STEM GAMES 2023
Engineering Arena

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Respected STEM GAMES 2023 Engineering Arena competitors,

Welcome to this years knowledge competition in which you and your teammates will compete against some of the other most motivated engineers in the area! This competition has been designed to test multiple facets important to the engineer's work – knowledge of basic concepts in your fields, your adaptability and skill in finding out information you haven't had a chance to learn (or you did, but forgot), teamwork, time management, and finally the ability to clearly and confidently present your work.

During the three days of the competition you will be tested through a task of organizing the initial design of an autonomous delivery vehicle. You will define the initial appearance and the general idea of the vehicle, define it's delivery, propulsion and sensor subsystems, as well as taking a look at the security of your solution.

The tasks are open format – beyond stating the initial, basic, conditions your vehicle will need to satisfy we have decided to not limit your creativity and ingenuity. Still, keep in mind that in engineering just a good story does not get you far. To paraphrase Linus Torvalds - "Talk is cheap, show us the numbers". As engineers, you are expected to base your statements on cold, hard, numbers. This means, that along your descriptions on why you have chosen a certain design route, you are expected to show the calculations supporting it (ideally mathematically sound and correct ones). Remember the quote made by Eric Temple Bell "'Obvious' is the most dangerous word in mathematics".

Before each day starts, the mentors in the arena will hold a short briefing that will help clarify the tasks to you, and allow you to ask any clarifications. We will be there during the day to support you and assist you in any way we can, so feel free to ask us anything!

Thank you for deciding to make this competition even better by choosing to participate in it!

During your work in solving the tasks presented to you, you may use any software or resources that may assist you in achieving your vision and correct answers. Still, to simplify your tasks below you can find a list of download links for various resources that we think could be useful to you during this competition.

Free/trial software recommendations:

- OnShape CAD
  - https://www.onshape.com/en
- Codesys Programming Language
  - https://store.codesys.com/
- WolframAlpha
  - https://www.wolframalpha.com/
- Math equation solver
  - https://www.symbolab.com/
- PLECS
  - https://www.plexim.com/trial/standalone

Resources:

- Festo Mobile Carrier System Datasheet
  - https://drive.google.com/file/d/1MALXDyHN84xzof4AFE5fUQJopavWdaJh/view?usp=share_link
- Festo Parallel Kinematics Robot Datasheet
  - https://drive.google.com/file/d/1pJD-M2iDhQyhmMyz9U7HfCzik2es7zms/view?usp=share_link

STEM GAMES 2023 – Engineering Arena
Day 1

Base vehicle design

(Total points 35)

1.1. Initial design of your vehicle (Max. 10 points)

As mentioned, this year's task for you as a team is to design a fully autonomous vehicle which tasks will be package delivery and design. While many subtasks need to be accomplished for you to design the vehicle (even in a simplified manner such as the one presented here) you need to consider some initial things that will help you in designing the vehicle.

Research and discuss the general design approach. Research similar solutions that already exist in the market. What are their pros and cons, and what are the areas in which you can improve the existing designs? What are some possible challenges with autonomous vehicle design and how will you address them?

Figure 1.1. Some of the existing autonomous delivery systems concepts

In this task, you need to brainstorm and propose an initial design for your vehicle. Some things that you need to generally address are:

- What will be the general shape of the vehicle?
- Will you convert an existing vehicle design or create a new one?
- How much will the vehicle weigh – both empty and full of packages?
- Where will you place all the necessary systems of the vehicle – propulsion system, power storage, control system, electronics system with sensors and actuators…

Use this task to set the foundations of your design. The more things you consider in this stage, the simpler will the other steps of the design be for you going forward. To assist you in creating your design here are some expectations that your vehicle would need to meet to match the standard delivery methods. The vehicle should be capable of delivering an average of 8 packages in an hour, or if we assume a 12-hour delivery window each day - around 100 packages. This does not have to be achieved in a single run - the vehicle can be allowed to return to the package dispatch center. You can design your vehicle with the assumption that it would cover a delivery area of 30 square kilometers. You can assume the delivery roads to be paved, and the delivery spots to be easily accessible - but account for the possibility of the road having elevation angles up to 15 degrees. Also, account for the minimum road width of 2.8 meters and the maximum turning radius of 5 meters.

As the answer to this question, you should provide a set of sketches and comments demonstrating your initial autonomous delivery vehicle idea. Any approximations you make should be supported by data – either information you have researched, properly cited, or supporting calculations. You will be scored based on:

- The novelty of the design
- Correctness of the provided supporting calculations.
- Does your initial design match the capabilities of standard delivery methods?
    - If yes, was your work in proving this shown, and were the calculations correct?
    - If not, did you justify the choice to not satisfy the condition?
- How well-supported is your design compared to other teams?
- Does the design address the following points:
    - Is the design appealing?
    - Is the design robust enough to handle daily use?
    - How complex is the design?
- Other considerations you may include in your design.

1.2. Mechanical requirements for driving system (Max. 10 points)

The vehicle should be able to work in a highly dynamic city traffic environment. One of the requirements for achieving that goal is to have a capable driving system. The vehicle should be able to accelerate fast enough, should be able to travel fast enough, and should be able to overcome the ascents which it can encounter.

You can design your vehicle with the assumption that it would cover a delivery area of 15 square kilometers and will be capable of delivering 100 packages a day, like in the previous task. The vehicle can have different types of energy storage systems (petrol tank, battery, hydrogen tank, …) but all replenishments of energy should be done at the delivery center. The number of packages that the vehicle can carry will determine the frequency of visits to the delivery center and the energy storage should be sufficient for the vehicle to return to the delivery center each time. Replenishment of energy can be done at each visit to the delivery center or only when needed or even only at the end of the day, you can choose which strategy serves this purpose most. The vehicle should also be able to achieve a velocity of 80 km/h and climb an incline of 15%.

For this task, you need to calculate:

- Required power and torque of drive motors.
- Required energy storage capacity for several different types of systems.
- Mass of energy storage system for each type from the previous point.

You will be graded based on:

- The novelty of the design of the proposed system.
- Correctness of the calculations regarding:
  - Driving resistance
  - Vehicle parameters
  - Powertrain losses
  - Estimation of driving conditions

1.3. Accessing the packages (Max. 15 points)

Once the vehicle arrives at the address, the end users need to access their packages. After all, the delivery is not finished until the package is in their hands! There are many different ways in which this can be handled but there are a couple of basic considerations that need to be taken into account when discussing the design:

- The package access needs to be automated once the end user needs to access the package. There should be minimal work by the package recipient.
- At the end of the delivery process, it needs to be easily accessible to the end user, taking into consideration possible limitations and special needs of the end user.
- The access to packages needs to be safe regarding the person accessing the package and the passerby.
- Access to the package needs to be done in a way that minimizes the risk of damage to both the vehicle and the package itself.

Figure 1.2. Example of the passive and active package delivery methods.

Two basic approaches can be applied to the problem at hand – passive and active.

- In the passive approach, the package is stationary within the vehicle and the access is controlled via a different mechanism. An example of this is sliding doors or different openings on the outside of the vehicle.
- In the active approach, the package is moved and “presented” to the end user in a convenient location within, or immediate vicinity, of the vehicle. This can be achieved with conveyor belts or articulated robotic arms.

Hybrid approaches combining the two are also possible.

Assume that the package dimensions can be at a maximum of 600x400x300 (width x depth x height, in millimeters). The maximum weight of the package can be assumed to be 5 kilograms. While most packages will be regular boxes, assume that some packages will be irregular. Note that all packages will have an easily accessible way of identifying the package as the correct one, such as a barcode, RF tag, or similar.

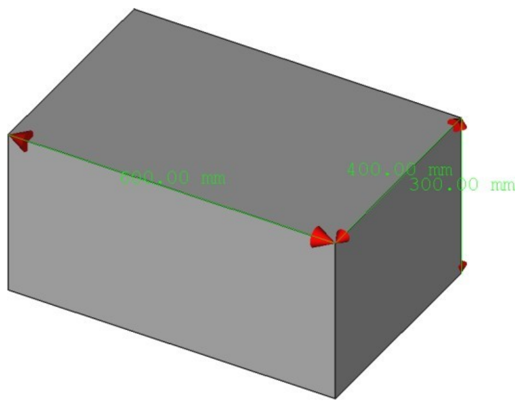


Figure 1.3. Maximum package dimensions

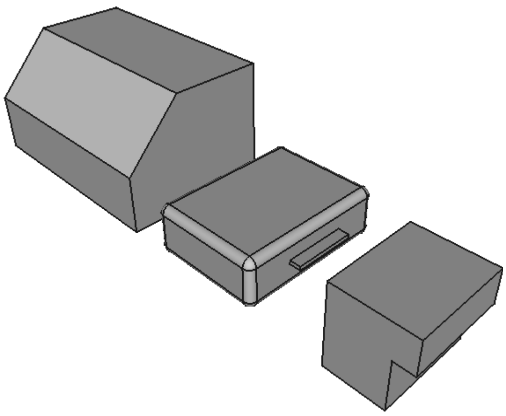


Figure 1.4. Examples of irregular shapes in the packages may be.

Your task is to discuss and design how the end user will access the packages in your autonomous delivery vehicle. In the case of a passive approach, you will need to calculate the dimensions of the delivery “window” that will allow for the package to be accessed. Present a preliminary design of the access control mechanism. Assure that the designed system fits within the vehicle, and provide an approximation of the amount of packages that can be fit inside the vehicle, taking the package handling system in mind. Take into account the size of the mechanism and its dynamics –

how much space is taken by the mechanism itself, what is the mass of the system, and how easy is it to move. For the active approach, provide the preliminary design of the system. Select the type of manipulator that will access and move the packages. Design how the packages will be presented to the end user. Based on your selection, calculate the time needed for the package to be delivered to the user from the point that the initial movement starts.

Based on your proposals select one of the two systems or propose a hybrid one. Provide the calculations which corroborate your discussions. Discuss how durable your mechanism is, especially concerning the possible external factors such as weather or unplanned impacts. Discuss the robustness of the proposed system.

You will be graded based on:

- The novelty of the design of the proposed system.
- Correctness of the calculations regarding:
  - power and the dimensions of the passive system
  - package access speed in the case of the active system
- Robustness of the final proposed system in regards to the outside factors including:
  - inclement weather,
  - possible impacts,
  - possible errors within the surroundings, including misaligned packages,
  - rough terrain at the delivery spot.
- The simplicity of the system (the simpler system, the better).
- User-friendliness of the system. Especially in regards to the end users with limited mobility.

STEM GAMES 2023 – Engineering Arena
Day 2

Propulsion and control

(Total points 50)

2.1. Force times mass equals... Propulsion systems? (Max. 10 points)

In today's digital age, almost every shipment is delivered by vehicle. In most cases, every order made by the user via the Internet or in a branch comes with delivery. For example, smaller deliveries such as food are delivered by scooters or smaller cars, and some brave delivery men deliver by bicycles or scooters (kudos to them!). But sometimes it is not very practical. The reason for this is overcoming the challenges of road traffic, such as road conditions, potholes, uphills, and downhill roads, which can have a significant impact on the mental health of the delivery driver who is in a hurry to make sure that the shipment arrives in one piece. For this reason, it is sometimes better to take an autonomous system that casually delivers the package in a defined time window. But to do this without excessive difficulties, it is necessary to wisely choose the drive system that will drive the vehicle, among which there are various such as internal combustion engine drive, electric motor drive, and many other motor drives are used.

Figure 2.1. Examples of different propulsion systems

Concerning the given guidelines, vehicle designers must pay attention to all kinds of categories, so today you will get a little deeper into the issues of that part, that is:

- Define the propulsion system with which the vehicle will drive your packages.
- Define the drive system, i.e. drive on the front two wheels, rear two, or individual drive.
- Define and calculate the energy required for your vehicle to deliver packages flawlessly in the city (for 8-12 hours at least).
- Define the method of resupplying the spent energy, and define the innovative way that the vehicle will be resupplied with the necessary energy so that at the end of its heavy work shift it can again deliver packages to further users in the morning.
- In addition, determine a working period during which the vehicle could perform delivery tasks for a longer period without excessive maintenance.

When solving, pay attention to the realistic conditions that can occur during delivery, sudden changes in the environment, and various threats that can disrupt the reliability of your system. In addition, it is necessary to define the advantages and disadvantages of your designed system, i.e. vehicle, and try to make sure that the system has more advantages than disadvantages because you are a future engineer after all.

2.2. CAD vehicle design (Max. 25 points)

It is time to make a CAD model of your vehicle. In this phase it cannot be the full model with every bolt and nut present but the “box-on-wheels” concept phase model which represents placements of different systems in the vehicle, some important interactions between system function principles of main subsystems, etc.

This task is the further development of task 1.1. Also, based on calculations in task 1.2. you chose the propulsion system in 2.2. and package delivery system in 1.3. Based on those decisions you should now give that system some dimensions and place them in the vehicle model. Special attention is put on powertrain components. Place all subsystems needed for delivering power from the energy storage to the wheels. Components of the package delivery system should also be presented so that functionality is demonstrated.

Apart from the propulsion system, for secure vehicle control, the steering and braking systems are needed. For conventional vehicles, those systems are controlled purely by the driver with mandatory mechanical connection for the whole system. The CAD model proposes the mentioned systems for a completely autonomous vehicle. Consider system actuators, sensors, and other components required for the dependant and secure operation.

You will be scored based on:

- Components and system dimensions
- The compactness of the design
- The functionality of the proposed systems
- Match of the model with previous decisions

Everywhere we turn there are some kind of sensors or some kind of artificial intelligence algorithms, without which today's world would be unimaginable. From cheekbone fingerprint sensors or facial recognition, infrared sensors, etc.

What would today's modern car be without at least 365 sensors? Probably some sort of old-timer.

Given that the theme of this year's STEM games is to design a modern and autonomous car, it is necessary to implement some sensors so that your vehicle can independently perform tasks such as delivering ordered packages.

Your vehicle must overcome various challenges to complete the given task.

With this in mind, it is necessary to define:

- proximity sensors from neighboring vehicles,
- line tracking to keep the car in its lane,
- a sensor that determines the speed of the car,
- a sensor for approaching the vehicle too fast (danger of collision),
- Light Detection and Ranging sensor,
- sensor for turning on the lights in poor lighting conditions,
- parking sensors,
- Global navigation satellite system,
- and of course, if you consider other necessary sensors that would contribute to the quality of your vehicle.

After the definition, determine the parameters of each sensor you have chosen, determine the minimum distances, and activation time, and confirm them with mathematical expressions. Finally, using the previously modeled car, implement i.e. determine the location, and define the position of individual sensors in your car in your own words.

The scoring of this part of the task will be based on the selection of the optimal sensor model, the safe distance for parking and driving through a crowded city, and the safety of your car from potentially creating a traffic accident.

2.3. A visualization is worth a thousand words, but maybe it's better to trust the technology. (Max. 15 points)

Every system that is automated consists of some kind of logic circuit that collect data from sensors, actuators, thrusters, etc. At the same time, such an automated system performs each action independently and possibly informs the monitoring station about potential hazardous errors. In most cases, these actions are carried out without any problems, but there are also those minority cases that, unfortunately, are not. For the human operator to have an insight into the current state of the vehicle, he must have some kind of graphic interface like HMI (Human machine interface) which he will monitor during his work shift with his favorite drink or donut. In the period from May 9 to May 14, 2023, designers and engineers are on annual vacation and right now such an interface needs to be designed, luckily you are there!

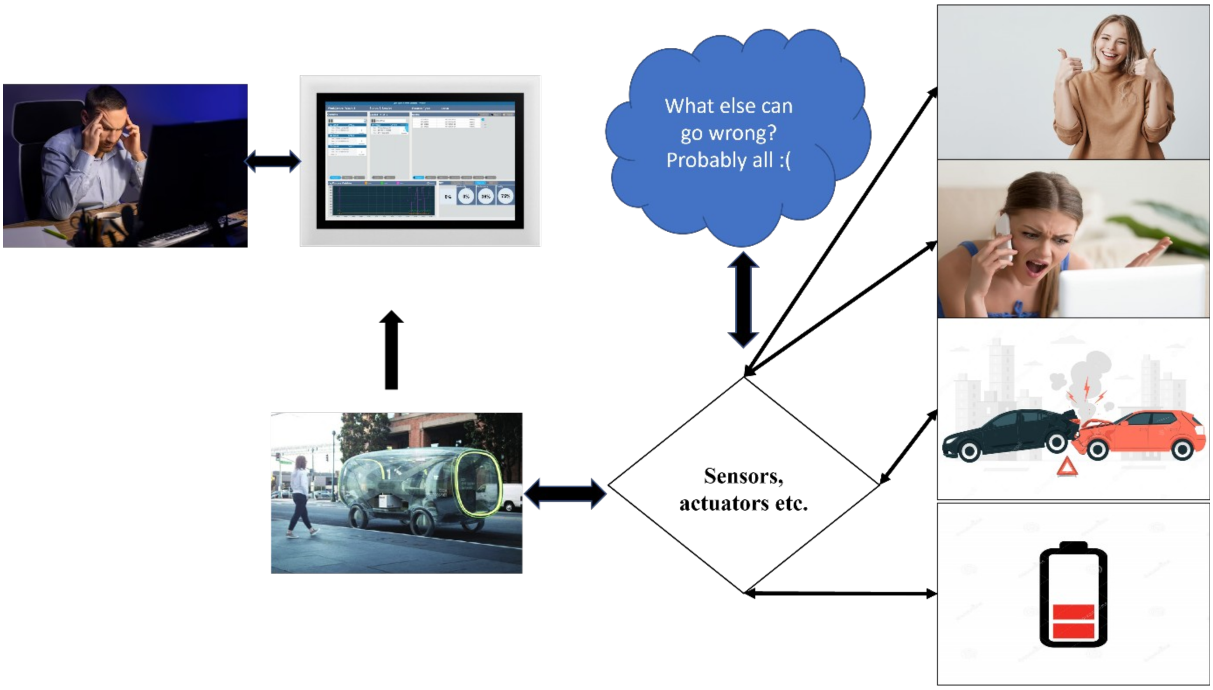


Figure 2.1. System illustration

In this task, it is necessary to design a graphic system whose properties will meet the supervisor's concerns when controlling his delivery units.
You must take into account all kinds of conditions, such as:

- tire pressure,
- the amount of energy in the energy storage,

- proximity sensors of the vehicle to certain objects (for example, a car in front of, behind, or next to an autonomous delivery vehicle),
- failure of your drive (selected engine),
- delivered package at the defined time, delivered package outside the defined time package, undelivered package,
- low energy level when requesting a larger moment at those devilish uphills in the city and
- security safety, for example, reporting in the event of a traffic accident and auto-shutdown of the car (in case the supervising operator cannot see on the HMI), and
- other potential (realistic) categories.

In addition to visualization, it is necessary to choose a management system that will regulate all this (at least what it can regulate). This is considered to be the selection of a qualitative assembly, i.e. a device that can handle your tasks, i.e. the signaling required for the smooth operation of an autonomous vehicle.
The principle of evaluating this task is based on the following parameters:

- the price of the selected control unit,
- which categories of challenges you took into account and their creativity,
- the form of signaling (for example, on the HMI, flashing, constant lighting, turning off when pressing the reset button, etc.)

2.3.2. Control system design

Having all of the sensors and actuators is nice, but the system needs to be controlled and programmed in some manner. This will be the task of the control system, that you will need to select in this part of the task.
In modern solutions, control systems can be based on many platforms - a classic x64 architecture computer, a PLC, FPGA, non-operating system microcontrollers… Multiple connected systems are also common. These systems are seldom designed from scratch - as such an approach would be extremely expensive but are more commonly selected from various existing solutions.

Based on your electronics system design, select a control system that will allow you to integrate and program the design. Make sure that the control system is appropriate for your task, based on the number of existing analog/digital inputs, processing power, and other capabilities.
Approximate the control system response time, using manufacturer data - assure that the control system is fast enough to perform all the tasks you have deemed necessary.

As the answer to this question provide the datasheets of the selected controller(s), along with the brief justification of their selection making sure you note if all the needs have been met. If possible find and provide the documentation showing the cost of the selected controller. Comment on the cost/performance of the selected controller and the validity of selecting such a solution regarding the cost.

You will be graded based on:

- How appropriate is the controller selected, based on your electronics design? [max X. points]
- How future-proof is the design, and how well would it handle possible expansion? [max X. points]

STEM GAMES 2023 – Engineering Arena
Day 3

Security of the system

(Total points 15)

3.1. Protecting the package access (Max. 5 points)

On the first day, you have designed a system that allows for the packages to be accessed by the person picking up the package. Still, we cannot allow anyone to access the packages, can we? In this exercise, your task is to design a package access control system that will assure that the person accessing the package is the intended receiver of the package before you begin the final part of package delivery (making the package directly accessible to the recipient).

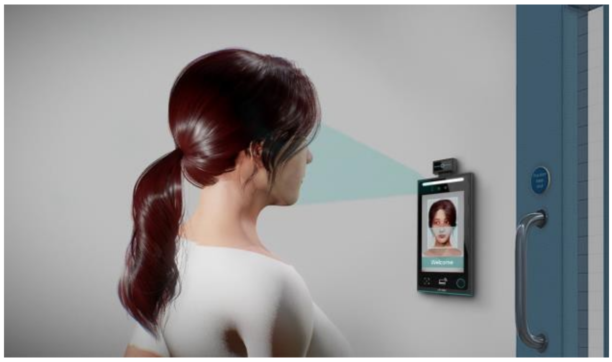


Figure. An illustration of common access systems

This system can range from a simple identification number provided to the vehicle by the person looking to access the package, or it can be a complex identity verification system based on various forms of identifying a person. It is important to note that, while the system needs to provide a satisfactory level of security, making it too complex can cause issues for the person attempting to access the package – making their package inaccessible to them and causing dissatisfaction.

The final element to consider is the efficiency of the system. For the package to be accessed your autonomous vehicle will need to be stationary. This means that each second of the user attempting to pick up the package is a second your vehicle is not doing deliveries – which is not only not efficient on a grand scale, but can cause delays.

You should also consider what to do in the case where the user does not show up to pick up the package – will you wait for the user to arrive? If, yes, how long? What about the case in which the user arrives but fails the authentication process?

Design the system according to the above considerations. Try to design the system in such a way that you satisfy the security, simplicity, and efficiency concerns.

Create a flow diagram showing the description of the process. Demonstrate how you would integrate the system inside the systems you have already created – both the sensor/actuator system and the vehicle design. Consider the accessibility to the users. Find appropriate existing solutions/sensors/actuators for the access authentication solution or describe them in detail if you cannot.

In addition to the diagram and system's design you will need to approximate the cost of the security system. Find the cost of individual system parts and evaluate it. Is your solution cost effective? Can you further optimize the cost of the system in some manner?

You will be graded based on:

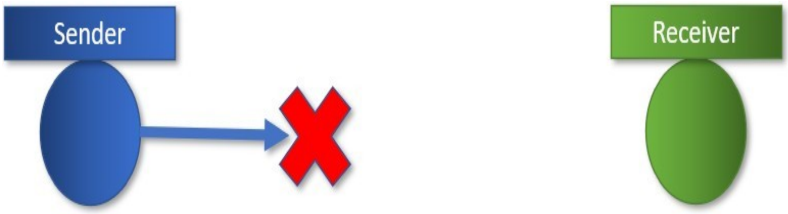
- The simplicity of the system's design
- The efficiency of the system's design
- The security level provided by the system's design
- How well did you integrate the system into the existing systems, mainly:
  - Integration into the vehicle design
  - Integration into the electronic system design
- Cost of your system.
- Accessibility of the system. Especially in regards to the end users with limited mobility.

3.2. Security of the delivery (Max. 10 points)

By designing and implementing the above system you have already made a significant step towards making your system secure! Still, many other considerations need to be given.

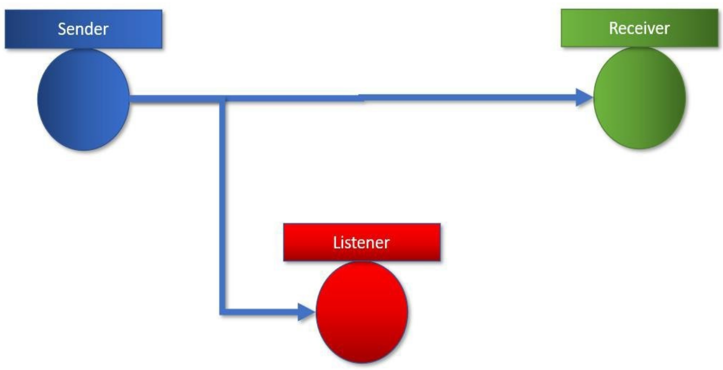
In security, we usually discuss four different types of threats:

Package destruction



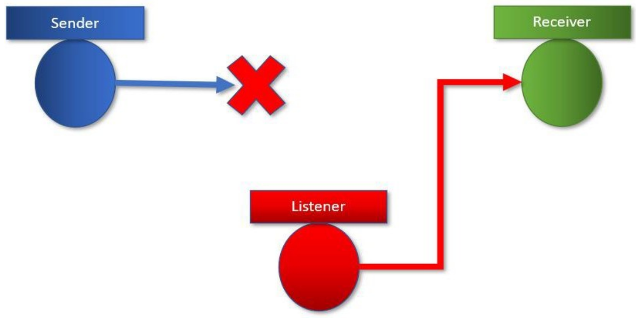
While the name of this process is rather bombastic - we don't consider the destruction to merely mean that the package can be destroyed - but any situation in which the package disappears - whether it's lost, stolen, misdelivered, or something else

Package leaking



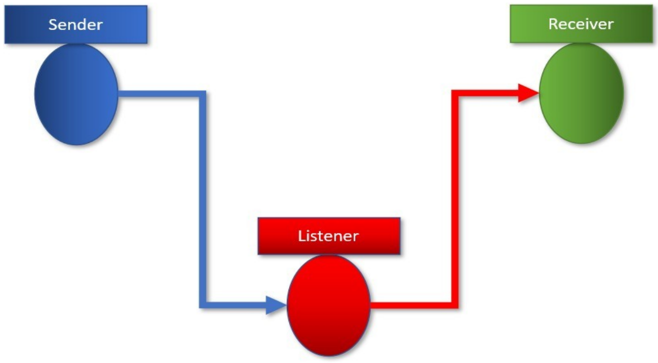
When packages are delivered to our end users we want their contents to be private, avoiding exposing them to anyone else. Still, a malicious third party could very well attempt to take a sneak peek at the wrong package and learn its contents.

Package replacement



In this instance, the original package is somehow replaced without the end user knowing it was replaced, leading to them receiving the wrong package. In this instance, we don't consider the package being taken and accessed by a third party.

Package interception



The package is taken by the third party, opened, and replaced by them - with the wrong package arriving at the planned end user. While at first look this seems very similar to the package replacement - there are a couple of important differences. The main one is that, in this instance, the third party knows the contents of the package, possibly nullifying some security measures taken at the package level.

How will you address these threats? Take the devil's advocate stance and look at the system you have designed critically, trying to determine its weaknesses. If you were someone looking to steal the package themselves or the certain information within it, how would you do this?

Each of the weaknesses you list can fall into a couple of possible categories:

- **physical/non-physical** - is the weakness something that requires physical tampering with the system (e.g. physically grabbing the package from within the vehicle), or can it be performed as a non-physical action (e.g. providing wrong information to the vehicle to get the package).
- **evident/hidden** - if the weakness is exploited will this be apparent? For example, picking a lock may be hidden, but smashing it with a hammer will be evident.
- **continuous/non-continuous** - a one-time threat is something that can be exploited once, while a continuous weakness is something that can be exploited again and again if someone is familiar with it.

As the solution to this question, provide a list of possible weaknesses you have found in your system. For each of them, assign the above categories (for example, a weakness may be physical, non-evident, and continuous). For each of the weaknesses, comment on how you would address them. You will be graded based on:

- Completeness of the weakness identified in the system
- Is each of the weaknesses correctly identified? [max X points]
- How well is each of the listed weaknesses addressed?