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IMPROVEMENT OF SECURITY MANAGEMENT IN THE WAREHOUSE SPACE THROUGH THE USE OF A VISION SYSTEM IN A SELECTED ENTERPRISE

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Purpose: The purpose of the presented research and analysis was to create design assumptions for a vision system supporting security supervision in the warehouse space to reduce threats.
Design/methodology/approach: In the first phase of creating the project concept, two methods of hazard analysis (FTA and ETA) were used in the warehouse facility. Then, at the stage of selecting the devices included in the video surveillance system, a simple FOKUS program was used to scale the cameras.
Findings: In order to create a vision system project for a selected warehouse facility, an analysis of its spatial structure, weak points and identification of possible threats was carried out, taking into account the specificity of work performed within the working space of the warehouse. Then, video surveillance zones were determined based on the classification of threats in the space of the facility. The devices included in the vision system were also selected according to the assumed functions of this system and their distribution in the tested object. In addition, the optimal parameters of the cameras (using a scaling program) and the characteristics of other necessary devices of the vision system were determined.
Practical implications: The solution can be an aid in making an investment decision by the management in order to improve security management in the examined warehouse facility of company X.
Originality/value: As a result of the analyses, an optimal and original design solution for the vision system was obtained for the tested warehouse in company X.

Keywords: security management, storage facility security, threat monitoring, video surveillance system.

Category of the paper: technical document, case study.

1. Introduction

Effective security management in industrial plants of any purpose is possible thanks to the use of all available tools, devices and procedures that are part of security systems (Lewandowski, 2000; Kołodziński, 2011). With the help of these systems, it is possible to ensure effective safety management in production processes, also in the transport phase (Rut, Wołczański, 2015). The task of safety systems is to reduce the risk to a minimum, improve occupational hygiene, but also to increase the quality and efficiency of the production processes carried out. An important role among technical protection systems is played by alarm systems equipped with detection devices that detect and generate information (warning) about the threat (Ignac-Nowicka, 2018). Due to the number of devices used and their functions, three levels of technical protection of the facility can be distinguished in the facility security management:

- low level of technical protection - it is characterized by the simplicity of planning the protection zones of the facility, no perimeter protection zone and the protection of architectural openings, e.g. windows; the most commonly used devices are motion detectors, magnetic door detectors, acoustic siren,
- medium level of technical protection - characterized by multi-zone protection (perimeter protection zone - magnetic detectors and glass breakage in window openings, internal protection zone - various types of motion detectors),
- high level of technical protection - it is characterized by the integration of systems, e.g. access control, burglary and assault alarm and fire alarm, as well as a closed-circuit television system (Wójcik, 2004).

Security systems, such as video surveillance, enable e.g. real-time insight into the production and transportation process. With its help, it is possible to recognize and verify emerging threats in a technical facility before a dangerous situation occurs. The vision system together with other security systems (e.g. fire protection system) creates a high level of technical security of the facility in the security management system.

In the warehouse space, there are problems with documenting threats such as: theft, destruction of goods, improper storage generating threats to employees and goods. The article attempts to solve the problem of effective identification of threats in the warehouse space. For this purpose, an appropriate configuration of the vision system was designed for the tested warehouse. It was assumed that this system would contribute to reducing the number of threats and accidents in the warehouse space.

2. Research methods used

In the first phase of creating the concept of the vision system project, two methods of hazard analysis were used: fault tree (FTA) and event tree (ETA) in the warehouse facility. Due to its specificity, the fault tree method (FTA) has a limited scope of application, but it leads in a simple way to determining the causes of threats and shows their logical interrelationships. In this method, events are determined whose combinations lead to a peak event. In this way, the so-called error tree, i.e. events connected by "or" and "and" logic gates. The FTA method can be used to describe events involving technical means (machines) and humans (working crew). In this method, emergency events of technical elements and failures resulting from human error (human factor) can be taken into account at the same time. This gives the possibility of a broader analysis of causes and effects that lead to the final event in the form of an accident or technical failure. The Event Tree Analysis (ETA) method allows for the analysis of alternative outcomes of a particular hazard event. The method of describing an object, process or workplace consists in determining a sequence of events leading from the initiating event to the threat and, consequently, to a specific loss. The event tree diagram consists of a header that contains a sequence of events determined by the procedure of the work process. The event tree method can be used to analyze a working technical object as well as the work of a man with a machine.

Then, at the stage of selecting the devices included in the video surveillance system, a simple FOKUS program was used to scale the cameras. Cameras used in video monitoring systems are characterized by different operating parameters, so each time the parameters should be selected for a specific supervised area. When choosing the parameters of the camera, focus on the two most important parameters: the working range of the camera and the size of the image converter (sensor), which determines the size of the image produced, and the focal length of the lens, as the distance between the image sensor and the central point of the optical system of the lens. Other parameters of the camera will be of secondary importance. The FOKUS program allows you to observe the size of the object seen on the monitor depending on the parameters described above.

3. Designing security systems in technical facilities

Designing an alarm system should begin with determining the formal requirements that must be met by the entire installation (due to the investor's expectations, legal conditions or those imposed by the insurer). Creating the initial concept and design as well as system implementation is a process on which the correctness and effectiveness of the security system in the facility depend. The designer's duty in the process of creating the concept of the alarm system is to present the real threat to the facility and to plan the security system in such a way that it effectively resists negative actions. For this purpose, the principles of designing alarm systems should be followed, with particular emphasis on the sequence and completeness of the design phases (Prussak, 2011; Sienkiewicz, 2015).

3.1. Creating a security system for a warehouse facility

Designing facility security systems requires:

- knowledge of the technical object and its surroundings,
- identification of threats, weak points and dangerous places,
- selection of the security system and its functions,
- determining the proper parameters of all components of the security system.

The process of designing protection systems for a technical facility consists of many phases, which are presented in Figure 1.

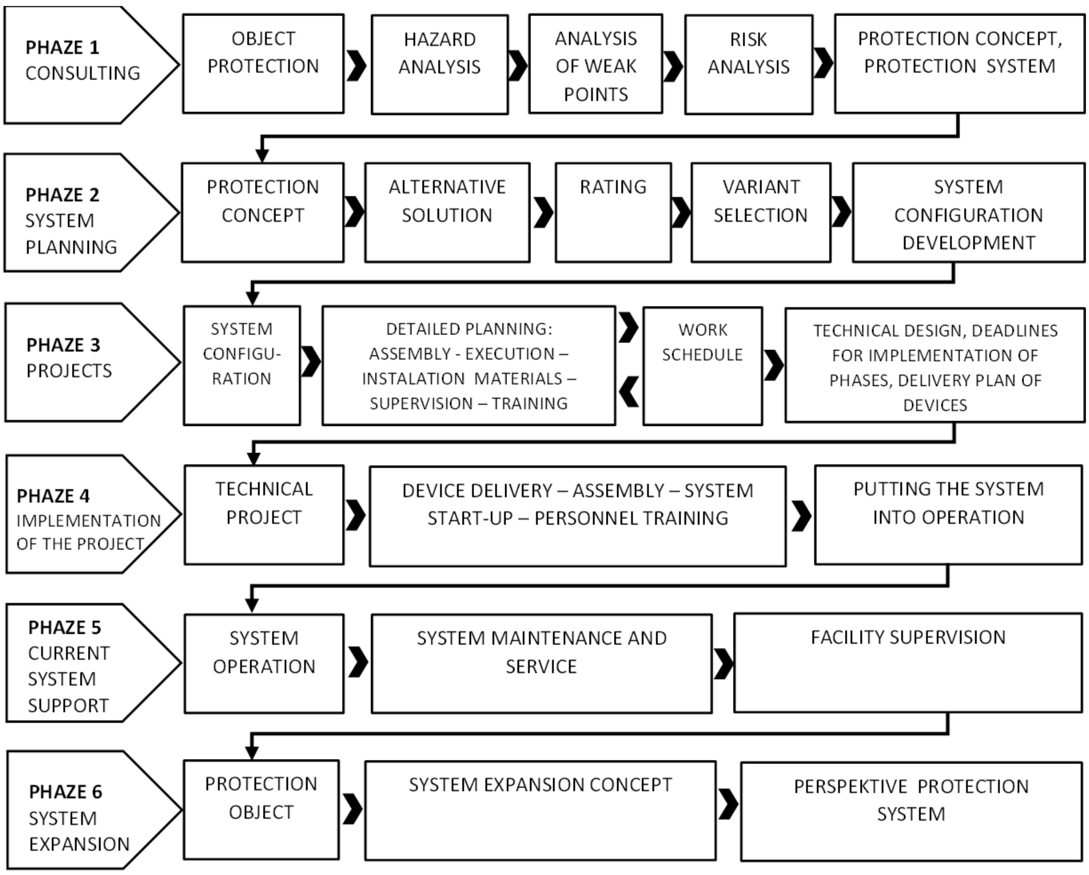


Figure 1. Scheme of the process of creating a security system in a technical facility.

Source: Ignac-Nowicka, 2018.

In the “consulting” phase, an important stage is the analysis of threats and identifying weak points. For this purpose, an appropriate method of identifying hazards should be selected according to the nature of the technical facility and the specificity of the hazards, taking into account the human factor. In the “system planning” phase, a protection system concept is created (usually in two or more variants), which are then assessed, after which the optimal variant is selected by the investor. In the “projects” phase, detailed planning of the work schedule is carried out in the form of: assembly, execution, use of installation materials, supervision and training of the staff. In this phase, the technical design of the security system is created. In the “project implementation” phase, based on the technical design, the following takes place: delivery of equipment, assembly, and then commissioning of the system, then training of the staff and commissioning of the system. In the "current service" phase of the system, uninterrupted operation of the security system should be ensured through its appropriate maintenance and service, as well as the organization of supervision of the security system. In the last phase, "system expansion", a concept for expanding the security system is created, i.e. a prospective system, indicating the possibilities of expanding the current system in the future (Wójcik, 2004; Jodełka, Rosiński, 2018).

3.2. Video surveillance system as a tool to ensure security in the facility

One of the definitions of video surveillance proposed by the Inspector General for Personal Data Protection in the provisions on video surveillance reads as follows: "monitoring (video surveillance) - remote reception of an image or image and sound from a space within the field of view of cameras installed at specific points near the monitored area ". On the other hand, "a monitoring system is a set of cameras, transmission devices, electronic data carriers, data recording devices, devices reproducing recorded data and software used to achieve a specific functionality in the field of monitoring" (Kardas, Cicekli, 2017). In industrial plants, video monitoring is becoming a standard and a common practice in terms of securing property, especially against acts of vandalism, theft or intrusion of third parties into the enterprise (Ignac-Nowicka, 2016, 2021; Eiharrouss, Almaadeed, 2021). Video monitoring in a company can play an important role of previewing a selected part of the technological process or controlling the behavior of employees by registering, for example, evasion of health and safety regulations. Video monitoring by recording emerging threats allows you to obtain important information related to the level of security in any area of the industrial plant (Badowski, 2021; Matuszek, 2020; Zieliński, 2019).

Due to the nature of the work of video systems in buildings and open spaces, three main functions of the CCTV system can be distinguished: preventive, operator and evidence. The preventive function consists in informing about the installed video monitoring in order to discipline the behavior of people who must take into account the possibility of recording their image and identification. The operator function consists in the reaction of the monitoring operator who tracks the image from the cameras in real time and reacts to threats visible on the screen. This function is often used in the monitoring of industrial processes and workplace safety. In turn, the evidentiary function consists in recording the image from the cameras on a suitable medium in order to obtain the possibility of reconstructing the events also after some time. This function is particularly useful when determining the course of events after an accident at work. Video surveillance systems are therefore an important means of prevention and protection, which allows you to view places and objects at a distance (Ćwikła, 2013; Ignac-Nowicka, 2018; Lim et al., 2014; Majkucińska, 2012).

The closed-circuit television (CCTV) system should be equipped with appropriate devices so that the video monitoring can fulfill its three basic functions. The vision system usually includes the following devices: cameras, monitors, devices transmitting the video signal, devices controlling utility functions (image changers and image dividers - quads, multiplexers, video switchers, control keyboards), archiving devices (time-lapse video recorders, digital recording). Multiplexers are devices that simultaneously perform the functions of an image changer and a divider. The multiplexer allows you to operate multiple cameras simultaneously and simultaneously display high-quality full-screen images on a split screen. The resolution of the multiplexer determines the quality of the image displayed on the monitor. Video matrix switchers are devices that transmit the video signal from cameras to monitors or multiplexers. They make it possible to organize cable connections for a large number of signals. Thanks to the use of patch panels, you can easily manage the network architecture of the video system. The matrix functions are programmable and allow for free directing of the image to the monitor or recording devices, enabling the creation of any network architecture of the video system (Ignac-Nowicka, Procel, 2019; Deligiannidis, Arabnia, 2015; Donald et al., 2015; Tsakanikas, Dagiuklas, 2018).

4. Identification of hazards specific to work in the warehouse space

The process of identifying threats and their causes in the tested storage facility was carried out using the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) methods. In these methods, emergency events of technical devices and events resulting from human error (human factor) can be taken into account at the same time (Ignac-Nowicka, 2017, 2018a, 2018b; Ignac-Nowicka, Krenicky, 2018). This gives the possibility of a broader analysis of cause and effect factors that lead to dangerous events in the warehouse in the form of an accident, destruction of stored products or failure of technical equipment (e.g. forklifts). Identification of threats is an important starting point for the implementation of the facility protection project, which affects the shape of the system (number of cameras and their location).

4.1. Characteristics of the analyzed warehouse facility

The analyzed warehouse facility has the following dimensions: length 90 m, width 70 m and height 15 m. Products are stored up to a maximum height of 10.4 m. The warehouse is divided into 13 corridors marked with capital letters. The corridors differ in length and number of racks. In the M and L corridors there are 36 racks and all kinds of food products are stored there, while in the T and U corridors there are 60 racks where alcohol is stored. The T and U corridors are separated from the rest of the storage space and have two separate entrances at the ends of the corridors. In the other corridors, all kinds of industrial products are stored. Corridors A, B, C and D contain 172 racks, while corridors E, F, G, H, I, J and K have 350 racks.

The analyzed warehouse facility has an appropriate fire safety system, consisting of an early warning system for fire and active extinguishing and smoke extraction. Safety in the warehouse also consists in respecting the permissible load value of the racks, securing the installation and designating passageways of the appropriate width. There are clearly marked corridor zones in the warehouse facility, which greatly facilitates the movement of employees and machines in the warehouse. The adaptation of employees to the rules regarding occupational health and safety in the analyzed warehouse requires, among others:

- compliance with specific load capacity or loading weight standards when using means of transport,
- securing transport loads in an appropriate manner,
- comply with the traffic rules on internal roads,
- designing and complying with appropriate signage,
- systematic safety inspections and maintenance of machines and technical devices.

In the space of the entire warehouse, there is a rule of arranging products that constitute stocks on the upper shelves of the rack, while products ready to be issued to order are stored on the lower shelves. Each product is stored on euro pallets, chep pallets or disposable pallets. Products are delivered by trucks to unloading docks (Figure 2) marked with letters from D1 to B, while between docks B and A3 there is an entrance for smaller vehicles (e.g. forklifts). After accepting the delivery, the products are delivered to the racks using forklifts. The general plan of the warehouse facility is shown in Figure 2.

4.2. Identification of threats in the examined warehouse

The use of the event tree analysis (ETA) and fault tree (FTA) method allowed to identify the causes of losses in the warehouse and other undesirable events. In the analyzed warehouse, there may be many threats resulting from both the incorrect behavior of staff and external persons, as well as the specificity of goods received into the storage area. The most common threats identified by the Event Tree Analysis (ETA) and Fault Tree Analysis (FTA) have been grouped and summarized in Table 1.

Some of the hazards listed in Table 1 have a direct impact on work safety in the warehouse, while others have a significant impact on labor costs and difficulties in the work process. In order to increase the level of safety and efficiency of the work process, it was proposed to use video monitoring.

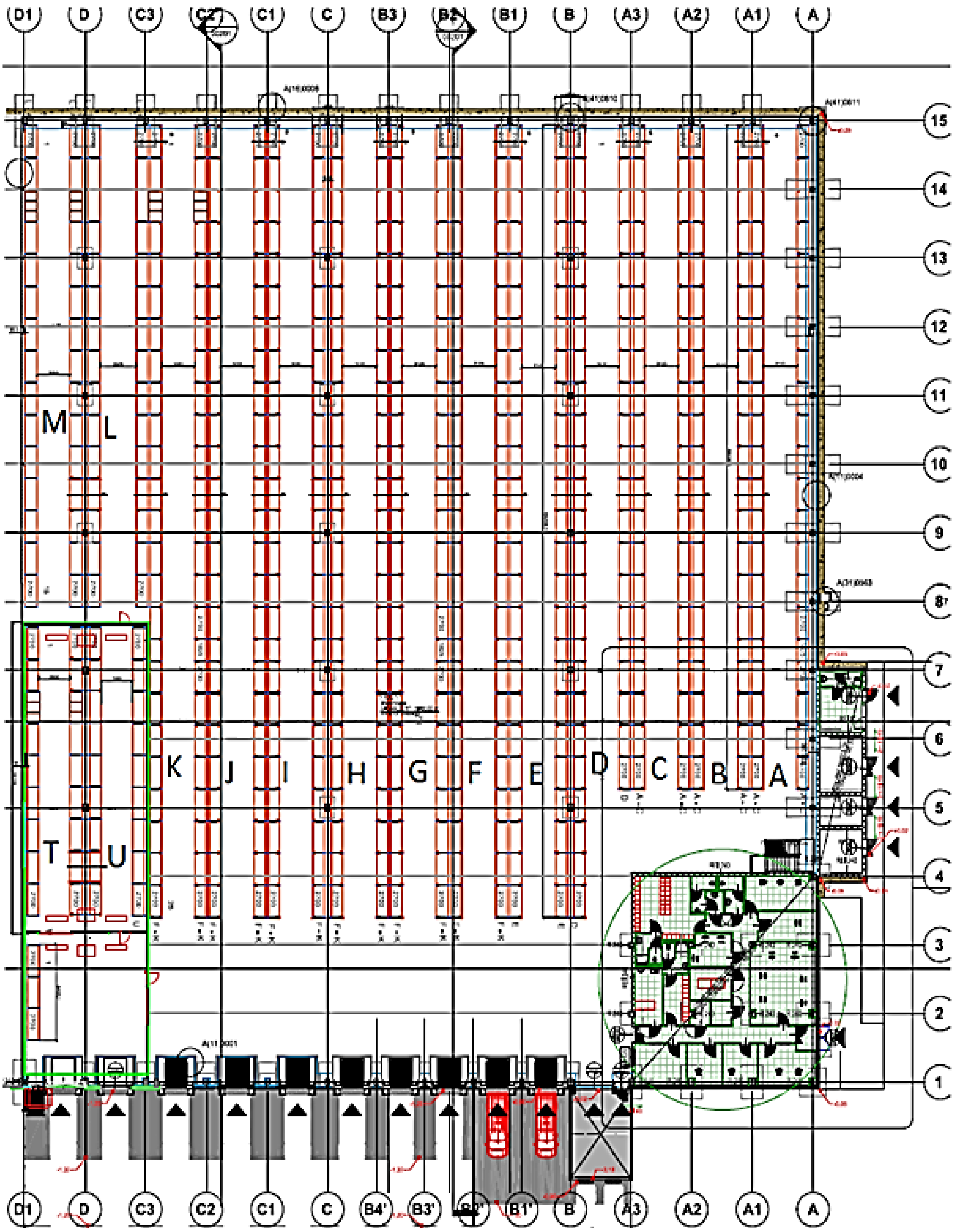


Figure 2. Plan of warehouse space divided into sectors (marked with a capital letter).

Source: Own study based on the technical documentation of the warehouse facility of company X.

Table 1.
Threats that occur most often in the analyzed warehouse facility

Place or source of danger	Threat description
Warehouse worker risks	• falls from a height, • falls due to slipping on a slippery surface, • employees being hit by forklifts or other vehicles moving in the warehouse, • collisions of machines moving in the warehouse, • physical overload of employees related to manual unloading work, • stress caused by employees' financial responsibility for the goods in the process of accepting them into the warehouse
Mistakes made during the work of warehouse workers	• acceptance of goods delivered in damaged loading units, • acceptance of goods that were delivered in incorrect packaging, • acceptance of goods classified as dangerous goods, • improper arrangement of goods on the racks resulting in the fall of goods from the rack
Threats from bystanders	• hazards posed by truck drivers (e.g. improper parking at docks), • unauthorized persons entering the goods unloading area
Risk of losing goods	• damage caused when accepting the delivery of goods, • goods theft
Environmental hazards in the warehouse	• risks associated with improper storage of goods that may be toxic or flammable, • fire in the warehouse, • excessive noise, • presence of an intense smell of goods containing chemical substances

5. Design assumptions for the vision control system of a selected warehouse facility

Threats appearing in facilities with large areas, such as: large-format commercial facilities, extensive production halls and large warehouses, are characterized by the difficulty of their monitoring due to the too large area to be controlled. In facilities with a large area, where specialized systems are used, e.g. fire control, explosion control or control of threats intended by people (theft, destruction, sabotage), in the event of activation of the threat signaling, it is difficult to quickly verify the event due to the huge number of sensor devices. Much faster verification of the event, in these cases, is guaranteed by an additional vision system with an operational function, allowing for immediate viewing of selected danger zones in real time.

5.1. Definition of video surveillance zones

The analysis of events within the warehouse showed the greatest number and variety of threats in the goods receiving and issuing zones. Providing full-scale protection to a warehouse facility requires securing products throughout the entire unloading process in the warehouse. The entire delivery path must be controlled from the moment the vehicle approaches the unloading docks or enters the warehouse. Due to security procedures, the entire access road must be controlled because in the case of goods that require special unloading restrictions, full documentation is necessary in the event of violation of procedures. Unloading can always result in physical damage to the packaging or the goods themselves.

On the basis of analyzes of loading and unloading activities, zones of special supervision have been designated, which will be equipped with video surveillance. There are four supervision zones marked in Fig. 3 with the letters: E, F, G, H. The first zone (marked with the letter E) is the zone of unloading docks, the second area where euro-pallets with goods are temporarily stored (marked with the letter F), the third zone is the office (marked with the letter G) and the fourth zone is the place where goods are stored and issued according to the order (marked with the letter H). These zones were selected as video surveillance areas due to the large number of events generating the greatest danger.

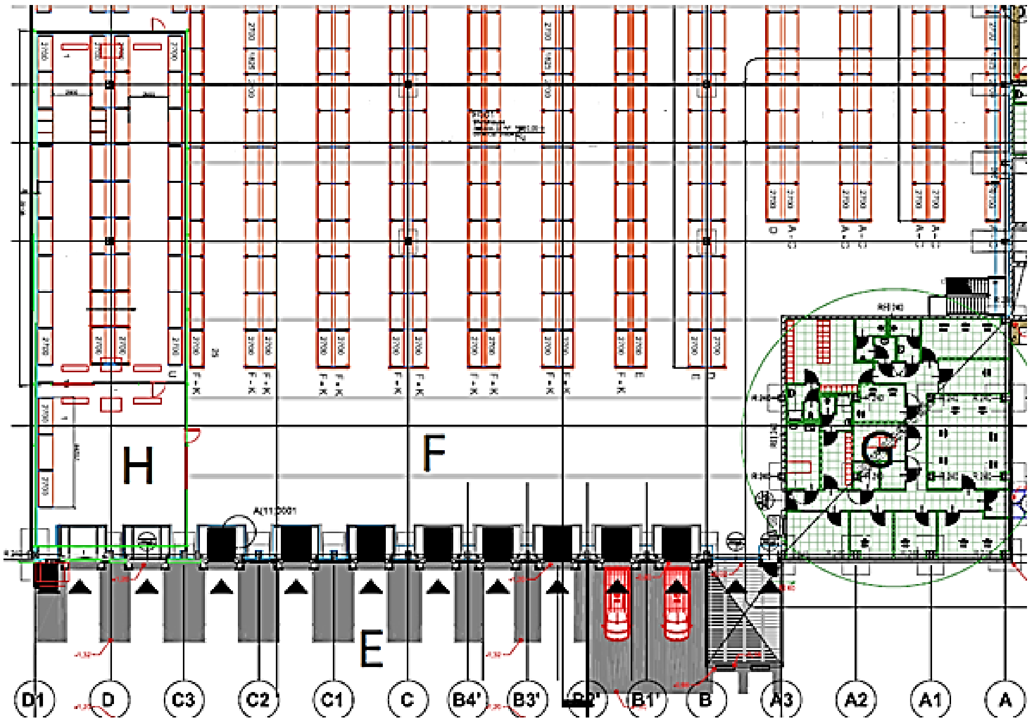


Figure 3. A fragment of the plan of the warehouse facility with designated supervision zones.
Source: Own study based on the technical documentation of the warehouse facility of company X.

In the area of unloading docks, quite frequent abuses of truck drivers were found, consisting in blaming staff for damage to goods that were damaged as a result of inadequate protection during transport. In the absence of evidence, the storage company incurred financial losses. Warehouse space F is an area where you can efficiently control the condition of packaging of goods on Euro pallets and verify whether the goods have been delivered intact to the warehouse. On the other hand, the office area (zone G) requires control of people entering and leaving in order to limit the movement of unauthorized persons in the administrative area of the warehouse. In zone H, where goods released from the warehouse are collected, additional video surveillance will allow for verification of the correctness of the process of collecting goods by carriers.

5.2. Selection of the type and parameters of cameras using the FOKUS tool

In order to determine the appropriate parameters for the cameras operating in a specific warehouse space, a simple FOKUS program was used to support the design of video surveillance systems. Start using the application by entering the appropriate input data into the program. The FOKUS program allows you to enter the following input data:

- range - is the actual planned distance of the camera from the object,
- sensor - describes the type of optics in the camera affecting the quality of the recorded image - the smaller the sensor, the more accurate the image will be,
- focal length – the parameter responsible for the camera's angle of view - the smaller it is, the wider the vision can be obtained (greater angle of view).

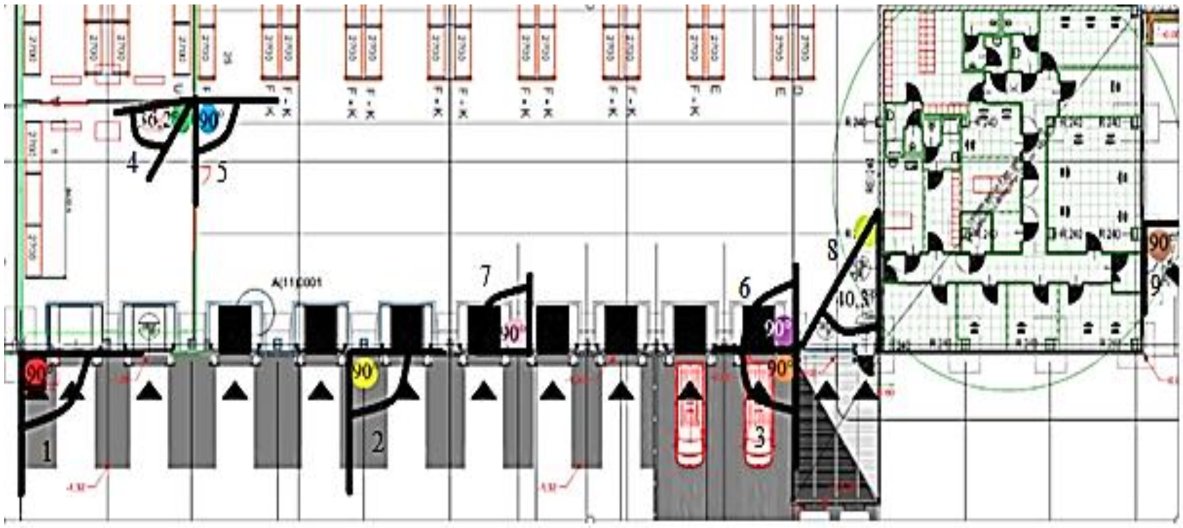
By changing the above parameters, the FOKUS program allows you to observe the simulated image that the camera with the given parameters will send to the monitor screen. This allows you to select the parameters according to what will be visible on the monitor and thus recorded, e.g. digitally on a computer disk.

When determining the appropriate camera parameters, it should be remembered that objects in the field of view of each camera may obscure part of the observed area, i.e. create blind zones in video surveillance. This phenomenon can be eliminated by carefully determining the location of the cameras and their appropriate suspension height. For the analyzed surveillance zones (areas E, F, G, H) 9 cameras were provided, for which optimal parameters were set. The results of the initial scaling of 9 cameras are summarized in Table 2, while their distribution is shown in Figure 4. Most cameras differ in their parameters due to the different tasks they are supposed to perform, therefore the video surveillance system can be divided into the following parts:

- monitoring the outer area of the warehouse while the goods are still in the trucks,
- monitoring the internal area of the warehouse when the process of unloading goods on the warehouse area of area F begins (fig. 3),
- office entry and exit monitoring.

Table 2.
Determined camera parameters according to the established monitoring functions in the warehouse facility

Camera parameters	**Camera number**					
	1, 2, 3	**4**	**5**	**6, 7**	**8**	**9**
Sensor	3/4	1/3	1/2	1	3/4	1/2
Focal length	4,4 mm	5,5 mm	3,2 mm	6,4 mm	12 mm	3,2 mm
The distance of the camera from the object	30 m	20 m	50 m	30 m	15 m	10 m
The height of the monitored area	60 m	17,5 m	100 m	60 m	11 m	20 m
The width of the monitored area	45 m	13,1 m	75 m	45 m	8,3 m	15 m
Horizontal angle	90°	36,2°	90°	90°	40,3°	90°
Vertical angle	73,7°	47,1°	73,7°	73,7°	30,8°	73,7°



Legend:

- Red – Camera number 1
- Yellow – Camera number 2
- Orange – Camera number 3
- Green – Camera number 4
- Blue – Camera number 5
- Purple – Camera number 6
- Pink – Camera number 7
- Light green – Camera number 8
- Brown – Camera number 9

Figure 4. Arrangement of cameras in the designed vision system of the warehouse facility.

Source: Own study based on the technical documentation of the warehouse facility of company X.

Individual cameras arranged as shown in Figure 4 perform the following functions:

- cameras no. 1, 2 and 3 monitor the unloading docks,
- camera no. 4 monitors the goods issue area,
- cameras no. 5, 6 and 7 monitor the areas of temporary storage of deliveries,
- camera no. 8 monitors the exit from the office to the warehouse area,
- camera no. 9 monitors the entrance to the office from the outside.

The viewing angles of the cameras shown in Figure 4 are horizontal angles according to the parameters shown in Table 2.

5.3. Organization of the vision system

The designed vision system has 9 cameras arranged as shown in Figure 4. In order to fulfill the three functions of video monitoring (preventive, operational and evidence), the cameras were connected via cables to a room in which a video surveillance center equipped with a monitor, multiplexer and a computer with suitable drive for archiving the recorded video.

The video surveillance system will be operated by one person responsible for monitoring in the security room, which is provided in the office area near the entrance to the warehouse. This enables a quick response to threats detected by the camera preview on the monitor (operator function). Due to such location of the security room, the employee servicing the monitoring has a real impact on security in the warehouse facility.

In order to meet the design assumptions, the video monitoring system was equipped with the following equipment:

- cameras of the DVS-HA5028NT-IRs model were proposed for positions 1, 2 and 3 - these are cameras with a durable IP66 housing, which makes them fully resistant to weather conditions (these cameras are located outside the warehouse facility); their wide-angle lens allows you to eliminate dead zones while maintaining image details,
- the LC-353 AHD model was proposed for the position of the camera number 4 - it is an internal camera and is intended for monitoring the goods issue area,
- the BCS-SDHC5230-II model was proposed for the position of the camera number 5 - it is the camera with the greatest range of view, because it monitors the entire area of the temporary unloading of the delivery,
- for camera positions no. 6 and 7, the proposed equipment is LC-676 AHD PREMIUM - these are cameras supporting camera no. 5 in monitoring the temporary place of unloading goods,
- for camera position no. 8, the proposed equipment is the LC-353 AHD model - the camera should monitor the entrance to the office from the warehouse side and the entrance for forklifts,
- for camera position no. 9, the proposed equipment is the IPC-HFW1431S-0280B-S4 camera, whose task is to monitor the entrance to the office from the outside, equipped with an IP66 housing, it guarantees full resistance to water jets (in case of fire) and dust,
- multiplexer model LV-NVR9918S connecting all cameras, supports up to 9 high-quality cameras, equipped with live image, recording, playback and archiving functions,
- a computer with a graphics card, a disk with a very large capacity - HDD Sata III disk, it is possible to store movies with a capacity of up to 8TB,
- monitor - Samsung 24 Odyssey G3 (LF24G35TFWUXEN) was proposed, with a screen ratio of 16:9 and a diagonal value of 24 inches (IVEL.PL store, Monitoring, Alarm systems ... downloaded on June 2, 2023).

6. Summary and Conclusions

The purpose of the conducted analyzes was to create a project of a video surveillance system for the warehouse facility under test. The vision system project was developed in October 2022. The implementation of the vision system in the warehouse space is scheduled for 2023. No feedback has yet been received on its operation at the facility.

The introduction of a technical element in the form of a vision system into the warehouse facilitates the detection of threats and can increase the level of security in the facility. The system consisting of 9 cameras provides surveillance of the area that is most exposed to undesirable events involving people and equipment. Video monitoring enables such control of threats that it facilitates the process of security management in the facility both at the stage of prevention and intervention in real time against threats, as well as at the stage of collecting documentation on threats. The vision system design concept for a selected warehouse facility presented in the article can provide information about such threats as:

- incorrect approach of vehicles to the unloading docks (surveillance of cameras no. 1, 2, 3), unauthorized intrusion into the warehouse or office (surveillance of cameras no. 1, 2, 3, 9),
- collision of means of internal transport (forklifts) with people and devices (surveillance of cameras no. 5, 6, 7),
- other accidents of employees, e.g. falling from a height or tripping (surveillance of cameras no. 1, 2, 3, 8),
- theft or destruction of goods ready for release (surveillance of camera no. 4),
- delivery of damaged goods to the warehouse or their damage during unloading (supervision of cameras no. 5, 6, 7),
- thefts in the area of temporary storage of goods - between the office and the warehouse (surveillance of camera no. 8).

The concept of a video monitoring system proposed in the article can help the company's management decide to implement an additional surveillance system in order to neutralize or reduce the number of events dangerous for employees and material losses resulting from the destruction of goods or equipment.

In recent years, certain trends in the offered equipment working in vision systems have emerged. Publication (Szymanek, 2022) describes six such trends that appeared on the market in 2022. There are also systems supporting the operation of cameras that enable automatic identification of events. Publication (Szwoch et al., 2009) describes an algorithm that can be used in a video surveillance system that automatically detects events in camera images. There is also the possibility of detecting events supported by 3D technology in video surveillance. The 3D technology makes it easier to observe details in the image from the cameras, enabling full identification of the event as described in publication (Balcerek et al., 2017).

The implementation of video surveillance is a costly investment. It seems, however, that it can significantly facilitate security management in specific technical facilities such as warehouses.

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