IETI Transactions on Ergonomics and Safety

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2025, Volume 9, Issue 2, 1-8, DOI: 10.6722/TES.202512_9(2).0001

ASSESSMENT OF SAFETY OF VENDING MACHINES FROM ERGONOMIC ASPECTS AND A NEW QUESTIONNAIRE FOR EVALUATION OF DELIVERY PORT OF AUTOMATED RETAIL MACHINES

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Abstract The paper assesses the safety deficiencies in the design of vending machines through the ergonomic lens, specifically, the product delivery port. The case study proves that the vending machine that was considered has severe design defects that can result in injuries to users, such as the possibility of getting their hands trapped, pinched, and abraded. The issues were found to be with the logic of the time-out feature in connection with the time the user had to retrieve the product, the lack of a presence sensor or slow activation of the sensor, and the imbalance between the force of the mechanism and the force of the user to push the product back into the vending machine. According to the international standard IEC 60335-2-75, a new questionnaire was created to evaluate the ergonomics and safety of the delivery ports of the vending machine. The first eleven questions are a result of what the standard requires, and five more questions were formulated according to the case study provided in this paper to address some of the major deficiencies that are not covered by the standard. The findings suggest that ergonomic safety and psychological factors should be incorporated in the design of vending machines to guarantee the safety and ease of usage with the machine. Moreover, the analysis revealed that the size of the delivery port should have been such that it can easily accommodate the entire hand and create a strong grip on the product, to minimize the chances of slipping and being trapped by the hand.

Keywords: Ergonomics; safety; vending machines; automated retail machines; questionnaire.

1. INTRODUCTION

The modern environment of retailing and service delivery has been radically changed by the spread of Self-Service Technologies (SST). These systems that have become common in the open areas are redefining the lines between the consumer, the vendor and the technology. According to scholars, this change demands consumers to become a partial employee because, according to the basic organizational theories, clients contribute effort, time, and other resources to the production process [1]. Moreover, the effectiveness of this redefinition is determined by the so-called technology readiness, which is the tendency of people to accept and utilize new technologies to achieve objectives [2].

The vending machine is the core of this technological change, a machine that, despite its ancient origins, continues to be a critical field of interaction between sophisticated mechatronic systems and a heterogeneous human population. Nevertheless, it is difficult to get the best interaction, since research on human factors suggests that to design a machine that is usable by a wide group of people, one must have a comprehensive knowledge of anthropometric variability [3], which is not always considered in standardized machine production.

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The object of analysis is an automated vending machine to distribute canned beverages. These machines are a typical example of self-service systems that are aimed at a broad audience of users, where the human-machine interaction occurs without the intervention of personnel. This is in line with the definition by Meuter et al. [4], who describe self-service technologies as interfaces that allow customers to generate services without direct involvement of service employees. Thus, everything related to safety should be considered structurally, assuming that the user is not experienced, does not have special attention, or technical knowledge of how the device works. According to Caporusso et al., ergonomic deficiencies in automated vending machines may have a considerable effect on usability and accessibility [5], especially in the case of users with sensory impairments. Henderson et al. [6] point out that usability issues in self-service technologies have been reported in a heterogeneous population of users of various genders and age groups, which proves that design should consider the heterogeneity of the population.

1.2. Problem

The vending machine under consideration is shown in Figure 1. An important flaw has been identified in the machine's operating logic during the product delivery phase, relating to the possibility of direct user contact with the mechanical components of the device. After payment is completed, the machine delivers the can to the retrieval position and opens the front protective flap.

However, the system is programmed so that if the sensors do not detect product removal within a certain time interval (time-out), a motorized mechanism is activated to pull the product back into the interior of the machine. The problem escalates because this time interval is very short, and the retraction process takes place through the same ergonomically inadequate opening, without the necessary detection of the user's hand presence in the delivery zone by the machine.

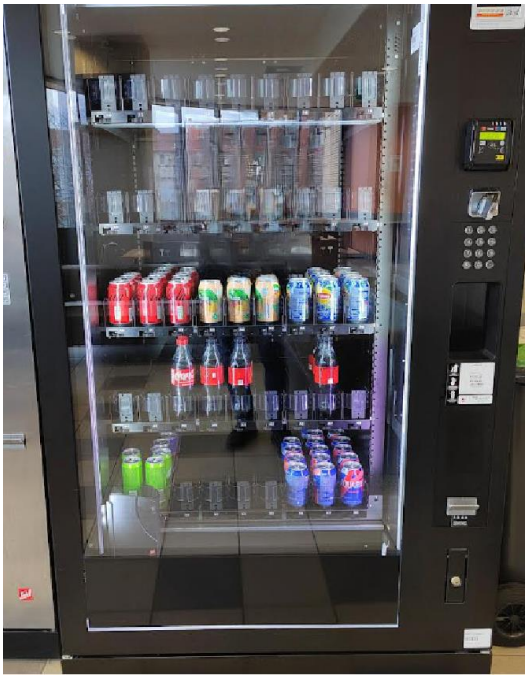

Figure 1. The vending machine that is the subject of this case study.

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2. ANALYSIS OF THE HAZARD ZONE AND THE RETRACTION MECHANISM OF THE VENDING MACHINE

The space of the delivery port has been referred to as the hazardous zone. The analysis shows that there is a mismatch between the size of the port, the building of the interior, and the user requirements. The port has small tolerances in comparison to the hand, which does not provide enough room to hold the can firmly to remove it. The port is too small to support the force needed to draw out the can, particularly given that the user can only hold the upper section of the can, which is smooth and could be wet (slippery) because of the cooling of the beverage cans. This makes the user, rather than using a natural full-hand grip, to use the fingertips alone. This position usually involves an undesirable angle of the wrist and forearm because of the positioning of the can in the port and it is hard to establish a stable grip.

The corresponding ISO 13854 standard [7] explicitly requires that the minimum gap to prevent crushing the hand, wrist, or fist must be a minimum of 100 mm. However, this applies to the hand in a lateral position but not to a multi-finger tip grip position, because here the can must be grasped by a five-digit tip grasp, due to the need to apply the initial force for extracting the can in the case of this vending machine, which can only be achieved if the hand is in the aforementioned position.

The actuator that pulls the can back generates a force in the opposite direction of hand extraction. Due to the tough access and poor grip on the product, a relatively larger amount of time is needed to remove the product safely, which directly causes the possibility of the return mechanism being activated before the user can successfully finish the action.

Once the mechanism for retracting the can has been activated, protective doors are also activated, which may press against the user's hand or part of the forearm if it has not been withdrawn from the delivery port in time. This type of hand entrapment in the vending machine, aside from the physical injury, also may lead to a panic attack. Figure 2 shows an attempt to pull out a can from the delivery port.

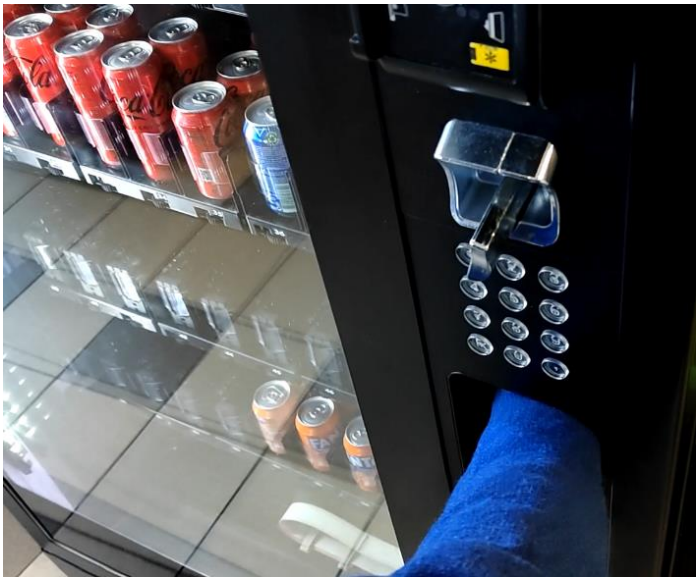

Figure 2. Delivery port and attempt to extract the can.

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3. IDENTIFICATION OF RISKS AND MODES OF INJURIES

Three main modes of injury can be identified that may occur as a result of human interaction with the vending machine in question. These risks occur at the moment when technical and human factors collide, and the user has no chance to foresee the danger.

3.1. Entrapment Hazard

When the mechanism starts to retract the can, the user instinctively tightens the hand (grasp reflex) in order to hold on to the purchased product. Research by Johansson and Westling [8] and Eliasson et al. [9] shows that somatosensory input from the digits triggers an increase in grip force reflexively when an object is suddenly pulled, and this creates a reaction that is faster than the ability of the user to let go voluntarily. Such a reaction is completely expected and in line with basic patterns of human behavior.

A possible scenario is that the can moves backwards, taking the user's hand with it. Instead of pulling the hand out, the user grips the can tighter and often pushes the hand even deeper into the opening (the hand is pulled deeper into the mechanism). Due to the anatomy of the hand (the width of the palm and thumb), it is difficult or impossible to withdraw the hand on time in the opposite direction of the retraction force through the narrow opening, under the additional pressure of the flap of the port, and the hand is trapped.

3.2. Shearing and Crushing Hazard

An additional safety concern is the indefinite behaviour of the front protective flap during this process. A possible scenario is if the protective flap automatically drops down in synchrony with the can retraction process, it may have the effect of a guillotine. If the flap comes down while the hand is engaged in pulling out the can, it may cause crushing of the soft tissues of the hand, wrist or forearm. If the force of closure is marked, contusions and even fractures of the bones of the hands may occur.

3.3. Risk of Finger Injury (Friction/Abrasion Burn and Laceration)

A possible case is that the user is trying to quickly remove the hand while the machine is pulling the can inward. Friction between the can and the metallic/plastic edges of the port, as well as the skin may result in abrasions. In addition, there is small but not imaginary risk that fingers may be caught in the moving parts of the return mechanism, resulting in serious lacerations.

4. HUMAN FACTOR ANALYSIS

An important element of this case study is predictable human behavior, which was not considered by the engineers. The interaction design is created on the assumption of the ideal user and ideal conditions, and the real human behavior under real conditions is ignored. This failure is an example of the principle formulated by Norman in [10], where he makes the argument that human error is usually a result of poor design and should rather be called system error.

In this case, there is a psychological principle at work, by which the unpleasant emotional resultant of the loss of the product overrides the rational analysis of the risk. This behavior accords with the basic discoveries of Kahneman and Tversky, who established in their "prospect theory" [11] that "losses

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loom larger than gains", which drives users to irrationally protect their possessions even in risky situations. Therefore, the user will not, in most cases, let go of the can when it moves backwards; rather, the user struggles with the machine to keep it, and is protecting rather than consciously safe.

The time it takes for a typical user to perceive that the can is being pulled back and to choose to let go of it because of the danger he is exposed to is longer than the time predetermined by the machine for retracting the product into the mechanism (with the possible entrapment of the user's hand or sleeve) and closing the protective flap of the vending port. Reaction times are substantially higher for stimuli that are unexpected [12], which means that "unanticipated events" cause delayed processing, which exceeds the rapid cycle time of the machine. In the resulting hazardous situation, the user will be unhurt even if the amount of force used to pull the can exceeds the force exerted by the mechanism used to pull the can back into the vending machine.

From an ergonomic perspective, a mismatch may be noted between what the user is able to do and what the system expects to happen. The vending machine does not consider reduced motor skills in elderly individuals, or such conditions as cold or wet hands, which further reduce the speed of reaction. Impaired proprioception caused by forearm muscle tension may be added to the decrease in fine motor control.

5. VIOLATION OF SAFETY PRINCIPLES

This design violates the fundamental principles of machine safety (such as ISO 12100) and does not provide adequate protection in situations of conflict between human action and the automatic activation of the machine. Specifically, the ISO 12100 standard [13] dictates that designers must account for "reasonably foreseeable misuse," which it defines as machine use resulting from "readily predictable human behaviour", such as the instinctive reaction to grab the product. Several design deficiencies of the machine can be observed, which are contrary to the ergonomic aspects of product safety in use.

Lack of presence sensor or its inadequate operation - the vending machine starts the retraction of the can without visible detection of the user's hand inside the opening of the vending machine. There is no mechanism that would immediately stop the mechanical parts from moving in case of danger. Furthermore, in case of the user's first time failure in withdrawing the can, they may move their hand away from the opening to try again (for example, to wipe a wet or sweaty hand). However, as a whole, even if there is a presence sensor in this magnitude of machine, this situation may be registered by the system as if the user's action has ended and may begin with the retraction of the product.

Faulty "time-out" logic - the system primarily reacts according to its own temporal logic, without adaptation to the flow of human action. The time limit predetermined by the system is too short considering the ergonomic difficulty of the task (especially when elderly or younger individuals or persons with special needs are taken into account), whereby penalizing the user by withdrawing the product provokes a panic reaction.

Priority of property protection over human safety - the retraction logic puts the protection of a single beverage can or the vending machine from potential misuse over the physical integrity of the user. However, ISO 12100 says that risk reduction measures must focus on the elimination of hazards to people [13], not necessarily the protection of machinery or products.

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6. DEVELOPMENT OF A NEW QUESTIONNAIRE FOR ERGONOMIC DESIGN AND SAFETY ASSESSMENT OF A DELIVERY PORT OF AUTOMATED RETAIL MACHINES

This case study has shown several serious shortcomings in the design of the product delivery port of the examined vending machine. It can be assumed that this is not an isolated case of design error in this type of machine. For this reason, the need arises to develop a questionnaire that would serve designers as a reminder when designing the delivery port of automated retail machines from the standpoint of ergonomics and safety.

The international standard concerning safety and ergonomics of vending machines is IEC 60335-2-75 [14]. This standard considers the requirements that the vending machines must meet in order to be safe to use. Therefore, the newly developed questionnaire should cover all of the requirements associated with safety and ergonomics as indicated in this standard. However, by analyzing the mentioned requirements from the standard, it is possible to look at many aspects related to ergonomic safety, which are not mentioned in this standard.

Taking this into account, a new questionnaire has been formed in order to assess the fulfillment of ergonomic safety aspects of the delivery port in vending machines. The first 11 questions in the questionnaire are directly based on the requirements given in IEC 60335-2-75 [14]. The remaining questions, from 12 to 16 relate to the case study presented in this paper.

6.1. Questionnaire for Ergonomic Design and Safety Assessment of a Delivery Port of Vending Machines (Automated Retail Machines)

1. Is the product delivery port designed so that the user cannot come into contact with hazardous moving parts of the mechanism?

2. Is the risk of finger entrapment, cutting, pulling-in, or trapping prevented during normal and abnormal operation?

3. If doors, flaps, or moving panels are used – is their movement limited so that it cannot cause injury to the user?

4. For machines that dispense liquid or powdered products – is it ensured that the user cannot come into contact with hot surfaces or pressurized parts during dispensing?

5. Does the design of the port provide for the safe dispensing of the product, without the possibility of contact with live parts or heated components?

6. In case of abnormal operation (e.g., product jamming, mechanism blockage) – is it ensured that the delivery port does not pose a danger to the user?

7. Does the delivery port maintain its functionality and safety after repeated cycles of usage and mechanically induced stresses are imposed?

8. Are the frequently used parts of the port (doors, flaps) designed to withstand long-term use without breaking or damage?

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9. If the port is also used for refilling or maintenance – is it designed so that it cannot accidentally close and cause injury?

10. For food and beverage machines – are the surfaces of the port that come into contact with the product made of hygienically safe materials, suitable for cleaning and maintenance?

11. Is the product dispensed at a height and in a position that allows easy and natural retrieval, without requiring unnatural movements or excessive bending?

12. Does the system reliably detect the presence of the user's hand in the port and prevent activation of the return mechanism while the hand is in the retrieval zone?

13. Does the time interval (time-out) for product retrieval allow sufficient time for users of different abilities to safely withdraw the product, without causing haste or panic?

14. Is the force of the product return mechanism limited so that it cannot exceed the typical gripping force of the user in an unfavorable position (e.g., grasping with fingertips)?

15. Does the system avoid causing panic in the user (e.g., sudden activation of the mechanism without warning or automatic retraction of the product), ensuring that user protection has priority over property protection?

16. Is the delivery port of adequate dimensions so that the entire hand can enter the opening in a way that ensures a firm grip on the product?

7. CONCLUSION

This study has revealed that there are serious shortcomings in the design of the vending machine studied, which under certain conditions may put the machine user at risk. Particularly critical problems are related to the absence of presence sensors or inadequate activation, the inappropriate time-out logic associated with retrieval of the product, the significant force of the product return mechanism and unexpected activation that may cause user panic. These aspects are not completely addressed by the existing IEC 60335-2-75 [14] standard, which has so indicated the need for its supplementation.

It is especially important that the dimensions of the delivery port allow the natural entry of the entire hand and the formation of a firm grip on the product, thus eliminating the possibility of slipping, unnatural positions of the wrist, and possible entrapment of the hand. The new questionnaire, which is a combination of the requirements of the standard and additional questions originated from this case study, represents a practical tool for designers and manufacturers as well as for ergonomists and safety experts when evaluating the design solutions of this type of machine. Its application can contribute to risk reduction, improvement of ergonomic quality, and making sure that user protection is prioritized over property protection. In this way, vending machines, as a part of the modern self-service technologies, are in step with the principles of human-centered design and international safety standards.

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Acknowledgment

I would like to thank the members of the Board of the Federation of European Ergonomics Societies, Pascal Etienne, Bernard Michez, and Gyula Szabo, who assisted and supported me during the interaction with the vending machine that is the object of consideration in this paper.

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