cognitive level of the robot in this case is its decision-making and execution of its task to achieve its goals. Based on the information gained from its various sensors and objectives, the cognition and control system decide how to act and what to do in specific situations. As a result, the robot needs a cognitive model to represent itself, the environment, and the interaction between them accordingly. Thus, much like the cognitive psychology and decision-making when it comes to human performed tasks, the robot needs to perform the same way, and make decisions and actions similar to what a human would do when making deliveries, i.e., avoiding collisions with other humans and objects, and following all city street and road regulations like stop signs and right-of-way [1].

   Human-computer interaction between the robot and people around it is important to consider and essential to keep in mind when developing the robot. Basic human actions such as listening, speaking, and reading should be taken into account for the interaction with the robot. More specifically, the robot should be equipped with alerts and warnings, both in text and in sound, to convey to humans when there are issues such as being too close to them. This takes into consideration anyone who may be blind or deaf and adds onto its accessibility functionality that could help it gain some trust within the community. The important idea here is that the robot builds trust with the people and changes their negative perceptions of any potential danger or trouble. Once it gains some traction and credibility, only then can it really take off and become a mainstream product and service in the future of delivery [2].

2) An important and highly applicable topic from Cognitive Ergonomics is the concept of a wicked environment, which is an environment where next steps and goals may not be clear, have rules that may change, and may or may not get feedback. For our robot, we are absolutely working in a wicked environment, as its surroundings is constantly changing as it moves towards its destination. Furthermore, external factors such as the

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weather can change at any time, from sunny to rainy to snowy, so the robot needs to account for that and be able to handle it. As a result, it is vital that the robot is properly protected and tested for these conditions. We added a protective casing to store all the electronics in, as well as a case for the packages, to protect it from the weather and other debris. Furthermore, we will test thoroughly under conditions such as harsh weather, as well as ensure it can handle the changing environment such as the movement of humans in its surroundings, with appropriate responses [3].

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PART C: Application of Signal Detection Theory

1) A relevant signal detection task within this problem space is the robot's ability to turn on the spot. This detection task is important to the performance of the overall system because it would most definitely need to perform turns to get to its destination, whether that be for following its route or avoiding an obstacle. Given an input, for example how much to turn at via a measurement of angle or position, the robot must react accordingly and actually turn that number of degrees. Furthermore, the time between the command being sent and actual movement of the robot needs to be minimized, in order to maximize its performance. As mentioned, this signal of turning would be detected in two ways: either from its GPS tracking and routing system, or because of an obstacle in its path. In addition, if events such as blocked sidewalks due to construction or special occasions occur, the GPS could trigger a re-route, resulting in another instance of turning. Before choosing a new decision-maker, first some context: due to the pandemic, we decided to first develop the robot being manually controlled via a game controller by humans. This was done to ensure we first had a working product before trying to implement autonomous control, which is especially difficult now considering we are effectively working on the project separately. With that being said, the decision-maker for this task will be the human controlling the robot through the game controller. The robot is currently programmed to accept controller-based input and react according to said inputs. Thus, it is now up to the human to perform the desired tasks and get the packages to their destinations. In addition, rather than autonomous navigation, it is the humans that have to avoid the obstacles and move at the appropriate speeds.

2) From the perspective of the human robot operator now being the decision-maker, the signal (or targets) will consist of two things: the signal from the GPS and routing system to re-route its path, and the signal from the decision-makers controller to perform the appropriate turn(s). Now that it is manually controlled by a human, it is up to them to carefully observe the state and view of the robot, via its various sensors and cameras on board. Once the human detects an obstacle such as a street sign, or sees a required re-route, then they would send the turning signal through the controller to the robot. Conversely, the noise (or non-targets) the human must consider are similarly two things,

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which are opposing the signals: either false/incorrect GPS re-routing detected by its positioning system, or mistakes made by the human to turn when not necessary. The objective of the routing system is to determine the shortest path to its destination in order to minimize cost, time, and usage. When a re-route is detected, it is up to the human to ensure this was intended before correcting its path. Along with that, there is also room for error on the human detection side, where they could mistake harmless obstacles as ones that they should avoid, even though they did not need to.

Using the signal detection paradigm, an outcome map for this case is as follows:

	Yes re-route or yes obstacle	No re-route or no obstacle
The human turns	Hit	False alarm
The human does not turn	Miss	Correct rejection

3) Response bias β, also known as the decision criteria, is the degree to which the perceiver is biased to detect or not detect. In this case of the human robot operator, more often than not, they would lean towards being more liberal, i.e., small β with maximal detection, as it is better to turn by accident and just correct yourself than it is to miss a turn and potentially crash into a human or other obstacles. Sensitivity d', more specifically perceptual sensitivity, is how different the signal is from the noise. In this case, the signal and noise are actually the same, i.e., a human or a wall; therefore, it is more dependent on the actual position of said obstacles, resulting in a smaller d', meaning the signal is less distinguishable from the noise. Lastly, sensitivity A', is a measure of the area under the ROC curve that provides an alternative sensitivity, i.e., the level of overlap between the signals. In this case, the A' would be relatively low, as it might be difficult at times to distinguish when and where to exactly turn, as it is solely dependent on the human's ability to identify when the turns are necessary, resulting in more hits and false alarms, which in turns results in a lower A' calculation.

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PART D: Application of Decision-Making

1) As mentioned in previous sections, the scope of this system is that the project aims to tackle the issue of autonomous delivery in dense urban environments. However, due to the pandemic, the group had to scale back our deliverables in order to still deliver a reasonable project and finish on time. As such, we had to set aside the autonomous navigation and substitute it with human controlled navigation via a game controller. This results in a change of decision-making, namely, from the robot making the decisions to the human operator making the decisions. Studying decision-making is important in this case because it is important that the system understands who is in control and who to listen to. This will allow it to function appropriately and be successful in the marketplace, that is, the focus is now on properly trained human operators for navigation.

2) The selected bias for the human robot operator from the Hindsight card deck is loss aversion, which is a term that implies people are more motivated by potential losses than by potential gains. With respect to general navigation and the act of turning and avoiding obstacles, the operators are much more inclined to avoid accidents if it means spending more money or time. For example, if there is a lot of debris up ahead, the operators have two choices: either continue through the debris and save time at the cost of potential collisions, or re-route and navigate around the debris, preventing potential collisions at the cost of time. For most people, the loss due to accidents is much worse than the loss due to time or late arrivals, therefore, loss aversion explains why they are most likely to decide to avoid the debris. From another perspective, the potential gain of saving that bit of extra time is outweighed by the potential gain of not getting into an accident by avoiding the debris in the first place. This is not all the time though, since some people may see the time save as more beneficial, therefore, the solution to this problem is proper and extensive training to ensure the operators make the best possible decisions.

3) Skill-based decision-making describes decisions made that are not only inherited, but also conditioned through experience and automated routines requiring little conscious attention. In this case, this would relate to the operator's level of experience, as the more they perform the tasks and operate the robots, the better they will get at making correct and effective decisions. Rule-based decision-making describes decisions made that are

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conditioned and codified by experience in the brain or in external references. In this case, this would be decisions made based on a documentation or guide towards certain scenarios; for example, whether or not to turn can be stated in supporting documentation by looking at specific parts of the user interface that display informational alerts or warnings. Knowledge-based decision-making describes decisions made with respect to the still mysterious process inherent in creative decisions and acts, where there is improvisation in unfamiliar environments, and no routines or rules available. In this case, this would be decisions made when unforeseen or unprecedented events occur; for example, if a big snowstorm or strong winds suddenly appear during the delivery, then the operator would have to adjust their decision-making accordingly to account for this change in the environment, perhaps by being extra cautious when navigating.

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PART E: Application of Mental Workload and Situation Awareness

1) As with the previous section, the decision-maker is the human operator who controls the robot through a game controller.

2) The first S, to switch attention between tasks, greatly influences mental workload in this case because the operator having to switch between navigating straight and avoiding obstacles is stressful, especially considering the environment is wicked, so they do not know when to switch until moments before. Next, to seek information minimally impacts mental workload because most of the important information is already there present in the user interface, so it does not take much effort to understand if there are any issues or alerts to be seen. Then, to study material moderately affects mental workload because there is a fair amount of knowledge and training to go through such as learning the basic operation and functionality of the robot before being able to navigate. Lastly, to safely behave greatly influences mental workload because it is of utmost importance that the operator performs the navigation carefully to avoid any accidents or harm to the robot. Therefore, for this project area of controlling an urban delivery system, the switching of tasks and safely behaving are the most mentally stressful, followed by studying material, and then seeking information. Switching tasks and safely behaving are the most important, and consequently the most stressful, because these are fundamental to the success of the product: switching tasks allow proper navigation of the robot to its destination, and safely behaving ensures protection of itself and others as well as gains the trust of the community members of the city.

3) The three levels of situation awareness (SA) are perception, comprehension, and projection. Perception is the first level of SA and is the awareness and recognition of relevant information from the environment, and in the case of the operator, this means being able to identify the obstacles that are present in the field of view of the robot. Comprehension is the second level and is perception but also demands that people understand the meaning and significance of what they have perceived; in this case, this means the operator not only identifies the obstacles, but understands what they have to do, namely whether or not to stop and avoid them or keep going because they mean no harm. Lastly, projection is the third level and is comprehension but also with the ability

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to forecast future situation events and dynamics; in this case, this means the operator adjusting their behaviour over time to account for similar obstacles and learn from these situations to make better navigation techniques in the future. For this case, it is best if the operators have a projection level of situation awareness, as this would allow them to perform better over time and learn from their mistakes and not repeat them again. For example, if they were going too fast before a stop and learned to slow down earlier, then every subsequent time this happens, they would have gained the experience and knowledge of stopping more effectively over time.

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PART F: Application of Expertise and Training

1) The scope of the system is a robotic delivery system with the intention of mechanically delivering packages in dense urban environments. The system would operate in markets such as Amazon and Uber Eats, where the companies would place their products in the robots, and then robot operators would control them to get to their customers. As such, the main decision-maker in this case are the robot operators, whose goal is to get the packages to their destination as quickly and efficiently as possible. Studying decision-making is important in this case because this robot will operate in a dynamic and constantly changing environment, with various obstacles such as moving people and street signs. Thus, it is important for the operators to make optimal decisions to not only successfully deliver the packages on time, but also ensure safe operation to avoid any damages to the system and accidents with people around it. Upholding this would gain the trust of the city and allow it to more easily integrate with society.

2) **Decision Ladder:**
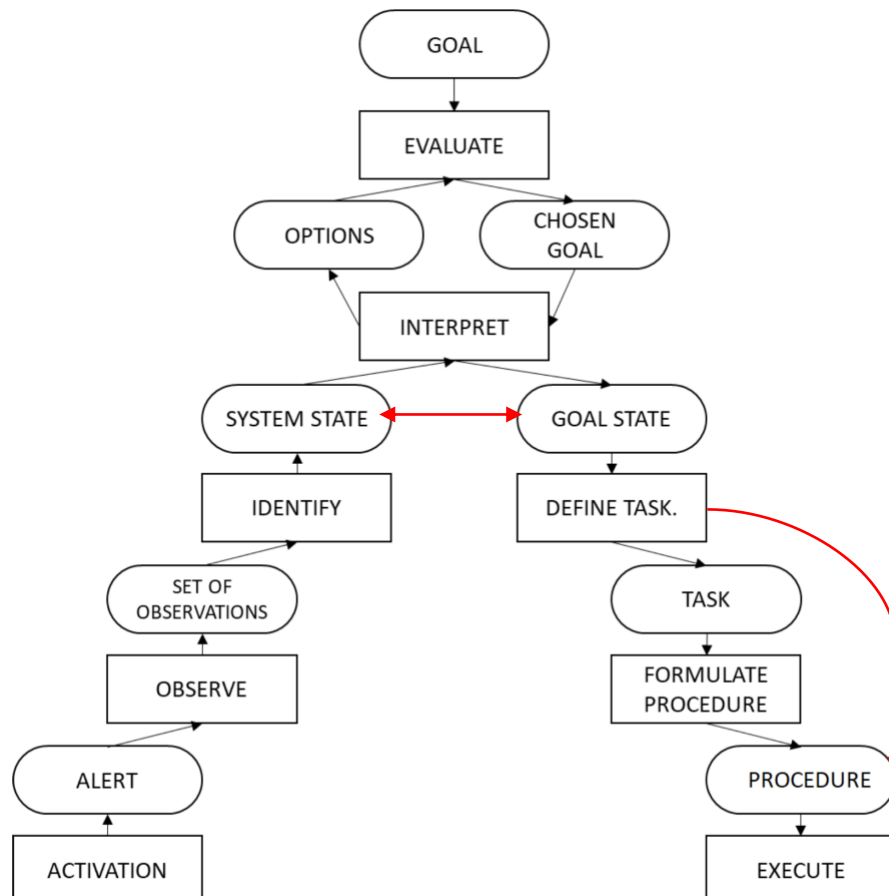
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Activation: Analyze the GPS route and detect that a turn is required at the next block. Since the robot's movement is fully controlled by the operator, they must constantly be following its designated path, so when a turn is required, they must make a decision.

Observe: Determine where the robot is relative to where it needs to turn. Similar to navigating with a GPS in a car, the operator needs to gauge the situation, namely, to see where it currently is, see how fast it is moving, see how far the turn is, and consider its surroundings like potential obstacles or construction in its path.

Identify: Recognize how many obstacles there are in its path and if there is any construction ahead or on the road it needs to turn at. The operator gains a perceived understanding of the work system based on information, and in this case, they now know the state of each obstacle in its path, how many there are in its view, and whether or not there is problematic construction.

Interpret-Evaluate-Reinterpret: For each obstacle on its path on the way to its turn, analyze whether or not they could result in a collision, and if so, whether or not they can be avoided. This is an iterative process because as the operator is navigating, objects are consistently entering and leaving its field of view, so they have to constantly decide whether or not its current path is safe, and if not then decide how to reroute on-the-fly.

Define Task: Decide whether to make the turn or to reroute. To achieve the target state while maintaining the overall goal, although the GPS has determined the optimal route, the operator has to ultimately decide if the turn is safe enough to be made, or if a manual reroute is needed due to any impeding obstacles, in order to complete its delivery safely and on time.

Formulate Procedure: If the turn is determined to be safe, figure out how to perform a turn, else figure out how to carry out a reroute operation. The operator has to determine a detailed action plan, namely that if indeed it can turn, then ensure they can properly perform this action, else ensure they can correctly activate the GPS rerouting.

Execute: If the turn is safe then perform the turning operation, else perform the rerouting operation. The operator has evaluated the situation and came to a conclusion as to whether or not it can perform the turn, so take the result of this plan and carry out the corresponding action, i.e., turn or reroute.

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Shortcuts:

The first shortcut between system state and goal state represents a more experienced robot operator that built upon their previous experience to progress over time and make informed decisions without the need for meticulous analyzing of each and every obstacle. More experienced operators will have the ability to assess the situation faster and determine if the route is safe with less mental stress. More novice operators will have a harder time gauging their situations since they have performed less deliveries, unlike more experienced operators who can compare current situations with past situations. This shortcut represents knowledge, as the utilization of previous experience to gauge current experience is a fundamental concept and practice in everyday decision-making, similar to how studying effectively for an exam usually leads to success.

The second shortcut from define task to procedure represents a more experienced operator having the ability to perform turns and reroutes without the need to figure out how to do it. They have performed these tasks dozens of times, and as a result, are able to do them without having to think about how to do them. More novice operators may need to ask for help when performing these tasks or may need to consult an instruction book or manual that details how to do the tasks. This shortcut also represents knowledge, as more experienced operators naturally have a better understanding and ability to perform these actions compared to novice users who are still in the process of learning and improving.

3) For activation, experts would be able to more quickly analyze the given route by the GPS, and cognitively examine if a decision is required, i.e., to turn or to keep going, faster than novices. Similarly, for observe and identify, the expert will be able to gauge the current state and situation of the robot and make more confident informed decisions about its position and surroundings as opposed to novice users. For interpret-evaluate-reinterpret, experts can utilize their previous experience to cognitively assess and make decisions more efficiently because they have been in similar situations before, naturally something that novices lack. For define task, formulate procedure, and execute, overall, the experts can perform these operations easier with less mental workload, since they can gauge situations better and react accordingly. Novices would require more time to think and make these decisions, especially considering there is a major emphasis on safety and upholding the trust of the community, i.e., your actions indirectly dictate the success of

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the product. Relating to situation awareness (SA), experts would have projection (level three) SA, as they would have the ability to forecast future situation events and dynamics based on their previous experiences, whereas novices would only have comprehension (level two), where they should know what to do, but would not have that much previous experience to justify their decisions.

4) Naturally, the first possible way to train novice robot operators would be to allow them to perform more deliveries, so that they can gain more experience, and then be able to utilize that experience later on to make better decisions. In addition, they could be assigned a mentor, perhaps a more senior operator, to watch over them to help them out and give them suggestions. This is typically the case in Waterloo's co-op program, where us as interns get assigned mentors to help us learn and become better employees.

   A second way to train novices would be to develop comprehensive but user-friendly documentation that details all the functionalities of the robot and how to operate it. That way, they would be more informed and be able to base their decisions off something, and that is, by justifying their actions through instruction given by official manuals. Relating again to the co-op program, this is like software companies with extensive documentation on how their software works, so that software development co-op students would be able to reference this to contribute better code.

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PART G: Application of Automation

1) What might be the positive and negative impacts of replacing the robot operators with fully autonomous robotic control?

2) Starting with the positive impacts, having fully autonomous control would allow the robot to most efficiently carry out its deliveries, which maximizes its value and performance. In other words, if the technology is advanced enough, the robot will always perform no worse than when a human operator does it, which is ideally the way it should be operating. Having such advanced capabilities would attract more investors, which in turn provides the company with more revenue, which in turn allows them to further innovate upon their product. In addition, autonomous control would obviate the need for having to employ robot operators, which would save the company money which can go towards advancing themselves and their product. These positive impacts can be magnified by looking at the idea of its degree of automation (DOA), whereby going from robot operators to autonomous control significantly increases its DOA [4]. This is because autonomous control requires real-time data collection and automatic decision-making, so by adopting this implementation, this would result in significant improvement to the capabilities of the system and hence, more investment and capital gains.

In terms of the negative impacts, one major impact would be the underlying risk that comes with technology like this, where a system is given the task of delivering these packages in the face of constant dangers and uncertainties. For instance, the developers must consider what happens if people intentionally mess with the system, i.e., deliberately blocking its path. The autonomous system would not be able to complete its path, unlike with a robot operator where they would be able to warn them of their actions or perhaps call authorities to help deal with the situation. In addition, another negative impact of autonomous control would be the loss of employment of the robot operators, as they would no longer be required to control the robots. As robots and artificial intelligence become more prominent in the world, there is growing concern over how these machines will make moral decisions [5]. In the case of other humans meddling with the system, it is difficult to program the robot to autonomously deal with the situation,

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both intelligently and morally, so it would be better to have a robot operator in this case to assess the situation and act accordingly.

So clearly there are arguments on both sides of the technology, where the positives mostly impact the company's revenue and success, whereas the negatives impact their reputation with other people and society. Since there are clear arguments on both sides, this makes it difficult to determine how one should proceed and advance their technology with respect to automation. It is certainly dependent on the type of company they are and what product they are automating. For instance, Tesla is significantly advancing their autopilot capabilities with features such as full 360-degree sensor coverage, advanced camera vision and autosteering, which partly explains their surge in stock value [6]. On the other hand, there is a rise in autopilot crashes, which not only resulted in injuries and deaths over the years, but also directly impacted the trust customers and investors have in the company [7]. Overall, the trend in reality appears to be that companies such as Tesla for automobiles, Amazon for delivery, etc., are constantly developing ways in which to automate and make processes more efficient, but for all of these developments, companies must consider the ethics behind such practices and follow specific guidelines put in place by the government and institutions to regulate the use of automation.

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PART H: Recommendations for Future Cognitive Ergonomics

1) In the case of the robotic delivery system, a priority cognitive ergonomics issue is the application of automation. In particular, there are two main ways for the system to function, and that is either manually through the employment of human robot operators, or automatically via the implementation of autonomous robotic control. The application of automation is most prominent in a design project like this because in reality, many companies today are working towards the automation of systems in society, with the goal of maximizing efficiency and revenue for their companies. However, an important consideration is whether or not it is even worth it to invest all this time and money into automation. More specifically, whether or not automation would indeed result in increased efficiency for their field of work, or if a human was already being more efficient this whole time. This leads to the following testable research question for this project: Does the application of automation really improve the efficiency of the robotic delivery system?

2) Participants of this lab study would ideally be experienced robot operators that currently exist for companies like Boston Dynamics but can even be people from local Waterloo robotics companies like Clearpath Robotics and Avidbots. Experienced operators are optimal over novice operators because the goal of the experiment is to compare the efficiency of these human operators to the efficiency of the autonomous control. However, if these operators are not available, the experiment can also be done with more novice people like junior operators or even university students. The gist of the experiment would have the operators perform simple to complex navigation tasks, and then compare their performance to that of the autonomous system. So, depending on the available participants, one could have a comparison between experienced operators performing complex tasks vs. the system, and then novice operators performing simple tasks vs. the system. That way, the experiment avoids outlier tests, namely that of novice operators performing poorly on the complex tasks due to their lack of experience, thus having more accurate and effective experiments.

3) The lab study will contain measurements in the form of both independent and dependent variables. The independent variables will be obstacle course selection, maximum speed,

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and starting battery power. In addition, the dependent variables will be time, distance, average speed, and power consumption. The independent variables are ones that will be varied at the beginning, commonly between the two parties, meaning for each experiment, the obstacle course setup, maximum speed, and starting battery power will change for the both of them. The dependent variables are ones that will be measured for performance evaluation to determine which party is better. In this case, the dependent variables will differ between the two parties, and hopefully by the end of the lab study, there will be a clear winner, which would help the companies determine which approach to the robotic delivery system is ideal.

4) The lab study will compare the performance of two parties: the human operators and the autonomous system. Ideally, if the participants are all experienced operators, then the test set will contain a series of complex tasks. These tasks include turning around corners, avoiding/navigating around obstacles, traversing changes in elevation, climbing up/down sets of stairs, and traversing difficult environments such as rocky terrain and slippery ground. With that being said, these tasks will be arranged into various obstacle courses, and the following measurements will be taken: time taken to complete each course, total distance travelled, speed at multiple points, amount of battery power used, and number of collisions. These measurements are used to score the performance of the two parties to determine which one is better. Moreover, these are the ideal measurements to consider because these are the main factors that affect the delivery time, safety, and reliability of the robot, all which are needed for success of the product.

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