User-packaging interaction (UPI): A comprehensive research platform and techniques for improvement, evaluation, and design

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this dissertation to my beloved parents, Abdelhafiz and Fathiah Mumani who encouraged me to pursue my PhD. To my brothers and sisters who have faith in my ambition to achieve my goals, I dedicate this dissertation. It is my pleasure also to dedicate this work to Yarmouk University in Jordan. I also dedicate this work to the souls of my grandmothers and grandfathers who passed away before I finish my PhD.

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ABSTRACT

Users are expected to interact with their packages through product life cycles with either good or bad experiences, depending on packaging design, which can be characterized by physical and verbal features, such as size, shape, symbols, picture, etc. User packaging interaction (UPI) field has evolved with the aim to provide user-friendly packages, which support performing tasks such as, opening, handling, disposing, and checking-out. A great deal of work addressing issues, related to packaging, and suggesting potential improvements has been directed toward UPI. However, this work is not easily accessible to researchers as it lacks a cohesive structure of UPI stages. Developing an efficient packaging design, which augments UPI, requires continuous evaluation and improvement considering UPI stages. In this dissertation, we consider the UPI field as a system of users who interact with packages and other components at different stages, and integrate concepts of human factors and systems engineering to improve this interaction.

In the first study, an effort is directed to organize the field of UPI, in order to facilitate a proper and inclusive understanding of this field. The current research structure is organized based on stages of interaction, with insights into the related packaging features. This organization results in the enumeration of the following stages: at point of purchase, checking out, handling, opening, and disposal. The review process has revealed different issues in the current research structure of UPI including the comprehensibility of the conducted research and the distribution of the reviewed articles.

In the second study, a stage of interaction was targeted for improvement while considering the involved packaging features. The implications of the Universal Product Code

(UPC) placement and the scanning technology in use have been studied with a focus on scanning process at the checkout stage. This study has approved the effect of UPC placement and scanning technology on self-checkers. The results showed that total scanning time was significantly reduced when using bi-optic scanner $F(1, 28) = 20.9$, $p < 0.01$, $\eta_p^2 = 0.43$. The recommended UPC placement led to a significant improvement on UPCs anticipation for both scanning technologies $F(1, 28) = 16.8$, $p < 0.01$, $\eta_p^2 = 0.38$. Additionally, exposure to non-neutral trunk posture(s) were shown to be significantly decreased in the bi-optic condition $F(1, 24) = 10.4$, $p < 0.01$, $\eta_p^2 = 0.30$. Understanding the tasks performed at a UPI stage with the involved packaging features can lead to a substantial operational and ergonomic improvements.

In the third study, an affordance-based multi-criteria decision making (MCDM) model is also proposed to help designers simultaneously consider multi-UPI stages and packaging perspectives. The model is built based on the fact that affordances provided by packages can facilitate the interaction between users and packages. Affordance properties, elicited from user's requirements, were utilized to evaluate packaging affordances at stages of UPI. The outcomes of the model are validated by a usability testing study with results supporting the ability of the model to distinguish between packages with different overall affordance levels.

Finally, a design for affordances framework is introduced to map users' requirements to packaging features, in such these requirements can be associated with affordance properties that facilitate packaging related tasks. The structure of the framework allows an affordance-driven design through linking users' requirements for affordances and packaging features. An affordance structure matrix (ASM) was constructed to document the relationships between affordance properties and packaging features. The framework will help create alternative

packaging designs while considering the link between affordance properties and packaging features. It can also locate the problems that lead to low affordance levels of packages and allow modifications on the features of impacts.

CHAPTER 1. INTRODUCTION AND BACKGROUND

1.1. Background

Packaging is a growing global industry [1]. A package is a container which has a common interface with the product contained [2]. In general, it can be defined as a system of product, package, and distribution, performing the basic functions of protection and communication in different physical and atmospheric environments [3]. Packaging is meant to perform the tasks of encompassing, protecting, storing, distributing, transferring, marketing and communicating with people. These functions can be categorized into functional and advertisement roles [4]. In addition to the basic functions, packaging has many things to do with logistics related aspects [5]. A package should ensure the delivery of products under a variety of physical and environmental conditions.

Packages can be classified into primary, secondary, and tertiary depending on their functions. Primary packaging is in a direct contact with contained products, while secondary packaging can be used to contain primary packages, and tertiary packaging can be used to wrap a number of products with primary or secondary packaging [6].

Over the life cycle of products users are considered to be main players who interact with primary packaged products at different times depending on the nature of a product. In general, users select products from supermarket shelves, check them out, handle them, open them, and store or dispose them. Based on problems or positive experiences during such activities, users may decide to purchase, repurchase, pay more, pay less, or switch to other products, all factors with significant impact on businesses.

Because user perceptions can be affected during such interactions [7], either negative or positive implications related to products, manufacturers, or other stakeholders are to be expected. Manufacturers tend to be unaware of the problems that users encounter with respect to packaging. Even if they were aware of the problems, they often don't know how to solve them [8]. Accordingly, the awareness of professionals in perceiving the user- packaging interaction (UPI) should be increased. This is to support a user-centered package design process [9]. Large investments have been made with respect to developing packaging design and studying the relationship between users and their packages [10]. Even with these efforts users are still commonly experiencing usability problems at different stages.

1.2. Problem Statement

UPI has attracted researchers from different fields, including marketing, graphical and mechanical design, and environmentally-related efforts. This growing interest in UPI results partially as a response to developing life styles, growing market competition, and problems experienced by users while interacting with packages. These efforts are oriented toward specific aspects of UPI. For example, marketing studies focus on users' perception when screening items on supermarket shelves, mechanical design-related studies focusing on design parameters and their effect on accessibility, while environmental studies consider users' behavior when dealing with disposal of empty packages. This partitioning tends to make a comprehensive understanding and improvement of UPI somewhat inaccessible by researchers unless the field is organized and structured to consider broader perspectives of packaging, so there is a general need to establish a platform for UPI field to support researchers in simultaneous consideration of different UPI stages and aspects of packaging. This necessitates answering the following research questions: What is the state of the art of UPI? How to make

this field accessible to researchers with different interest? What are the open research problems in UPI? Answering these questions will establish the specific issues that require scientific evaluation as they related to UPI.

Recently, while a great deal of effort has been directed toward improving UPI and designing more friendly and efficient packages, users still encounter problems with their packages at different occurrences of UPI, even when simple interventions have some potential to make a difference. Without considering the implications of packaging features and other involved components on UPI stages, efficient improvements will not be achievable. Accordingly, there is a general need to answer particular research questions when we consider a UPI stage. In this dissertation, self-checkout has been considered to demonstrate the potential implications of such features and components on users at particular interaction stage. This stage is mainly composed of scanning a universal product code (UPC), located on a package, by a scanning device. To improve this stage of interaction, the following research questions need to be answered. Can standardizing the UPC location effectively augment UPI at self-checkout (SCO) stage? Which scanning technology is more efficient and ergonomic at SCO? How the weight and the size of a package can affect the scanning process? Answering these questions will help using proper scanning technology and UPC placement. It will also establish the importance of understanding the effect of packaging features on UPI stages.

Users perform tasks such as opening, unpacking, and storing, etc., while interacting with their packages. This interaction is highly dependent on information provided by packages that basically affords the actions required to perform specific tasks. Failing to provide the information required to facilitate UPI is considered a major contributor to packaging usability problems. Continuous evaluation and improvement of packaging is thus necessary to ensure

the existence of the facilitator affordances. An affordance refers to "the perceived and actual properties that determine just how the thing could possibly be used" [11]. Affordances provided by packages determine packaging usability since they facilitate the interaction between users and packages. It is thus important to evaluate packaging designs against their ability to provide particular affordances. In general, there has been little attention to develop evaluation methods that can be used to improve packages while also considering affordances associated with UPI stages. To develop such methodology, the following research questions are to be answered: How can a comprehensive evaluation of packaging be linked to affordances? How can users' requirements be linked to packaging affordances? Answering these questions will allow an affordance-based packaging evaluation, which considers users' requirements for affordances at stages of UPI.

A package can be characterized by features such as transparency, shape, size, and material. Such features are responsible for providing the affordances required to facilitate users' tasks. Manipulating packaging features can affect particular affordances with implications on users. A packaging design framework is thus necessary to ensure the existence of the features required to support the affordances required to guide users to perfrom particular actions. These affordances could be open-ability, store-ability, unpack-ability. To this end, the following research questions should be addressed: How designers can design packages through the concept of affordances? How to connect users' requirements to packaging features through affordances? How can we quantitatively assess conceptual designs while considering the affordances requirements? Answering these questions will have impacts on the design process of packaging. It will support a proper understanding of the relationships between different

packaging features and affordances and give insights into the potential improvement in packaging designs.

This dissertation will address the previous research questions with a scope covering user interaction with primary packages only, excluding secondary and tertiary packages. Interactions between a package and packagers, handlers, or others who sort/arrange items in supermarkets were also not considered.

1.3. Dissertation Structure

This dissertation is written to conform to journal paper format. Six chapters are presented: Chapter 1 presents a general introduction and highlights the importance of UPI and its impact on users and business and also introduces the problem statement of this work. Chapters 2-5 contain two published articles and two submitted manuscripts. Chapter 6 contains general conclusions from the work presented and shows the contributions of the PhD dissertation.

Chapter 2 is an article published in the Packaging Technology and Science Journal-Special Issue on Human-Packaging Interaction, entitled: State of the Art of User-Packaging Interaction (UPI). The article was structured through an extensive literature review focused on articles related to packaging science. More than one hundred articles were reviewed to examine the research structure in this field; they were then categorized based on stages of interaction. As more articles were reviewed, these stages of interaction were modified to ensure that they reflected ideas from all the reviewed articles. This review process resulted in the enumeration of the following stages: at point of purchase, checking out, handling, opening, and storage and disposal. The articles are discussed and potential related future work for improving the research

structure is suggested. This manuscript establishes a comprehensive understanding of the field of UPI and answers the first group of research questions.

Chapter 3 presents an article published in the Packaging Technology and Science Journal and entitled: The Effect of Scanning Technology and UPC Placement on Supermarket Self-checkout. A study at the checking-out stage was conducted with particular focus on supermarket SCO. The scanning technology and UPC placement were considered as factors affecting UPI with respect to self-checker performance. A controlled experiment was designed and conducted to investigate the effect of the scanning technology and UPC placement on self-checker performance. To that end, each participant was tested while using either a bi-optic or a handheld scanner to check out items using either the current or the recommended/new universal placement. Participants' scanning time, trunk posture, the number of wrong flips, muscle activities, and preferences were obtained and analyzed, with the results revealing that scanning time was significantly reduced when using the bi-optic scanner. The recommended UPC placement led to a significant improvement on UPCs anticipation for both scanning technologies. Exposure to non-neutral trunk posture(s) also significantly decreased when using the bi-optic condition. This study found that a standarized UPC placement and use of a bi-optic scanner can positively improve the efficiency and experience of the SCO. This study answers the second group of research questions and demonstrates the importance of understanding UPI stages and the involved components to UPI improvements.

Chapter 4 introduces a manuscript submitted to the Packaging Technology and Science Journal-Special Issue on Human-Packaging Interaction, entitled: An Affordance-Based MCDM Approach for Packaging Evaluation. A multi-criteria decision making (MCDM) model is introduced to evaluate packaging affordances. Users' requirements associated with

affordance properties were elicited from previous packaging usability studies. These requirements were combined and restated into thirty-eight requirements associated with affordance properties such as intuitiveness, responsiveness, and clear information. These properties cover the affordances required to facilitate the tasks of purchasing, storing, opening, reclosing/reopening, handling, unpacking, and disposal of packages. They were utilized as an initial set of evaluation for packaging affordances. Experts were recruited to verify and weigh the importance of these properties for particular products and rate alternative packages. The Model has been applied to four groups of products with two alternative packages for each. The outcomes of the model were validated by a usability study conducted on 37 subjects, with results supporting the ability of the model to distinguish between packages with different overall affordance levels. This paper answers the third group of the research questions.

Chapter 5 introduces a manuscript submitted to the Journal of Applied Packaging Research, entitled: A Design for Affordances Framework for Product Packaging: Food Packaging Case Study. A framework linking packaging design features to users' requirements for affordances was introduced. An affordance structure matrix (ASM) was built to construct and assess the relationships between affordance properties and packaging features. The framework was demonstrated by a food packaging case study, in which packages with different packaging features were shown to have different affordance scores. This framework is directed toward answering the fourth group of research questions. Chapter 6 will present a general conclusion and show the contribution of the presented work.

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CHAPTER 2. STATE OF THE ART OF USER-PACKAGING INTERACTION (UPI)

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Abstract

User packaging interaction (UPI) has evolved in packaging research because of its importance to users, manufacturers and designers. A great deal of work addressing problems and suggesting potential improvements has been directed toward UPI. However, this work is not easily accessible to researchers as it lacks a cohesive structure. This paper serves as a platform for UPI researchers by presenting previous work in the field of UPI in an organized structure based on stages of interaction. Over one hundred articles were reviewed to identify the scope of research in this area and then categorized according to stages of interaction. During the review of more articles, these stages of interaction were modified to ensure that they reflected all the reviewed articles. The review process resulted in the enumeration of the following stages: at point of purchase, checking out, handling, opening, and disposal. The related articles in each category are presented and discussed, and potential future work is presented. The articles were further categorized according to the age and gender of users under test, and packaging and product types considered. The review process has revealed different issues in the current research structure of UPI including the comprehensibility of the conducted research and the distribution of the reviewed articles. Based on this review, a model is proposed

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[1] The publisher of this journal "Wiley "allows the authors to use the accepted version of the work in their institutional repository.

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for improving the UPI by quantitatively evaluating the package design and affordances provided at each interaction stage.

2.1. Introduction

In recent years the packaging industry has become a main pillar for different businesses in supporting their products in the market. Practically, packaging plays an important role in providing users with their products under a variety of conditions. It is presently unlikely to buy any product with no aspect of packaging, so it has become a common part of our life. As a response to changes in modern lifestyles such as continuous pressure on the food supply and market globalization, packaging functions have evolved while always performing the main functions of protection, communication, containment, and convenience.

Within this context, consumers are considered to be the ultimate users of packages who will buy, open, close, reuse, recycle, or dispose of packages. Based on the problems or advantages encountered during such activities, users may decide to purchase, repurchase, pay more, pay less, or switch to other products, all of which can have important impacts on businesses. It is thus important to understand perceptions, experiences, and problems users may encounter while interacting with their packages at different stages of use.

Problem-free interaction between users and packages should be the ultimate goal of designers and manufacturers. Manufacturers tend to be unaware of the problems that users encounter with respect to packaging. Even if they were aware of the problems, they often don't know how to solve them [1]. As a consequence, the awareness of professionals with respect to perceiving user-packaging interaction (UPI) should be enhanced in terms of supporting a user-centered package design process [2].

Greater efforts have recently been directed toward improving human-packaging interaction, efforts framed as marketing, ergonomic and human-factors related studies [3]. However, there is still a need for a platform to provide designers with the information required to understand the stages of UPI. Such a platform makes it possible to comprehend the UPI holistically while conveying other researchers' experiences in addressing different interaction problems.

To help manage UPI, an effort should be directed to identify the specific stages where users interact with their packages because understanding the elements involved at each stage of interaction can support designers and manufacturers in evaluating, modifying, or developing their packages to help companies and users achieve their ultimate goals of profit and convenience. In this paper, UPI will be framed through an extensive literature review focused on articles related to packaging science. The several stages of UPI have been identified through a consecutive screening process to make sure that each stage contains all articles addressing the elements related to that stage. The articles are discussed and potential related future work to improve the research structure is suggested.

This paper is organized as follows: Section 2.2 will present the methodology used, and Section 2.3 will present background information to familiarize the reader with the topic. The interaction stages are presented consecutively in Sections 2.4-2.8, while Section 2.9 will introduce other possible categorizations of the reviewed articles, and Section 2.10 will provide a general discussion. Conclusion and insights into future work are presented in Section 2.11.

2.2. Methodology

The scope of the review focused on covering the various stages at which users interact with the primary package, with secondary and tertiary packages not included. Primary

packaging is in a direct contact with contained products, while secondary packaging can be used to contain primary packages, and tertiary packaging can be used to wrap a number of products with primary or secondary packaging [4]. Interactions between the package and its packagers, handlers, or others who sort/arrange the items in supermarkets was also not considered, nor were articles published in languages other than English. Under these boundaries, the review process began by identifying journals specializing in packaging, marketing, food, ergonomics, medical, and design sciences, and searching them using the keywords packaging, human packaging interaction, user's perception, and the names of the potential interaction stages, such as purchase, checkout, handling, opening, and disposal. Most of the reviewed references were journal articles (about 85%), while books, conferences, magazines, and newspapers represent the remaining of the references. Most of the references included in this review were published during the time span of 1992-2016 with their distribution shown in Figure 2-1.
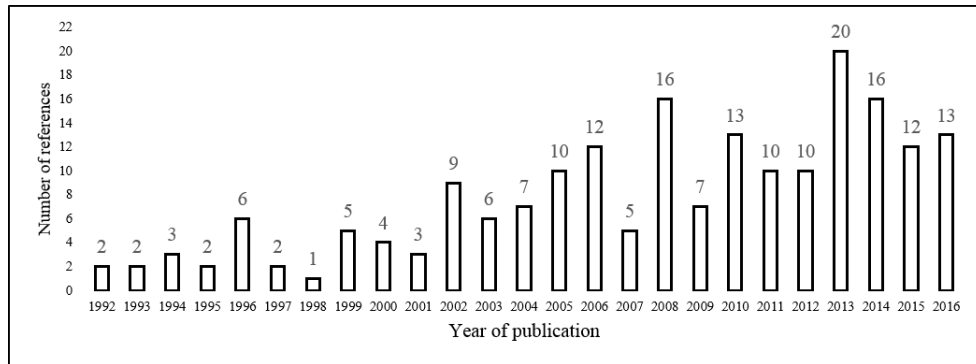
Figure 2-1. The distribution of the reviewed articles in the period 1992-2016.

More than one hundred articles were carefully reviewed and arbitrarily categorized based on their contents related to user packaging interaction stages. This initial categorization was helpful in identifying the basic elements of the research structure and clustering them

appropriately. After review of additional articles, these categories and elements were updated to ensure that they continued to reflect the reviewed articles. The authors decided to terminate the review process once they came to believe that those reviewed articles comprised a reasonably representative body of the research conducted that was related to the potential interaction stages. Eventually, the interaction stages and elements shown in Figure 2-2 were identified. To obtain more insights into the focus of the current state of UPI with respect to packaging and product types and subjects age and gender, the articles were further categorized.
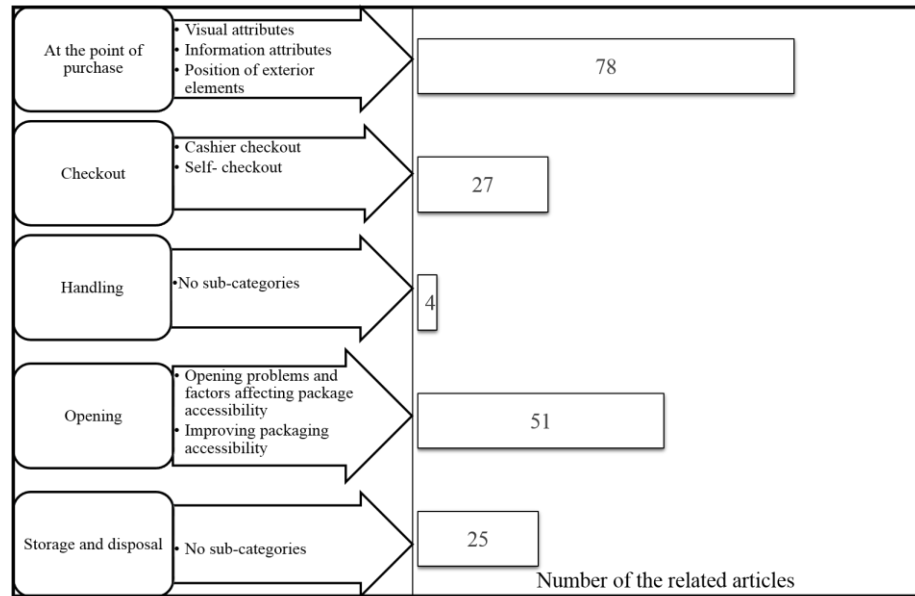
Figure 2-2. User-packaging interaction stages and the distribution of the articles reviewed.

2.2.1. Limitations

This review does not represent all the work conducted on UPI, but it is representative of the research body in this field. Because the scope of the study is focused on end-users, it also does not address the stages of interaction when end-users are not involved. In fact, the stages presented may not all be experienced while interacting with some types of packages. They were also identified solely based on the reviewed articles, while other stages of

interaction, including package closing, dispensing, reusing, and online shopping could also be considered, they are not presented because there has been no sufficient research conducted on them. The order of the stages is suggested by the authors and based on previous research. This order, however, may not be representative for all products.

2.3. Background

Packaging is not a new term; it was utilized about 15,000 years ago for pottery produced by late Paleolithic settlers [5]. In general, a package can be defined as a system of product, package, and distribution, performing the functions of protection, utility, and communication in physical, atmospheric, and human environments [6]. Specifically, the traditional food packaging can be described as a mechanical barrier protecting contained food from external effects. It should preserve the quality level of the food and afford convenient handling while ensuring that no significant interaction takes place between the package and the food [7]. While performing the traditional functions of protection, communication, containment, and convenience [8], a successful package is also required to appeal in a few seconds to users while they are shopping to help the product compete with other products in the market [9]. It should also be informative, easily open, and safe [10], and effectively communicates with people from different cultures [11].

Based on the this discussion, it can be concluded that a package should be designed to perform primary and secondary functions [12]. Primary or functional functions are those related to encompassing, protecting, transportations, storage, and distribution, while secondary or advertisement functions are linked to the communication aspects of the package exterior. These functions have been developed in response to changes in peoples' lifestyle and trends [13]. Even with considerable development in the packaging industry, the traditional purposes

and functions of packaging seem to have remained the same. For example, between the time span 1500 BC-500 AD, Jars were used by Greeks to transport wine and other products between countries, providing the same functions as those of contemporary packages [14].

Packaging has much to do with marketing and logistics [15, 16]; it can support a company's long-term goals in various ways, so a package should perform its traditional functions while also considering the company's goals [17]. Packaging has a respected role in adding value to the supply chain where interaction between the package, packaging manufacturer, and user occurs. It can also help achieve the supply chain's ultimate goal of feeding people by reducing food waste throughout the supply chain [18]. Packaging design thus should be considered when building product supply chain [19].

The necessity for reducing food waste throughout the food supply chain has led to increase the need for developing a packaging industry focused on improving food quality and safety, prolonging shelf life, and improving the ability to control and manage products in stock. To that end, a variety of packaging technologies have been developed to serve food supply chains. Active and intelligent packaging are terms describing modern technologies with the capability to improve food supply chain performance [20].

Practically, an active package may interact directly with its contained food to improve its quality through either simple or complex design [21], resulting in improving quality, safety, shelf life, and preservation of food characteristics [22, 23]. An example of active packaging is antimicrobial food packaging that reduces microbial contamination of the product during different stages [24].

Modified atmosphere packaging is another modern packaging technology with the ability to control temperature and humidity of the products, in turn helping preserve the

freshness level of food products [25]. In an improvement effort, a study was conducted to determine the optimal head of space gasses that would produce a longer shelf life for products stored in a modified atmosphere packaging [26].

To attain improvement through food packaging innovation, a food packaging system that could "sense, detect, or record changes in the product, the package, or its environment" could be developed [27]. As a part of this evolution, intelligent packaging would help maintain the quality level of the products at different points by communicating the current and historical states of the food and the surrounding environment [28]. Sensors, indicators, and other communication devices can be used in constructing intelligent packaging [29].

2.4. At the point of purchase

The first stage of UPI takes place in shopping districts where shoppers can scan on-shelf items to choose one that best fits their needs. At this stage, users can interact with the package, letting it perform through its appearance as a silent salesman [30] that could be capable of attracting users and affecting the purchase decisions [31] usually made at this stage of interaction [16, 32, 33].

Various attributes such as color, typography, graphics, and illustrations can contribute to framing users' perceptions and product positioning [34]. These attributes are capable of building a communication bridge through which different messages that could affect the users' perception can be sent [35]; for example, a natural package design usually conveys a sincere brand [36]. However, only mandatory messages should be conveyed, since providing irrelevant information can distract users and lead to unintended responses [37]. It is therefore necessary to determine the optimum package graphics design [38], keeping in mind that users' perceptions are mainly affected by packaging functionality, recyclability, quality, cleanness,

and informative attractiveness [39]. Users usually build their own associations, either positively or negatively, between package design and food product characteristics [39]. Accordingly, it is necessary to relate the physical attributes of a product to affective values, since size, shape, color, brand, packaging, and surface texture can significantly affect such affective values [40].

The influence of packaging attributes on users' perceptions depends on their characteristics, needs, and involvement in the product. Relatively uninvolved users are influenced more by visual elements [41], while those who care more about the product are more influenced by the information elements of the package when making purchase decisions [42]. Also, informative cues play a major role for those worried about health and weight control issues [43]. Nonetheless, other attributes can sometimes override users' preferences regardless of their level of involvement. For example, the color and the existence of a picture on the label were found to be the most affective attributes, regardless of level of involvement, when considering buying functional and regular chocolate milk dessert [44].

Packaging can be characterized by four main elements, including size/shape and graphics as visual aspects, and information provided and packaging technology as information aspects [42]. The following subsections address previous efforts that have been performed regarding visual and informational aspects of the packaging design. An overview of the research related to this stage of UPI is shown in Table 2-1.

2.4.1. Visual Attributes

The visual attributes of packaging have a considerable effect on users' purchase decision, and can effectively be a dominant factor when making a purchase decision. For example, appealing packaging with higher prices can be preferred more than products with

familiar brands but only standardized packages [45]. Accordingly, the packaging itself can be considered to represent an opportunity to enhance the market value of a product if its appeal is improved [46].

The exterior of a package can affect user's perception of factors such as healthiness of a product by conveying different messages about the products through utilizing different attributes [47, 48]. Consequently, to design an effective package that conveys the required messages, consideration of users should be central at the design stage and should play a major role in identifying package attributes. This helps ensure that users' preferences with respect to graphical design, shape, size, and packaging materials are effectively identified [49] so the designer can use these preferences to achieve the required users' responses. For example, dietary foods can be packaged with more appealing packages to attract children and affect their attitudes [50].

Since this review focuses on only the primary aspects of product packaging, the visual attributes of shape, size, color, labels, logos, signs, and brand are all the graphics that can be seen by users as they interact with the primary package. An overview of the research related to these aspects can be found in Table 2-1.

The shape of the package can influence how users make purchase decisions and perceive the other characteristics of products [51, 52]. Specifically, it has effects on the perceived volume and usages practices [53-55]. The attractiveness of package shape can also induce a considerable bias toward the perceived volume of the package [56-58]. In general, package shape has been investigated from a marketing perspective, in research studies focusing on the perceived volume and the user's consumption of fluid packages. More effort is required to relate the shape of a package to the purchased amount and the consumption practices of

different kinds of products. Furthermore, the effect of the packaging method or material on the perceived volume can be targeted for future research to study whether strongly structured packages can be perceived to have more/less volume than weak packages. The research structure could be further improved by relating the effect of the package shape, the perceived volume, and users' physical and nutritional characteristics. In particular, the affordance properties provided by packaging shape to facilitate handling actions, and their effects on the intention to purchase the product, could be highlighted by considering the users' physical characteristics.

The shape of exterior design elements was also studied to gain insight into users' perception [35, 59, 60]. However, these studies have focused on the effect of the shape of the package, the exterior elements on the perceived taste of products and they might also be correlated to other elements. Elements such as perceived nutritional values, perceived healthiness, and intention to purchase.

Package size also has an effect on user perception both at the point of purchase and at the point of usage [61-65]. Given that products are provided in different sizes and users' preferences could differ based on the perceived amount. Hence it is important to understand the user acceptance of larger size packages for variation in user physical abilities. In addition, more focus can be directed toward the determination of elements that could motivate users to buy large packages. Elements such as making them easier to handle, use, and manage. Indeed, design features supporting easier product management can play a role in attracting people to buy larger size products. It is worth mentioning here that the shape and size of the package and its exterior elements can be correlated in different ways. More investigation of interaction

between these elements and their influence over one another while conveying their messages could be addressed from both marketing and user perspectives.

Other elements may also have roles in affecting users' preferences, including product visibility, color, orientations of exterior elements, primary packaging, label size, and brand. Previous research has focused on these aspects as factors affecting user's perception.

Usually, users like to see the actual product contained in a package, since this will give them more useful information about the product [66]. Package color may also have an important role in affecting users' intention to buy within the context of brand packaging [67], and the association they may have built between colors and their experience [68, 69]. Color and shape can also affect user sensory expectations, expected linking scores "like or dislike", and willingness to buy [70]. For partially packed products, the selection of the package color could be affected by the product color; understanding this effect will help in designing an attractive package. The tradeoffs between transparency requirements and utilizing colors to attract users should be investigated with respect to designing an efficient package.

With respect to graphic design, the orientation of a design element (e.g. Logo and picture) can make a difference relative to users' preferences and attention [71, 72]. This can create an opportunity to improve readability of important information by writing the important information using specific shapes and orientation to attract the attention of users. Also, the most attractive shapes and orientation could be utilized by placing the most important information close to them to help ensure that users will read the information. On the other hand, the compatibility between element shape and orientation with package shape and orientation needs more investigation.

As a part of packaging visual elements, brand identity has an influence on user purchase decisions [41, 73, 74]. It is worth mentioning here that companies can differentiate their brands in the market [41]by utilizing the package shape [75]; this contributes to brand-building and preserving the identity of the brand in the markets, and should be designed to serve this purpose [76]. The association between products brand and other elements, including, size, opening /dispensing methods, and transparency could be investigated to discover to what extent a package design can be changed without affecting its identity in the market.

Product presentation, either in packages [77-79] or on shelves [80-82], can contribute to a user's purchase decision. Even though packaging is important in presenting products, many products are provided without packaging, labeling, or branding. To compensate for the absence of packaging, users usually tend to physically inspect the products to add to their expectations and perceptions [80]. Currently, unpacked products can be arranged into specific shapes to attract users. Investigating the most appropriate presentation shape for different products could be promising in terms of compensating for the absence of packaging and its capability for attracting users.

The presentation of products in supermarkets affects the user perception, in turn affecting sales and market share, but the implications of the presentation method should also be considered at the supply chain levels: producer, distributor, wholesaler, retailer, and user [81]. With respect to users, it was stated that they perceive the items placed on top vertical shelves or on the right hand side of horizontal shelves as being associated with higher prices; this could infer perceived quality [82]. In this regard, more investigation is required to examine the effect of package size, shape, and weight on the positioning policy while considering user perceptions and physical capabilities.

Symbols, labels and signs are usually used to convey different messages about a product, and in turn can affect user responses [83-85]. Because of the difficulties that may be associated with comprehending international symbols, more efforts should be directed to examine the capability of users to comprehend other labels and signs such as kosher food signs placed on packages.

2.4.2. Information Attributes

One of the main functions of packaging is to deliver messages about the product conveyed through verbal texts. These elements of packaging can effectively collaborate with visual elements to attract users who may be screening products on shelves [86]. Nowadays, users rely largely on the information listed on a package to make the purchase decision. For example, over-the-counter (OTC) medications are provided with labels that can help users make drug-buying decisions without asking physicians [87]. To perform its desired purpose, information on the package should be readable and comprehensible [88-90]. Practically, this information can be presented in terms of many cues that convey various messages to users, which in turn affect their perception [91-94]. One of the informational aspects of packaging is, packaging technology, which has the potential to affect users' perceptions [32, 95-97]. Table 2-1 summarizes the studies related to the informational attributes of packaging.

In general, the aforementioned studies have shown the effect of the presence of information content on user's perception and responses, but there is still a need to categorize information contents based on importance to the users. Ranking the information content can ensure that the most important information is given adequate space and appropriately presented. To that end, multi-criteria decision-making methods, with user collaboration, can be used to assign a weight for every information element.

2.4.3. Positioning of exterior elements

The location of graphical and textual elements on a packaging interface has an impact on users, retailers, and many others. In general, placement of these elements should be convenient to observe for humans and/or machines interacting with the package. The positioning of such elements on the package can induce an effect on user perceptions [98-100]. Eventually, locations of images or verbal contents of the packages can be manipulated to attain the required users' responses and preferences. Proper placement of verbal and visual elements can be determined by considering the alterity of the brain processing [86, 101].

With the advancement in information technologies, different labels, tags, signs, and universal product codes (UPCs) can be utilized to help users. Previous research has shown that placement of such elements has a direct impact on users [102, 103]. Proper placement of UPCs is important for managing the products throughout all the supply chain stages. Many principles have been introduced to ensure that the placement of barcodes/tags is suitable from both technical and practical perspectives [104-106].

The previous results can serve as guidelines for positioning different exterior elements; following the rules presented will ensure that the maximum user attention is secured. In general, there is a need for a model that can evaluate the positioning of different elements on the package exterior, with respect to considering user perception as well as any other practical and technical issues. In such a model, these rules could be used as criteria for evaluation of the quality of the exterior elements' positioning and identify the best tradeoffs, given the limited space provided. The affordances associated with the positioning of specific elements could also be evaluated throughout the UPI stages.

Table 2-1. Overview of the research conducted at the point of purchase.

Attribute	Sub-Attribute	Reference	Revelations
Visual Attributes	Packaging shape	[51, 52]	Package shape affects users' perceptions.
		[53, 55]	Packaging shape affects the perceived volume and consumption practices.
		[56- 58]	Attractiveness of the package shape can induce a considerable bias toward the perceived volume.
	Shape of exterior design elements	[35, 59, 60]	The shape of exterior elements can affect the perceived taste.
	Package size	[61]	Package size can affect the perceived value of the purchase
		[62-65]	Users' usage practices are affected by package size.
	Product visibility	[66]	Users prefer to see the contained products.
	Package color	[67-69]	Colors are usually associated with brands and users' experience, and affect their intentions to buy.
		[70]	Color and shape affect willingness to buy.
	Orientation of design elements	[71,72]	Orientation of exterior elements affect users' preferences and attention.
	Brand identity	[41,73]	Brand identity has an influence on user purchase decisions and attention.
		[74]	Consumption practices can be affected by the brand.
	Product presentation	[77-79]	Products' presentation in packages affect users' perception.
		[80-82]	Products' presentation on shelves affect users' perception.
	Symbols, labels and signs	[83-85]	Symbols, labels and signs can affect users' responses and perception.
Information Attributes	Information readability	[88-90]	Font size and arrangement of products' information affect its readability.
	Information cues	[91-94]	Different cues covey messages affecting users' perceptions.
	Packaging technology	[32, 95,96]	Utilization of smart, active, intelligent, and nanotechnology packages affect users' purchase decisions.
		[97]	Utilizing natural material motivates using packaging technology.
Positioning of exterior elements	Verbal and graphical elements	[98-100]	The location of pictures/information can affect users' perception.
		[86,101]	Proper placement can be determined considering the brain processing of pictures and texts to attain the required responses.
	UPCs, tags, and signs placement	[102, 103]	The placement of these elements has impacts on users.
		[104-106]	Specific principles can help place these elements properly.

2.5. Packaging checking out

Packaging checkout is the second stage of the UPI where either cashiers or self-checkers perform specific tasks for checking out the purchased items. Practically, many players may be involved in the checkout process, including, humans, package, and the checking system. Many studies on professional cashiers and self-checkout stations have been conducted to consider this interaction from different perspectives, as described in the following subsections. An overview of the studies related to this stage of UPI is shown in Table 2-2.

2.5.1. Cashier checkout

A cashier usually performs the checking out process without considerable effort required from the shoppers' side. The checking out task is a cyclic task, including "grasping, scanning, and deposition of products" [107, 108]. During each cycle, cashiers may be exposed to different awkward postures that could contribute to musculoskeletal disorders [109]. Many factors such as checkout station design, shopping cart design, and checking out strategy, and scanning technology, affect cashier profession from both ergonomic and productivity perspectives [110-115]. Uncomfortable workstation design is one problem experienced by cashiers which needs to be evaluated and improved [107, 114, 116-118].

To perform the checking out task it is necessary to scan the UPC printed on items to automatically identify them. While advancements in scanning technology would be expected to have a fruitful impact on scanning performance and behavior, this impact can be limited by package design, and quality and proper placement of the UPC [115, 119, 120]. Failing to scan the barcode without reorienting the package usually leads to handling and manipulating the products to be scanned, potentially exposing cashiers to increased ergonomic risk [111, 121].

Many interventions for improving workstation design have been made, including modifying the scanning process, and/or providing training sessions for cashiers. These improvements have usually targeted workstation design, scanning, and human elements, but one of the main players, the package, has not acquired sufficient attention, even with the proven importance of this element as a factor affecting the checking out process since it is present through the checkout cycle and has a significant effect on humans and overall checkout performance.

Humans should securely control a package while it is in the checkout stage. To that end, the priority should be to reduce the actions of manipulating the package while in the checkout. If this is not possible, then it is at least mandatory to reduce the risk associated with manipulation actions. Proper packaging design and efficient and standard UPC location may have the potential to reduce the required manipulation and associated risk. Studying the effect of the surface texture of packages on the ability to handle and control the package could also help reduce the associated risk. Moreover, adding simple handling features to the packages can facilitate the checkout process and reduce the negative manipulation effects. The effect of the center position of the package mass on the checkout task biomechanics also should be addressed in future work because this effect is expected to be a severe limitation when heavy items need manipulation.

2.5.2. Self-Checkout

Self-service technologies (SSTs) are widely used at many different shopping locations. Such technologies are attractive because of their considerable ability to reduce costs and improve shopper satisfactions [122], and perform transactions quickly in a cost-effective manner [123]. As one type of advanced SSTs, self-checkout (SCO) systems have come into

wide use in supermarkets. Using SCO stations, shoppers are able to perform the checkout process without cashier intervention [124].

Recently, SCO systems have come into wide use in many countries. For instance, in the US, self-checking has become very common in stores such as Home Depot and Walmart [125]. Despite the existence of self-checking stations, cashier station is still dominant because of the advantages of controlling payments [111]. Meanwhile, SCO stations are being continuously improved to be secured and antitheft [126]. Even with the debate surrounding SCO, it preserves its position as a successful technology [127].

In general, users' characteristics and expectations can determine the acceptance of SCO technologies [122, 128-130]. This requires more understanding of users' requirements and experience to attain a higher utilization of SCO stations. Study of supermarket SCO necessitates more research because of the need to identify and address the problems experienced by users to ensure that user's preferences with respect to SCO will not be degraded [131]. As can be inferred from the previous research, a considerable effort has been directed toward understanding users' perception and their interest in supermarket SCO by considering the macro-level of the process, but the micro-level of the self-checking process has received sufficient consideration only in [132, 133], where the study considered a specific group of users. User's preferences toward using the SCO could be more completely investigated with greater consideration on the package as a factor. The effect of the package and users' characteristics on the intention and preferences toward using the SCO stations should be specifically investigated to help in distributing SCO stations efficiently in supermarkets, and provide users with the technology that best fits their capabilities.

2.6. Package Handling

Package handling is a function during which users should be able to handle their products without considerable problems. While handling a package, many problems can be experienced, including difficulties in holding, gripping, picking, carrying, and controlling the package, that, in turn, makes it difficult to safely manipulate the package [134]. In this regard, the handling function was evaluated by using different metrics, including the suitability of the package shape, weight, and size for handling, rigidity of the package, and the handling options offered [135].

Table 2-2. Overview of the research conducted at the point of checkout.

Attribute	Sub-Attribute	Reference	Revelations
Cashier checkout	Checking out task	[107,108]	It is a manual repetitive task.
	Ergonomic problems	[109]	Cashiers are exposed to variety of awkward postures.
	Factors affecting cashiers' profession	[110-115]	Workstation design and scanning technology can affect cashiers' profession.
	Improving cashiers' performance	[107, 114,116-118]	Workstation design may not be comfortable; design interventions were approved to improve the checking out process.
	UPC location and scanning	[111,115,119-121]	Packaging design and UPC placement can limit the usability of scanning technologies.
Self-checkout	Users' characteristics and SCO	[122,128-130]	Users' age, gender, and expectations can determine their tendency to use SCO.
	SCO problems	[131]	SCO is associated with problems related to the workstation design, checking system, and packaging shape.
	SCO improvements	[132,133]	Design interventions were performed to improve the accessibility of SCO stations for disabled users

The ease with which a package can be handled is affected by its dimensions, and considered to be one of the factors affecting user satisfaction while accessing the package [136]. Specifically, the convenience of flexible packaging for disabled users was evaluated all

the way from the point of purchase to disposal [137]. A nice fit with hand size, handling features, rigidity, ease of carrying, and comfort with both left/right hands were considered to be determinants for convenient handling. As presented in the study, package handling is a stage coming before and allowing the opening stage.

Limited number of studies were conducted on package handling even with its potential impacts on users. Further investigation is required to improve package handling. For instance, packaging design can be evaluated to ensure that it helps users to adhere to safe practices of material handling, especially when they interact with heavy and delicate packages. Even though handling features are provided, users may not employ them or may not be aware of them. The effectiveness of the affordances provided to facilitate using such features and appropriately handle the package requires further investigation. The potential effects of ease of package handling and the provision of handling features on users' product size/weight choices also require more examination

2.7. Package opening

After buying a product users usually access the contents of a package to gain useful value from the purchase. At this stage of interaction, they may open the package with ease, with difficulty, or even may fail to open the package, so their perception and willingness to pay can be affected by this experience [138]. Indeed, user satisfaction is sensitive to package attributes and benefits both at the point of sale and the after-purchase stages of use [30]. Accordingly, further investigation is required to understand such after sale interactions [139]. The following subsections describe the problems associated with opening, factors affecting this process, and the design efforts applied to improve package accessibility. Table 2-3 summarizes the studies related to this stage.

2.7.1. Opening problems and factors affecting package accessibility

While opening packages, users may experience different problems/risks depending both on their personal characteristics and on the packaging properties. Identifying such problems is the first step to improvement. This aspect has attracted many researchers with the aim to make package opening a difficulty-free task. For example, the effectiveness of explanations given by pharmacy technicians was investigated, and if they help patients to overcome medicine packages' opening problems [140]. The study constituted an assessment tool showing problems associated with opening medication packages and proposing solutions for such problems.

Considering that users are different with respect to physical, cognitive, and various other capabilities, a package should be designed to ensure that the great majority of users will access products easily without being exposed to risk. Ideally, under normal conditions of use, packages should not create a considerable level of risk to the users [136], but in some situations opening food and drink packages can lead to accidents and injuries. A study revealed that, among many types of packages, steel cans were associated with the highest level of injuries; the sharp edges of the can and the opening tools can both contribute to such injuries. Another study recommended providing clearer instructions to facilitate the opening process [141]. To reduce the risk associated with methotrexate packages (dosage amount) and produce a user-friendly package, package design, patient behavior, and capabilities were simultaneously studied [142]. In general, social characteristics along with individual practices and capabilities can be considered to be causes for opening related accidents [143].

Even with agreement on opening problems and potential risk associated with these problems, the associated risk level still needs to be quantified and managed. This quantification should

account for the likelihood of such problems and the severity of their occurrences, taking into account the package, the user, and the environment in which the user and the package interact. By understanding these aspects, designers can reduce the severity of opening problems, if any, at the design stage. Warning labels describing potential for opening accidents based on this quantification may also alert users.

Many factors can play important roles in determining the accessibility to different types of packaging and associated opening problems. In general, a package can be difficult to open because of the complexity of the opening system, useless instruction, or the force required [144]. Identifying such factors can help designers to produce efficient packaging designs while eliminating opening difficulties. For example, predicting the most preferred grip style while opening peelable packages gives designers valuable information and helps them in designing a package considering users' behavior and preferences [145]. Considerable effort has recently been applied toward understand factors affecting ease of opening.

One of the main factors affecting package accessibility is age of users. Among the different age groups, elderly people are exposed to opening problems the most because of their degraded capabilities. Within this context, many studies have investigated the capability of elderly users to open packages with the aim to understand the problems experienced [146-149]. Other major factors affecting the opening process include the physical capabilities of users since these capabilities can determine their ability to open packages. Understanding users' capabilities and characteristics will help in designing a user-friendly package [150-155]. Packaging characteristics [156-158] and the choice of opening technique can also affect the opening process. Consideration of package handling, gripping, and manipulation is vital to

improve the ability to manufacture accessible packages [159]. The opening posture was also found to have an effect on packaging accessibility [160, 161].

The previous work showed that factors affecting the opening process can be categorized into human, package, and opening technique related factors. Because the packaging designers cannot control human capabilities, they should understand both the design restrictions invoked from the human side and the best opening techniques and practices. Eventually, designers should be able to provide design features that fit with user capabilities and facilitate the opening task. At the same time, they should ensure that a package affords the best opening practices and techniques, as well as guide users to more efficient and safe opening.

2.7.2. Improving packaging accessibility

While maintaining its basic functions, a package should be designed to ensure that tradeoffs among the aspects of safety, ergonomics, sustainability, logistics and marketing are efficiently managed [162]. Within the context of ergonomics, a package should be designed to facilitate the opening process for the majority of users. As an ultimate goal for designers, a user-friendly package should satisfy the conditions of simplicity in opening and easy handling; these can be measured in terms of biomechanical strain, subjective preferences, opening time, and the activated range of motion [163].

A considerable effort was directed to designing a package that could be easily opened by most users. Ease of opening is partially determined by the opening force required, and even more by the design of the package[164]. Accordingly, packaging design has many parameters that could be manipulated to be consistent with users' capabilities and produce a user-friendly package. Considering the variety of these capabilities, more complexity in packaging design is

to be expected. For example, elderly and young people may have different force and torque profiles [165] corresponding to different opening capabilities.

User's limitations, if accurately identified, can help designers achieve efficient packaging design, and this aspect has attracted the focus of many researchers [166-168] with a focus on elderly users. However, young people need more considerations since they may have difficulties similar to those experienced by the elderly while opening packages [169]. While previous work has focused on the elderly as a group that needs more consideration during the packaging design process, with changes in family lifestyles, children now buy and open their own products. Clearly, more investigation is required to understand the physical limitations of children, their ability to comprehend opening instructions, and capability to independently open their own packages, while eliminating the associated risk.

Many studies to improve packaging design focusing on end users and package performance have recently been performed [170-172]. Given the inconsistency in the methods used and the measures in packaging design-related studies, it is important to achieve a high level of consistency in experiment design, so that the repeatability and validity of the studies will be confirmed to provide an opportunity to enlarge the data set in this area [173].

Designers strive to gain more insight into the opening process with the aim of making it easy for most users. Different analysis tools for packaging design have recently come into wide use, including Finite Element Analysis (FEA), mathematical modeling, and Monte-Carlo simulation [174-177]. Practically, an efficient package can be achieved through understanding user requirements that can be used as guidelines to assess package performance [135]. Within this context, many studies have been conducted to structure the packaging design process with more insights into users' requirements [38, 178, 179]. Because of the growing complexities

and challenges associated with package opening, researchers began to focus on specific types

of packages [144, 180-182] and introduced opening-aiding tools [183, 184] to overcome

degradation in elderly physical abilities.

Table 2-3. Overview of the research conducted at the point of package opening.

Attribute	Sub-Attribute	Reference	Revelations
Factors affecting packaging accessibility	Age of users	[146-149]	Elderly users' may have degraded capabilities, and they experience problems and difficulties when opening their packages.
	Physical capabilities of users	[150-155]	Physical capabilities of users such as grip strength, torque, squeeze and compressive forces can determine the ability to access their packages.
	Packaging characteristics	[156-158]	Packaging characteristics such as dimensions, surface properties can affect the accessibility of packages.
	Opening techniques	[159-161]	Grip styles, and opening posture are considered to affect the ability to open packages.
Improving packaging accessibility	User's limitations	[166,169]	Understanding user's limitations (physical, vision, and cognitive) helps produce an efficient packaging design.
	Packaging design	[170-173]	It is important to consider the user and package performance.
		[174-177]	To improve packaging design, opening process can be investigated utilizing mathematical and modeling techniques.
		[38,135,178-179]	The packaging design process should be structured to link between users' requirements and design parameters.
		[144,180-184]	Opening difficulties can be addressed either by introducing opening aiding tools or applying design efforts.

Previous work has mainly focused on the stage of opening a package as a necessity to

access its contents. However, many packages allow users to reuse or reclose them, and it is

important to investigate possible design efforts that might facilitate such actions. This has

potential to motivate users to reuse their packages in the future instead of wasting them, and

manage their consumption practices. Also, in some situations, even using an easy open

package, it can be difficult to retrieve the ingredients from inside the package, especially if

deep tubs or jars are used. More investigation of such situations is required to ensure user satisfaction and safety.

Previous research shows that a structured design process can be demonstrated in a systematic manner. Achieving an initial understanding of users' capabilities and the factors affecting opening performance is considered to be a basic diagnostic stage. A second step would be identifying the design parameters that have an influence on these factors, and examining the relationships between these parameters and opening performance. Then a potential improvement can be systemically achieved by manipulating the design parameters.

2.8. Packaging storage and disposal

Package storage and disposal have come to be an important part of the package design process [185], and are considered to be packaging functions [135, 178]. Usually, users buy products and then either directly use them or store them for future use. At this stage of interaction, the package instructions should provide the users with the required storage information [135]. The package should then be easy to place in a storage area [136]. The package should also not expose humans to awkward postures [137]. Within the context of storing, [186] investigated how the users store their food and at what temperatures, with results showed that user characteristics did not play a significant role in determining the temperature.

Once the contained material has been completely consumed, the package may either be disposed or reused, depending on the packaging attributes. Such attributes can play a role in determining users' behavior when dealing with empty packages [136, 187]. Moreover, a mixed study stated that the recycling and littering behaviors of individuals are affected by their surrounding social environment [188].

Users and governments became increasingly concerned about the environmental impact of packaging [15]; reducing the negative impacts of packaging on the environment is consistent with users' tendency to protect the environment and is therefore considered as creating a competitive advantage [10]. Accordingly, users' preferences are expected to be affected by the potential impacts of packaging on the environment [147, 189].

Packaging is the only media that can reflect and communicate the efforts applied by producers toward achieving sustainability, in turn affecting users' perception. The package can convey three main categories of ecological cues, including structural, informational, and graphical-related cues; such cues can infer the eco-friendliness of the product and the package itself [190]. Also the effect of visual and verbal ecological elements was studied with respect to user's attitudes and willingness to purchase, while considering their environmental concerns [191]. The ecological visual elements are perceived more positively by users with environmental concerns, especially with the absence of the verbal elements [192].

Package design can influence the after usage activities and in turn' users' behavior [193-195]. Considerable effort has been applied toward improving packaging design in terms of using advanced materials with more environmental considerations [9, 12, 196]. Refillable packaging was also introduced to provide an opportunity for reducing the environmental impact of packaging through reducing the amount of material used. However, users should be motivated to use packages that provide convenience, cost-effectiveness, good quality, easily-usage, and cleanness [197].

From environmental and economic perspectives, the development of sustainable packaging is restricted by user needs for effectiveness, suitability, and price preferences [198]. Accordingly, the process of designing an efficient and sustainable package is expected to be

somewhat more complex. To manage these tradeoffs, [199] introduced a multi-criteria decision support system that can be used to help a decision maker handle packaging requirements in terms of functionality while also considering environmental aspects.

On the other side, users can reduce the effect of post-consumer package disposal by collecting them. In this regard, different techniques proposed by [200] included putting empty bottles in containers located on roadsides, collecting empty packages in large bags in homes, using thermal presses at home to reduce the size of plastic bottles, and transporting empty beverage containers to supermarkets where they would be compressed. Motivating users to collect packages in such ways will definitely be translated into a reduction in pressure on the environment.

The efforts applied to this stage of UPI can be categorized into two main areas. The first is related to affecting users' perception and behaviors by utilizing the design elements of the package, including material, graphical, informational, and structural elements. In fact, this category may play a major role in motivating users to reuse or recycle their packages. The second category is related to users' practices in terms of collecting their post-consumer packages.

In general, packaging material and design have the potential to increase tendencies to reuse or recycle empty packages. Investigating these aspects of packaging is important to attain higher user satisfaction while preserving the environment. Some specific elements of the packaging design, including the shape, breakability, weight, perceived value, and safety issues, can affect the reusability or recyclability of empty packages. Essentially, packaging design should afford the best practices of packaging disposal, recyclability and reuse while

eliminating the likelihood of injury. For example, potential uses of empty packages can be described and printed to make users aware of reusability options.

2.9. Other possible categorizations

The previous sections introduced UPI according to the encountered stages of interaction. UPI, however, involves packages, users, and the functions performed by them while interacting with their packages. The previous categorization efficiently covers the latter element of the UPI with insights into the different stages of interaction. However, there is a necessity to consider the other elements of UPI to understand its state of the art in an inclusive manner. This section introduces categorizations related to users and packages.

The first category links to the human subjects involved in previous studies. The age and gender of the humans participated in those studies were categorized. As for the studies involving human subjects, it is clear that most of them were conducted on humans from both genders, while few studies included female participants, and two studies involved males. The exclusion of male subjects was to ensure representing the majority of humans working in specific sectors. For example, female cashiers were tested as this sector seems to be females dominated. Excluding males or females from a study is an objective driven decision, which is usually taken to study gender dominated tasks.

The age of the human subjects tested was also categorized. In general, a majority of the previous studies involved human subjects who are neither seniors nor children, with a considerable number of studies considered senior humans to understand their capabilities and the problems they experienced while dealing with different packages. However, there is a limited focus on children in previous studies, and this necessitates more focus on this sector of users, especially with the increased dependency on themselves in using their goods.

Another important element of UPI is the package which exists all the way through the different stages of UPI. A group of studies was conducted without considerations on the types of products or packages, while other studies gave these elements more considerations as shown in Figures 2-3 and 2-4. As for the products considered, it is clear that the main focus was on food products with little focus on medications and non-food products as shown in Figure 2-3. This focus on food products can be explained by the high proportion of food products compared to other packed products [193]. However, given the fact that medications and non-food products have different problems experienced when using them, it would be important to raise the focus on these products.

The products considered in the previous studies were packed using different packaging types as shown in Figure 2-4. Bottles and Jars were the most researched packaging types with the highest number of studies considering them. The second most researched packaging types were Boxes and Cylinders and Cans, followed by Flexible, Bags, while few studies included Jugs, Blisters, and Tubs. The focus on Bottles and Jars may be explained by the problems associated with these types of packaging. However, other packaging types were shown to have problems at different stages of UPI [136]. Indeed, packaging types are different in their structure and opening systems, and it would be imprecise to generalize the results of the studies considering Bottles and Jars to the less researched types.
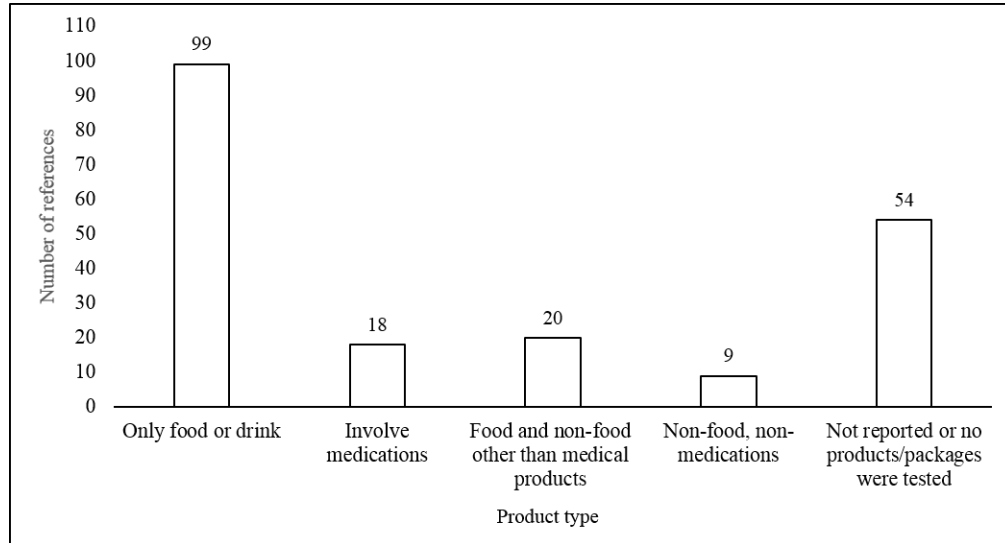
Figure 2-3. Articles distribution according to the products involved.

In general, the previous studies were mainly related to packaging accessibility and marketing. Physical packages were mainly used to perform accessibility related studies, while images of packaging aspects were used to perform marketing studies. This could be explained by the differences in the objectives of these studies, since accessibility related studies are mainly meant to improve the open-ability of packaging, while marketing studies are directed to improve the attractiveness of packaging exterior elements and users' perceptions.
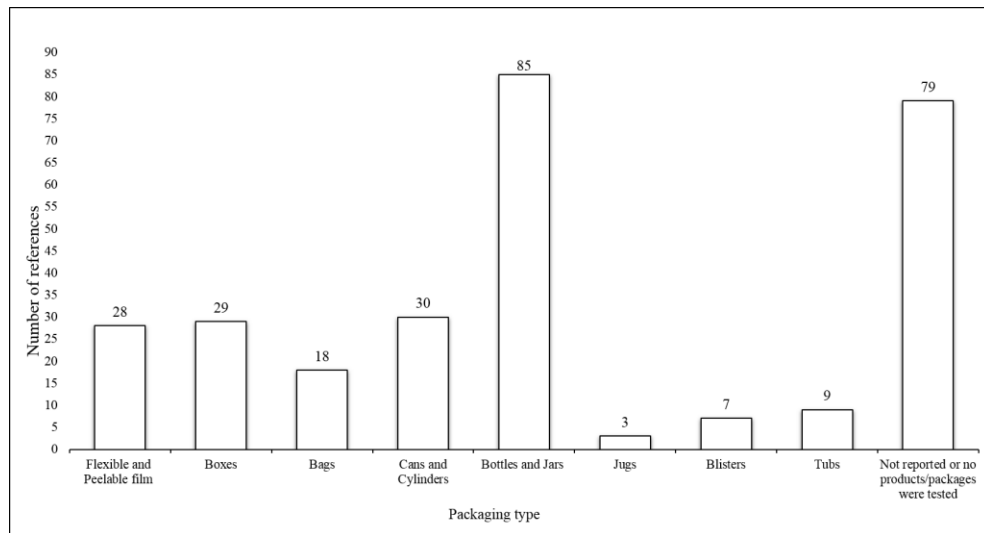
Figure 2-4. Articles distribution according to packaging type.

These categorizations were further reviewed simultaneously to explore the potential links between them. The review has revealed that the group of seniors was considered as the main group of users tested on medicine packages [142, 147, 153, 155, 163, 166, 169]. This could be explained by the problems they face when using their medications and the importance of providing them with user friendly medications packages. A considerable amount of efforts was directed to test the accessibility of bottles and jars and blister packs considering senior users. In fact, senior users may have degraded capabilities and this may not allow them to open such packages easily, so there is a need to improve the opening systems of these packaging types. Different age groups, on the other hand, were tested on food packages with a focus on bottles and jars [18, 35, 36, 39, 49, 53, 188]and flexible packages [23, 24, 32, 40, 78, 135, 185]. These packaging types were considered to be associated with opening difficulties and they are widely used within the context of food packaging. Other packaging types used in food packages acquired less attention even with the potential problems associated with them.

2.10. General Discussion

In this article, the stages of the UPI have been identified based on a literature review that considered the most relevant articles in the field of packaging; the particular ordering of these stages, proposed by the authors, are the point of purchase, checkout, handling, opening, and disposal. Other stages that could be considered include re-storing, reclosing, reusing, and dispensing, but the stages considered in this article compromise the structure of the reviewed articles. Generally, the review process yielded the evidences described below regarding research conducted in the UPI field.

The first stage of UPI takes place when users are looking at the products on shelves. The articles related to this stage focused on the visual and verbal attributes of exterior

packaging design. This stage of interaction is important because of associated marketing functions, including communication and advertisement. Even though these functions are considered to be secondary functions of packaging, they acquired the highest level of focus in previous research. Indeed, this stage of interaction has significant importance since it can determine whether or not a user will buy the product, especially if new products are presented.

The visual and informational attributes of packaging considered include the elements of shape, size, graphic design, product visibility, color, element orientations, label size, brand, product presentation, symbols, labels and signs, packaging technology, and the elements' placement; while the effects of these elements on users' perception and practices have been discussed from various marketing perspectives, these elements also may have an impact on other stages of interaction. For example, barcode location can affect the ease of the checkout task, and the shape and size of the package can determine the ease of package handling and disposal practices. In general, there is a need to understand how the exterior elements can be designed to afford the proper checkout, handling, opening, and disposal activities that can support the overall UPI.

On the other hand, ergonomic design of packaging may contribute to framing users' perceptions and willingness to pay. Indeed, users' perceptions can be affected while interacting with their packages with either negative or positive implications related to products, manufacturers, or other stakeholders. A limited number of studies confirmed this point while highlighting the importance of producing a user-centric packages in supporting the marketing function of packaging. Ergonomic packaging design should be considered as a competitive advantage with a considerable return to stakeholders. To that end, the potential impacts of ergonomic features on the amount of purchase of a product can be further investigated and

quantified. Within this context, the investments directed to produce user-centric packages can be justified and supported. Ergonomic packaging design may affect users' perceptions at the point of purchase and even more at the point of use. Consequently, providing the users with such design has a potential to motivate them to buy a product at the first time and re-purchase it in the future. Even with the importance of ergonomics as a marketing aiding tool, the previous articles have focused mainly on graphical and informational elements of packaging as the main marketing tools.

The second stage of the UPI is the checkout stage, i.e., the stage when the users scan, bag, and pay for purchasing items. This stage was discussed within the contexts of both cashier-based and self-checkout stations to reflect the options presently offered in supermarkets. While this stage of interaction is not introduced as having an influence on users' perception and intention to purchase, it relates to their satisfaction with the SCO service, and the overall performance of the service as well. Logically, if users can check out their packages easily and quickly, they will be more motivated to return to the same supermarket, and the supermarket will provide efficient service that attracts more users.

Previous research on this stage has mainly focused on cashier-based checkout, but with the dissemination of self-checkout stations, a broader investigation is required to ensure users' satisfaction. Within this context, packaging design has a potential to affect the checkout process in different ways, as suggested in previous studies. Even with agreement on the effect of the package at this stage, while package design has not been further investigated in this context, it is important to examine the compatibility of the package design with scanning technology in use and users' capabilities.

While engaged in self-checkout, users may have to manipulate a package to perform the actions of scanning and packing, and package design can play a role in reducing the manipulation actions and associated risk. To that end, handling features which facilitate and afford proper handling methods could be provided and further investigated within the context of checkout. The barcode should also be placed in a position that facilitates and affords convenient scanning of different packages.

The third stage of the UPI is package handling where users carry, manipulate, and move their packages. In the articles presented, while package handling was not discussed within the context of material handling, it is important to determine the risks associated with package handling. Ease and safety of handling are important since their achievement supports the UPI at other stages. Accordingly, as long as package handling is involved, it is important to address its effects on the quality of the UPI. While handling features can facilitate package handling even with the presence of these features, users may not be aware of their purpose. Affordances should be provided in the package design to ensure the proper utilization of possible supporting features.

Package opening is the fourth stage of the UPI, where users may open a package easily, with difficulty, or fail in opening it. Because of the important role of this stage in affecting user's perception, it is considered to be a main pillar in the research structure. In fact, it is the second most researched stage, with a focus on opening problems, factors affecting the opening process, and design efforts applied to improve package accessibility. According to previous work, a systematic design approach can be structured to ensure achievement of an efficient design in terms of openness. First, users' capabilities and practices related to factors affecting the opening process should be identified. Next, design parameters related to the opening

process must be determined. Finally, a package design can be optimized by manipulating design parameters in a manner that moderates the effect of users' capabilities. Even when users are provided with modern packaging design intended to enhance easy opening, they may still be unable to open a package. Accordingly, along with the effective opening methods and techniques, suitable affordances are required to guide users to open the package in the manner intended by the designers.

The final stage of the UPI is packaging disposal. While this stage of interaction may not have the same impact as the opening and product-screening stages with respect to users' perception and satisfaction, with growing pressure provided by both users and legislators, more effort will be required to improve this stage. This stage was explored in previous studies that considered the effects of packaging design and material used on users' waste-disposal behavior. In this context, the package design should afford possibly-achievable options at the disposal stage.

The reviewed articles were further categorized to understand the state of the art of UPI in a comprehensive manner. In general, the focus of the previous work was mainly on elderly as a group of people who have limitations affecting their ability to interact with their packages, especially while opening. A little focus was directed to understand children's capabilities and limitations even with the increased dependency on themselves as they interact with different packages. This requires more focus on this group of users to understand their problems and achieve a universal packaging design.

The previous articles have mainly focused on food products and this can be explained by the high proportion of food products compared to other packed products. However, other products, especially medications or medical related products, need more investigations because

of the problems associated and the criticality of using them. Different packages were considered in previous research with a major focus on Bottles and Jars. Given the different problems reported when using other packaging types, there is a necessity to raise the focus on these packaging types.

2.11. Conclusion and Future work

This paper presents a review of previous research regarding UPI, wherein the reviewed articles appropriately represent the body of the research conducted in this field. This review structured a generic platform for researchers interested in the UPI. The articles were mainly categorized on the basis of the stage of interaction between users and packages. Product screening at the point of purchase, checkout, handling, opening, and disposal were introduced as stages of the UPI. To gain a comprehensive view of the current status of UPI, the reviewed articles were further categorized according to products and packaging types and humans' gender and age.

The first stage of interaction takes place at the point of purchase. Articles related to this stage presented the different attributes of packaging and their role in framing the purchase decision and preferences of users. These attributes can be categorized into structural, graphical, and informational attributes. The marketing function of packaging was the main focus of the articles related to this stage with little focus on the potential effect of different packaging attributes on other UPI stages.

The second stage of interaction is the checkout stage which is presented within the context of self-checkout and cashier stations. Even though the checkout process has three main players; the user, package, and the checking system, the previous work has mainly focused on

users and workstation design with considerable interventions made to improve the checkout process. Packages exist all the way through this process, these packages have the potential to affect the performance of both users and the checkout systems, so more focus should be directed to understand the relationship between packaging design and other players. As for supermarket self-checkout stations, the focus was on user perceptions and intention to use these stations with little focus on the effect of workstation and packaging design, and users physical capabilities on these perceptions.

Package handling is the third stage of UPI. This stage is introduced before the opening stage as it is important to facilitate the opening actions, however, it can be accompanied with other stages of interaction. Accordingly, this packaging function is important because of its potential effect on UPI at different stages. This importance however is not reflected in the previous work with few studies focusing on this stage of UPI.

Opening is the fourth stage of interaction. Because of the increased issues of opening, researchers started investigating the factors affecting the opening process of different packages. In general, these factors can be categorized into users and packaging characteristics, and opening techniques related factors. Accordingly, packaging designers should provide a package which is suitable for users' capabilities and able to inform them about the best opening techniques and practices. In general, the previous efforts of designers have been directed to identify users' limitations and requirements and utilize advanced analysis tools to fully understand the opening process.

The last stage of UPI is packaging storage and disposal. From previous research, it was shown that different packaging attributes can affect user behavior while dealing with empty packages. Specifically, packaging design and material can be manipulated to motivate users to

reuse or recycle their empty packages. This stage of interaction is important with a potential to affect user perception related to the environmental impact of packaging. This importance however is not sufficiently reflected in the research structure.

To understand the state of the art of UPI while considering more dimensions other than the stages of interaction, the reviewed articles were further categorized on the basis of the humans tested and products and packaging types under considerations. These categorizations have revealed different issues in the current research structure of UPI which need to be addressed. In general, the focus of the previous work was more oriented to understand the limitations and capabilities of senior users. Practically, there is no problem with this trend, but with modern lifestyles, children are getting more and more independent with respect to the use of their products and this necessitates more understanding of this group of users. The previous work has also focused extensively on food products with few studies conducted on medical and non-food products. The main focus was also on Bottles and Jars with less focus on other packaging types. The research structure can be further improved by directing more efforts to understand children's capabilities and investigating the problems associated with different products and packaging types.

The current state of the art of UPI has two more issues related to the comprehensibility of the conducted research and the distribution of the related articles. UPI has attracted many researchers from different fields, with interventions oriented toward specific aspects of UPI. For example, marketing studies focus on users' perception when screening items on supermarket shelves while mechanical design-related studies focusing on design parameters and their effect on open-ability. With this research structure, a comprehensive understanding and improvement of UPI seems to be unachievable. Currently, designing a package which

appeals to users is the main focus of the ongoing research as reflected in the distribution of the reviewed articles. However, the implications of packaging design on other packaging perspectives related to after sale occurrences acquired little research. Even though the users' perception may be asymmetrically affected by their experience at UPI stages, more focus should be directed to checkout, handling, and disposal stages to achieve an efficient UPI.

While a great deal of effort has been directed toward improving UPI and designing more friendly and efficient packages, users still encounter problems with their packages at different occurrences of UPI, even when simple interventions have some potential to make a difference. Considering the implications of packaging design on the different stages of UPI may help reduce these problems at the stage of design, and give inclusive insights into improving the UPI efficiency. Users may also encounter problems when interacting with their packages because of their lack of awareness of design features, so a structured and systematic improvement of UPI is required.

As a future work, a generic affordance-based model could be built to quantitatively evaluate packaging usability through the UPI stages. It will help designers simultaneously consider different packaging perspectives and direct their attention to the modifications required for users' satisfaction improvements. User requirements will be elicited from previous packaging evaluation studies and restated in terms of affordance properties, such as intuitiveness, perceptibility, and responsiveness. These properties will then be further verified by users to determine their importance to packaging usability at the different stages of UPI. Different packages can be evaluated against the elicited properties with a usability score assigned to each package. Eventually, packaging usability can be evaluated quantitatively with more insights into user requirements. Based on this evaluation, the missing design features and

affordance properties reported by users could be determined. Following this, designers could modify their designs in manners suggested by the evaluation model. Less researched or missing interaction stages could also be targeted for further investigation.

All in all, organizing the field of UPI is necessary to provide a comprehensive understanding of the field, and allowing researchers to apply the most effective improvement efforts when considering different packaging perspectives. Reviewing the state of the art of UPI has confirmed the necessity for improving this field with respect to different dimensions. In general, the current research structure of UPI has many gaps related to the stages of interaction, packaging and product types, and the humans tested. If these gaps are filled appropriately, considerable improvements of UPI are expected. These gaps should be addressed taking into account the possible effects on the overall performance of the UPI throughput product lifecycle.

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CHAPTER 3. THE EFFECT OF SCANNING TECHNOLOGY AND UPC PLACEMENT ON SUPERMARKET SELF-CHECKOUT

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Abstract

Self-checking services are offered in many supermarkets. In order to checkout efficiently, customers must locate and scan the Universal Product Code (UPC) of the items with relative ease. Otherwise, their preferences toward using the self-checkout (SCO) stations may be negatively affected. The current literature has no focus on UPCs location and the scanning technology used effect on performance and preferences. The purpose of this study is to investigate the effect of these from an operational and ergonomic perspective. To that end, two UPCs placement techniques (current and recommended placement) and two scanning technologies (bi-optic and handheld scanners) were tested. The total scanning time, individual items scanning time, trunk posture, total number of wrong twists/flips, individual items wrong flips, muscle activities, participants' subjective preferences were measured. The results revealed that total scanning time was significantly reduced when using bi-optic scanner $F(1, 28) = 20.9$, $p < 0.01$, $\eta_p^2 = 0.43$. The recommended UPC placement led to a significant improvement on UPCs anticipation for both scanning technologies $F(1, 28) = 16.8$, $p < 0.01$, $\eta_p^2 = 0.38$. Additionally, exposure to non-neutral trunk posture(s) were shown to be

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significantly decreased in the bi-optic condition $F(1, 24)= 10.4$, $p < 0.01$, $\eta_p^2= 0.30$. Proper UPCs' placement and bi-optic scanner can positively improve the efficiency and experience of the SCO.

3.1. Introduction

Recently, self-service technologies (SSTs) have come into wide use in different fields, including banking (automatic retailer machine), health care systems, and grocery self-checkout (SCO) [1]. Reducing cost, improving competitive advantage in customer service [2], and speeding up customer transactions in a cost-effective manner [3] have motivated their dissemination. One of the advanced SSTs, SCO, has been rapidly implemented in many shopping districts. It allows customers to deal with a system rather than a cashier; customers can perform the tasks of scanning, bagging, and paying by themselves [4]. Development of Universal Product Code (UPC) and scanning technologies has facilitated the use of SCO at different points of sale (POS). These pillars are considered to be the main SCO elements in supermarkets where users can scan UPCs to automatically recognize items. These elements specifically determine the ease with which the SCO process can be performed.

The invention of UPCs has contributed to solving manual key-entry deficiencies such as low throughput, checking-out errors, and high cost. UPC was introduced in 1952 at a relatively low cost to automate the checkout process in supermarkets. However, it was not until 1974 that this invention came into common use [5]. Once established, standardized UPCs printed on packages were used to identify and control different packages, while retailer-generated UPCs were used to identify internally produced items [6]. UPCs should be unique, trackable, readable, easily scanned, anti-damage, accurate, and comfortable from a visual

perspective. To this end, UPC locations are recommended on the basis of product types and categories [7, 8].

The introduction of the UPC motivated the development of scanning technologies that can accelerate the package identification process. A scanner can read package information using a light beam that moves over its UPC [9]. Scanning technologies were first presented in the 1970s and substituted for the old-fashioned manually-operated cashier's stations [10]; it was in 1974 when the first scanner was used in Ohio, and after that many stores began using this technology [11]. The advent of these technologies led to a manifest productivity enhancement at the POSs [12]. They proved to be effective devices with respect to improving inventory management, checkout time, customer satisfaction, and error reduction [13]. These advantages, however, are limited by the quality, the proper placement of UPCs, and the package design. Accordingly, ergonomic scanning environment, cashier productivity and accuracy can be improved by proper placement of good quality UPCs [12, 14].

Many studies have been conducted on the cashier profession; many problems have been identified, including awkward posture, discomfort, and problems with improperly anticipating the barcodes. These studies have contributed to improving the checkout process, either by modifying the workstations or changing the scanning technology used. On the other hand, few studies have been performed on the SCO process. These few studies were either focused on determining users' preferences and motivations to use the SCO services or on improving workstation design. However, there has been no adequate focus on the effect of the scanning technology and UPC placement on self-checker performance. Compatibility of UPC placement for different scanning technologies has also not been addressed.

UPC location and particular scanning technology used are important when considering scanning, so that the user can anticipate the UPC location for different items and use an appropriate scanning technology. In particular, these elements have proven to affect cashier performance. In general, the effect of UPC locations and choice of scanning technology on supermarket self-checker performance have not been addressed from operational and ergonomic perspectives. Also, in previous studies self- checker behavior did not attract sufficient concern. The purpose of this study is to assess the effect of UPC placement and scanning technology on the self-checker and to identify ergonomic problems that may occur while in SCO. Moreover, the compatibility of UPC placement with different scanning technologies is examined.

A controlled experiment was designed and conducted to investigate the effect of the scanning technology used and UPC placement on self-checker performance. To that end, each participant was tested while using either a bi-optic or a handheld scanner to check out their items with either the current or the recommended universal placement. The scanning time, trunk posture, number of wrong flips, muscle activities, and participants' preferences were obtained and analyzed. The rest of the paper will be organized as follows: An overview of the related work found in the literature will be presented in Section 3-2. The detailed method used will be described in Section 3-3. The results and discussion will be presented in Sections 3-4 and 3-5 respectively. Finally, the conclusions and proposed future work will be presented in Sections 3-6 and 3-7 respectively.

3.2. Related work

Several studies have been conducted on the supermarket SCO process. For example, a survey-based study was conducted to evaluate SCO systems, and the results disclosed many

issues with these systems, including problems with a small bagging area, barcode recognition, and scanning items with unfamiliar shapes. The study proposed many improvements in different areas such as layout design, system interaction and feedback, a policy of using SCO, providing larger bagging areas, and improving scanner recognitions [15].

An effort was also made to redesign the SCO station to make it more accessible and usable for wheelchair users. The redesigned station lowered the electronic devices and provided room below the countertop for wheelchair users' knees. This design suited both wheelchair and non-wheelchair users, with a considerable decrease in the peak shoulder angle and trunk flexion for wheelchair users. The modified design demonstrated no negative impacts on non-wheelchair users in terms of accessibility, posture, and task time [16].

Preference toward using SCO stations was also addressed. The tendency of customers to use SCO is largely determined based on their individual characteristics [17]. For example, compared to women, men may have a greater tendency to use SCO because of gender-related differences in perceiving technology. Also, older customers usually have a lesser tendency to use SCO because of their desire to interact with people [18]. In contrast, younger shoppers usually tend to use SCO stations since they are more comfortable with technology [2].

In addition, Dabholkar et al identified the factors affecting customers' perception in self-scanning checkout (SSCO) [19]. According to Dabholkar et al, customers like to use SSCO because of fast checkout, low human interaction, ease of management, usability, fun, and reliability. On the other hand, customers who do not prefer SSCO have their own reasons; they may prefer to deal with employees and get service without effort. Eventually, customers will evaluate SCO based on usability, accessibility, responsiveness, goodness of design,

assurance, and enjoyment [2]. To benefit from SCO technology, customers must be encouraged to use SCO and be involved in training programs to help them deal with its features [20].

The task of checking out items in a supermarket is usually performed by cashiers who find and scan UPCs to perform the task; this activity is similar to what should be performed by self-checkers. The literature has many studies focusing on the cashier's profession, as shown below.

Cashiers' tasks include repetitive light manual handling and scanning; these tasks account for the largest portion of cashier operations, on average 45-50 percent of the time incurred in checking out items [21]. Accordingly, using scanning technologies can sometimes be considered as a source of musculoskeletal disorders because of the awkward postures required in the course of scanning; these postures are affected by the size of the order, the product type, and the cashier height [22]. Baron and Habes identified unfavorable awkward postures encountered in check-stand cashiers' daily work [23]. Flexion, extension, and deviation of the wrist, forearm supination and pronation, abduction and forward bending of shoulders, and trunk rotation were considered to be unfavorable postures. Improving workstation design accompanied with modifying the scanning technique was found to have a significant impact with respect to eliminating the level of occupational risks associated with checkout tasks [13, 24].

Checking out tasks include "grasping, scanning, and items deposition" [25, 26]. Usually, items may have different weights, and this requires consideration because of the predictable level of risk that could be experienced while interacting with different items [25]. One study showed that cashiers had to turn, lift and/or flip 73-82% of checked-out items to find and scan UPCs. Modifying the placement of UPCs to be "on two opposite sides of

packages" and adjusting the scanners were suggested as approaches for eliminating these activities [27]. Compatibility of the UPC placement with the scanning technology used is crucial. Accordingly, continuous evaluation of UPCs' placement guidelines is mandatory to make sure that UPC locations will be compatible with scanning technologies [12].

Cashiers' performance and comfort can be affected by many factors, including scanning technologies and cashier's posture. For instance, both flat-bed and bi-optic scanners have been studied, and the bi-optic scanner was shown to improve productivity while preserving an acceptable ergonomic comfort level [13]. Also, Lehman et al concluded that the scanning technology used at the POS, either bi-optic or vertical window, and the posture of cashiers, either standing or sitting, have an impact on the level of discomfort experienced [21].

In addition, Madigan and Lehman concluded that cashiers' scanning strategies affected their movements and performance in terms of check-out time and accuracy [13]. These strategies usually depend on the package type, the location of the barcode, and the scanning method being used. The check-out process can be evaluated based on user perception, on workload anticipated by measuring heart rate, by physical load, and by productivity measured in checkout time [28]. The scanning time, the kinematic motion and muscle activities are also considered as effective measures [29].

The exterior design of packages should convey meaning and provide important information about the product contained. Many elements of external package design have been studied in the context of human-package interaction. For example, the function of package colors and their effect on consumer perception at the point of purchase was studied over a wide theoretical base [30]. Also, the ideal font size of a product name was empirically determined as a proportion of package size based on participants' preferences [31]. Sansgiry and

Shringarpure evaluated the manufacturers' compliance with US food and drug administration (FDA) requirements for labeling over the counter (OTC) medications [32]. Labeling these products, if appropriate, can help consumers to make their decision and buy the most suitable medication. Existing packages were evaluated against the FDA guidelines, and the results showed that these guidelines were not followed by a number of manufacturers at the time of the study.

Tags or labels are required to identify packages, but such tags should be accessible and observable without affecting the information listed on the package. For example, tags or labels can be added to OTC medications to reduce theft by shoplifting. However, improper placement of these tags sometimes results in obscuring important information such as drug facts, warnings, and expiration dates [33]. A study conducted on shipping containers showed that package content and tag orientation affected the performance of radio frequency identification (RFID) [34]. The role of tag orientation was clear when the containers were filled. If the tags were oriented outward (facing the line of sight of RFID) the package was readable regardless of the contents. Low readability was recorded for water-filled containers because of radio-wave interference and improper tag orientation.

3.3. Method

A controlled experiment was conducted to investigate the effect of the UPC location and the scanning technology in use on the self-checking process. The study was approved by the human subjects' institutional board (Appendix), and was conducted in the Augmentation and Training of Humans with Engineering in North America Lab (ATHENA) at Iowa State University. Twenty-three different items, shown in Table 3-1, were selected to be self-checked out. These items were carefully elected to reflect the normal variety of grocery items in terms

of size, shape, weight, and UPC location, and covering the categories of bags, boxes, bottles and jars, thin items, multipacks, jugs, trays, tubs, tubes, and egg carton [8]. The arrangement of items in a shopping cart was based on volunteers' suggestions, so common practices were used as a guide to arrange the items. The nature of the product; frozen or fragile, played a role in arranging the items in the cart. For example, egg carton was placed on the top part of the cart and frozen items were placed close together.

A self-checking station was built to simulate the dominant bi-optic stations in wide use at the time of the study. There was no need to build a station for the handheld scanner. Figure 3-1 shows the setup used. The scope of this study focuses on the scanning process, and does not cover the steps of paying and bagging because of the direct relationship between the UPC location, the scanning technology, and the scanning task.
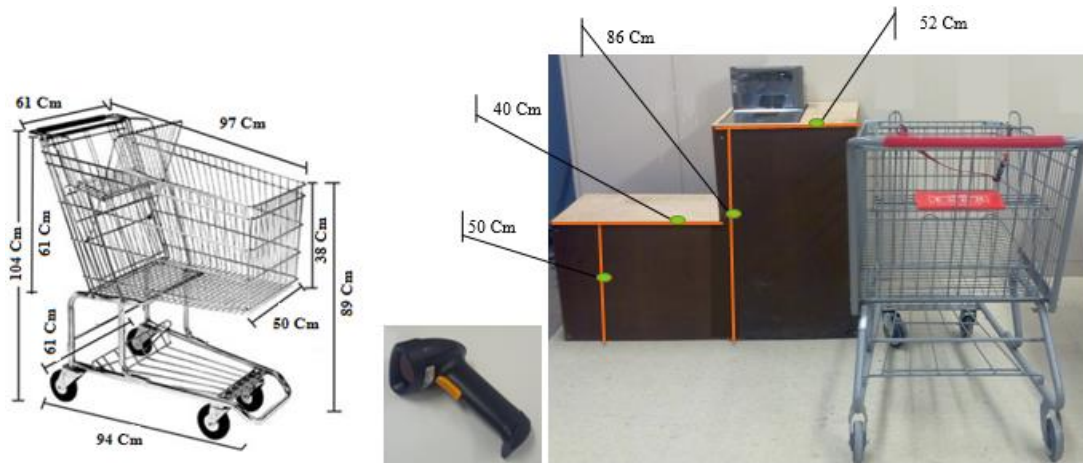
Figure 3-1.The experimental setup; shopping cart (left) modified from [35], the handheld scanner (middle), and the bi-optic workstation (right).

3.3.1. Participants

Thirty-two healthy participants (23 males and 9 females) voluntarily participated in the study. There were twenty-six right-handed and six left-handed participants, all above 18 years

in age (Mean =20.1, S.D= 1.2). The participants were selected because of their familiarity with using self-checking POSs. Also, they had no osteoarthritis, rheumatoid arthritis problems affecting their hands, or any medical record of having walking problems. This is important because of the need to do delicate tasks while in SCO. The height of the participants was reported to be (Mean: 177, S.D = 10) Cm. Because of the potential effect of the participant's physical characteristics on their scanning performance, the experiment was counterbalanced with respect to height, gender, and dominant hand as much as possible.

3.3.2. Procedure

A brief overview of the study was given to participants; the objective of the experiment and the experimental details were explained. Thereafter, a consent form was reviewed and signed by each participant before the experiment. To understand participants' shopping and scanning practices, a general survey with 17 multiple-choice questions provided was conducted before the experimental work. The participants were then prepared for the Electromyography (EMG) test; four sensors were placed on Carpi Radials and Extensor Digitorum muscles of both arms, and the maximum voluntary contractions (MVCs) were measured. In the course of the experiment, participants were requested to do self-checking tasks for the items placed in the cart.

The participants tested using the handheld scanner were required to return the items to the cart regardless of the way they scanned them, so they approached, held/ grabbed items if needed, and scanned, but at the end they returned the items to the cart. The participants using the bi-optic scanner were asked to approach the items in the cart, then grab, scan, and put them in the bagging area. Common occurrences of these tasks were identified based on informal observations conducted in two shopping districts. The EMG setup was then removed and each

participant was requested to respond to an experimental survey with 10 multiple choice questions provided. This survey was designed to help understand participants' experience and perceptions regarding the scanning technology and UPC placement used. Finally, the participants were interviewed with six open-ended questions.

3.3.3. Independent variables

Two different UPC placement techniques, the current and the recommended placements, were used for each checked-out item. The current placement of the items was not consistent, even for similar items, while the recommended UPC placement was the same for most of the items, i.e., on the "lower right quadrant of the back" of the items [8], as shown in Table 3-1. Practically, the front of a package includes marketing information, while the opposite side is considered to be the back side of the package. To apply the new placement, the current UPCs were hidden using like colored stickers to make sure the eye would not target a specific color. The new UPCs were then printed and placed on the recommended location while conserving the size of the corresponding current UPCs. Figure 3-2 shows the UPC locations under evaluation while Table 3-1 contains the key for these locations.

Two scanning technologies, bi-optic and handheld scanners, were used in checking out. Therefore, the independent variables were the UPC location and the scanning technology used with two levels for each. This resulted in a 2x2 factorial design with four different combinations of independent variables; current UPC-bi-optic, current UPC- handheld, recommended UPC-bi-optic, and recommended UPC-handheld; these combinations were randomized in each experimental session. Under each condition, eight participants were tested, for a total of 32 participants. The controlled variables in this experiment were the checked items, the shopping cart, and its location with respect to the scanning station (Figure 3-1) that

was determined based on informal observations, and the arrangement of the items placed in the cart.

3.3.4. Dependent variables

The total scanning time, scanning time of individual items, percentage of the time the trunk recorded a non-neutral posture, the total number of wrong twists/flips, number of flips of individual items, muscle activities, and subjective preferences were documented for each participant. The total scanning time was considered to be the time required to scan all the items placed in the cart, it starts when participant approaches to scan the first item and ends when last item is scanned. It included the actions of approaching, holding/ grabbing, and scanning the items. The actions of putting the items on the bagging area and re-arranging the items in the cart were not included. The scanning time of individual items was also measured.

Table 3-1. Checked items' details with the UPCs locations indicated

Item Number	Product	Packaging description	Dimension L*W*H (cm)	Volume (cm^3)	Weight (g)	Current UPC location (description and number)	New UPC placement (description and number)
1	Pizza	A folding carton thin box	30.9*30.5*3	2830	535	Left half of the lower edge (1)	Lower right quadrant of the back (2)
2	Pizza	A folding carton thin box	31.2*31.2*3.3	3210	402	Lower half of the back to the middle (3)	Lower right quadrant of the back(2)
3	Cake Mix	A folding carton box	18.1*14*4.1	1050	517	Lower half of the left side (6)	Lower right quadrant of the back(5)
4	Cereal	A folding carton box	33*22.6*8.3	6150	760	Left lower quadrant of the bottom (4)	Lower right quadrant of the back(5)
5	Juice bottle	A folding carton multipack	18.3*21.7*14.5	5730	4540	Middle of the bottom(9)	Lower right quadrant of the back(7)
6	Milk packs	A plastic wrapped multipack	12.8*16.3*9.7	2010	1660	Lower right quadrant of the top (8)	Lower right quadrant of the back (7)

Table 3-1 Continued

7	Fruit cups	A folding carton multipack	8.3*16.2*8.9	1190	425	Middle of the bottom(9)	Lower right quadrant of the back (7)
8	Fruit cups	A folding carton multipack	8.3*16.2*8.9	1190	454	Middle of the bottom (9)	Lower right quadrant of the back (7)
9	Peanut butter	A plastic jar	12.6*7.4*7.4	684	492	Upper right quadrant of the back (10)	Lower right quadrant of the back(11)
10	Pickle	A glass jar	13.8*11*11	1670	1360	Lower right quadrant of the front(12)	Lower right quadrant of the back(11)
11	Soda	A plastic cylindrical bottle	30.5*10.9*10.9	3600	2140	Upper right quadrant of the back(13)	Lower right quadrant of the back (14)
12	Juice	A plastic square bottle	23.7*10.3*10.2	2480	1900	Lower right quadrant of the side (15)	Lower right quadrant of the back (14)
13	Milk	A plastic jug	25*9.8*9.8	2430	2000	Lower right quadrant of the front (16)	Lower right quadrant of the back (17)
14	Juice	A plastic jug	27.2*16.5*16.5	7410	3900	Lower right quadrant of the side (18)	Lower right quadrant of the back (17)
15	Cookie dough	A plastic tube	22.9*5.4*5.4	675	494	Middle of the back (19)	Lower right quadrant of the back (20)
16	Butter	A lidded plastic tub	15.8*12.9*11.5	2330	1270	Lower half of the bottom to the middle (22)	Lower right quadrant of the back (23)
17	Ice cream	A lidded plastic tub	18*12*11.4	2460	802	Lower half of the side (24)	Lower right quadrant of the back (23)
18	Sugar	A folded paper bag	19*12.7*7.6	1840	1810	Lower half of the front to the middle (25)	Lower right quadrant of the back (26)
19	Flour	A folded paper bag	22.1*15.7*10.9	3790	2270	Middle of the bottom (27)	Lower right quadrant of the back (26)
20	Flaky biscuits	A hard carton tube	14.1*7.6*7.6	820	453	Upper right quadrant of the back (21)	Lower right quadrant of the back (20)
21	Cookies	A thermoformed tray	20*20*7	2800	392	Middle of the bottom (28)	Lower right corner of the top (29)
22	Muffins	A thermoformed tray	19.8*26*4.3	2210	340	Middle of the bottom (28)	Lower right corner of the top (29)
23	Egg	A plastic thermoformed carton	10.2*29.5*7.3	2200	681	Front to the middle (30)	Near the edge, on the right half of the back (31)
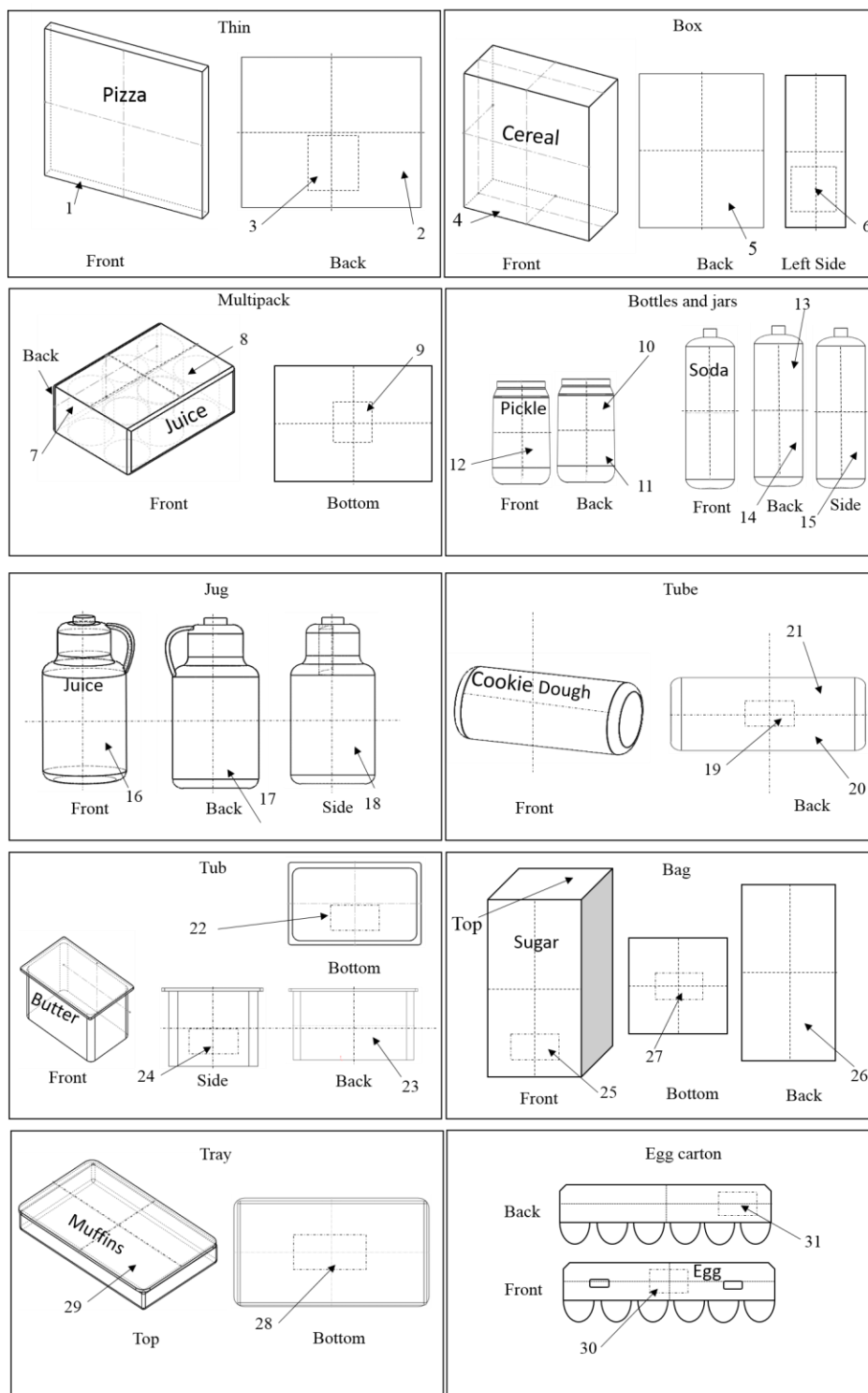
Figure 3-2. A graphical representation of the UPC locations for the packaging types (Table 3-1 contains the key for these locations).

The non-neutral posture of the trunk occurred when the trunk flexion or lateral bending angles exceeded 20 degrees. This posture has been found to contribute to musculoskeletal disorders [36]. The percentage of the time during which the trunk angle exceeded this threshold is the dependent variable. To monitor the trunk posture, Kinovea$^©$ software was utilized to instantaneously track two points of the trunk angle; either flexion or lateral bending. These points create a straight line, and the angle between this line and a perpendicular line (trunk angle) can be calculated using simple trigonometry. The trunk angle then can be recorded along with the time over the course of the experiment. Then the percentage of time during which the trunk angles exceeded 20 degrees can be calculated. Figure 3-3 shows the tracked points and associated calculations. Kinovea$^©$ software was used for motion and posture analysis purposes to produce efficient outcomes [37, 38]. By importing recorded videos into this software, it will be capable to track a point's coordinates as long as a good color contrast between the point and its surrounding exists.

$$\Theta = \tan^{-1}\left(\frac{X2-X1}{Y2-Y1}\right) \quad *\Theta \quad \text{in degrees}$$
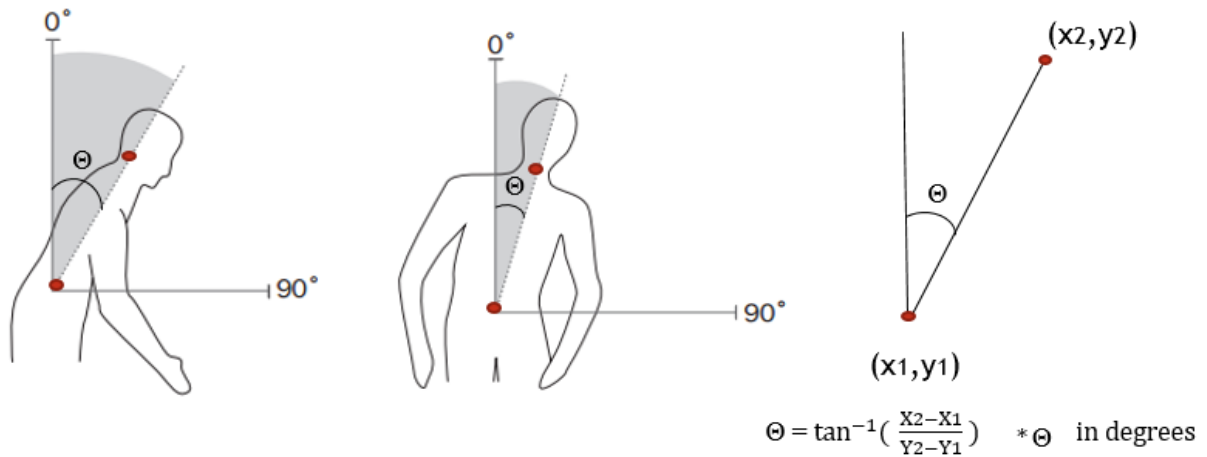
Figure 3-3. Trunk flexion angle (left) and lateral angle (middle); modified from [39], and the trunk angle calculation (right).

The total number of wrong flips/ twists is also considered to be a dependent variable. This measure reflects the ease with which the UPC can be anticipated or found. It is defined as the total number of flips and twists that the participant did before targeting the correct UPC location of objects to be scanned. The number of wrong flips of individual items was also measured. EMG was also used to measure the electrical activities of Carpi Radialis and Extensor Digitorum muscles during the experimental task. These muscles were considered because of the principal use of arms in flipping/twisting the items to find the UPCs. The arms' range of motion was not restricted by the EMG setup including wires, encoder, and sensors. Finally, subjective preferences were obtained from each participant after each session using a short survey.

3.3.5. Apparatus

Two self-checking scanners, bi-optic and handheld, were used. For the bi-optic scanner, a standard workstation was built; no special workstation was needed for the handheld scanner. Also, a shopping cart was used to carry the items to be checked, as shown in Figure 3-1. To observe participants' postures, two video recording cameras (HD Cannon camcorder) were mounted at two different angles with perpendicular views using two tripods (compact tripod with handle). The ProCom Infinity electromyography encoder was used to record participants' muscle activities using four sensors. General and experimental surveys were also used; within these surveys the categorical questions had 1-5 Likert scale scores reflecting the participant's preferences. In addition, an informal interview with six questions was conducted. Like colored stickers were used to hide the current UPCs and place the new UPCs. Finally, the scanning times observed in the recorded videos were measured using a stopwatch.

3.3.6. Analysis plan

The total scanning time, scanning time of each item, trunk posture, total number of wrong flips, number of wrong flips of each item, subjective preferences can be analyzed within the context of between subjects experimental design, because these responses were measured once for each participant. The statistical analysis was performed using the analysis of variance (ANOVA) method with the aid of Design Expert 9.0.6.2 software. While performing the checkout task under each combination of independent variables, each participant scanned 23 items. The scanning time and number of wrong flips of individual items thus were analyzed within participants while considering specific combinations of UPC placement and scanning technology. The Fisher's least significant difference method was used to compare the means of items' scanning time and number of flips. In fact, this plan ensured revealing the effects of UPC placement and scanning technology on the overall scanning process, while providing more insights into the potential influences of packaging characteristics on the scanning process.

3.3.7. Limitations

The participants were young college students (Mean=20.1) years old; no participants from other groups were tested. Nonetheless, the inclusion of young people in the study was appropriate since this group has been shown to have a high tendency to use SCO [2]. The number of items considered in the study (23) was large, but the representative items selected were mostly grocery items, and this appropriately supported study of the scanning process. Also, the selected items were not heavy or bulky and did not include products from other categories, i.e., pharmacy, electronics, and clothes. The effect of packaging characteristics, specifically weight and dimension were investigated informally without separating the main

effects of these characteristics on the scanning process. However, this gave more insights into the potential effects of them while deciding on UPCs placement.

3.4. Results

3.4.1. General survey

The general survey was delivered before the experimental task began. It included 17 questions designed to help understand participants' shopping practices. The results showed that 94% of the participants visit the shopping district 1-3 times per week, 3% of the participants shopped 4-6 times per week, and 3% of them visit the shopping district more than 9 times per week. Practices before shopping were also addressed, the results showing that 63 % of the participants usually prepare a list of the items to be bought. With regard to self-checking preferences, the results revealed that 88% of the participants usually use the SCO points of sales. Among these participants, 86% have been using the SCO point of sale for 1-5 years and 14% for 6-10 years. The participants who usually use the SCO stations were asked several questions with the results shown below.

Motivation to use the SCO stations was also investigated. Most of the participants (86%) use the SCO stations when they have only a few items, and when there is a long queue at cashiers' stations (82%). Also, 36% of the participants use the SCO stations when they have small-sized items, while a minority of the participants (4%) uses the SCO stations when they have large items. 57% of those who usually use the SCO stations have 1-5 items while in self-checking; 36% usually self-checkout with 6-10 items. A minority of the participants usually checks out with 11-15 or 16 -20 items (4% for each category). The factors that affect the arrangement of the items in the cart were also considered. Most participants consider the nature of the products (61%), while 36% of them have no such considerations. Furthermore, 29% of

the participants consider the ease of unloading while a minority of them (7%) position the items for self-checking. Also, the factors that identify items that might be self-checked out were studied. 54% of the participants selected the size of the items, 43% the items' weight, 36% of them selected the shape of the items, and 25% of them reported that no factors would restrict their use of self-checking.

Situations in which the self-checker call for help while in self-checking were explored. The majority of the participants (96%) reported that they call for help when there is a system error. 50% of them call for help if there are items without UPCs. A minority of the participants (7%) call for help when they struggle with finding the UPCs; 4% of them do not call for help. The preferences toward scanning technologies were also obtained; 43% of the participants prefer the horizontal scanner, 43% prefer the bi-optic scanner, and 14% of them prefer the handheld scanner. A 5 point Likert scale was used to determine perceptions regarding the ease of finding and anticipating the UPC locations. The averages of the Likert scores were 3.14 and 3.57, respectively, for the ease of finding and anticipating the UPC locations.

3.4.2. Scanning time

The total scanning time was defined as the total time required to scan the items in the cart. The time was measured without considering the actions of putting the items in the bagging area when the bi-optic scanner was used, and rearranging the items in the cart when using the handheld scanner. A stopwatch with the aid of videos was used to measure this time. To attain the normality assumption of the F-test, the raw data were transformed using the inverse transformation. This transformation was determined based on Box-Cox method. The results showed that the scanning technology resulted in a significant change in the total scanning time $F(1, 28) = 20.9$, $p < 0.01$, $\eta_p^2 = 0.43$, but the total scanning time was not significantly affected

by changing the UPCs placement technique $F(1, 28) = 2.3$, $p = 0.14$. The interaction effect was also not significant $F(1, 28) = 0.5$, $p = 0.49$. Figure 3-4 shows how the total scanning time (in seconds) changes when the scanning technology and the UPC placements change.

Further analysis was conducted to investigate the effect of UPC placement and scanning technology in use on the scanning time of individual items. The results showed that the UPC placement significantly affected the scanning time of items 1, 2, 11, and 17 ($p < 0.05$), and affected the scanning time of item 21 with marginal significant ($0.05 < p < 0.10$). In general, shorter scanning time resulted when the new/recommended placement was used for items 1, 2, 17, and 21. The scanning technology significantly affected the scanning time of items 3, 7, 8, 9, 10, 11, 12, 14, 18, 19, 20, and 21 ($p < 0.05$), and affected the scanning time of item 15 with a marginal significant ($p=0.09$), in particular, the bi-optic scanner reduced the scanning time of these items. Table 3-2 summarizes the analysis results for each individual item.
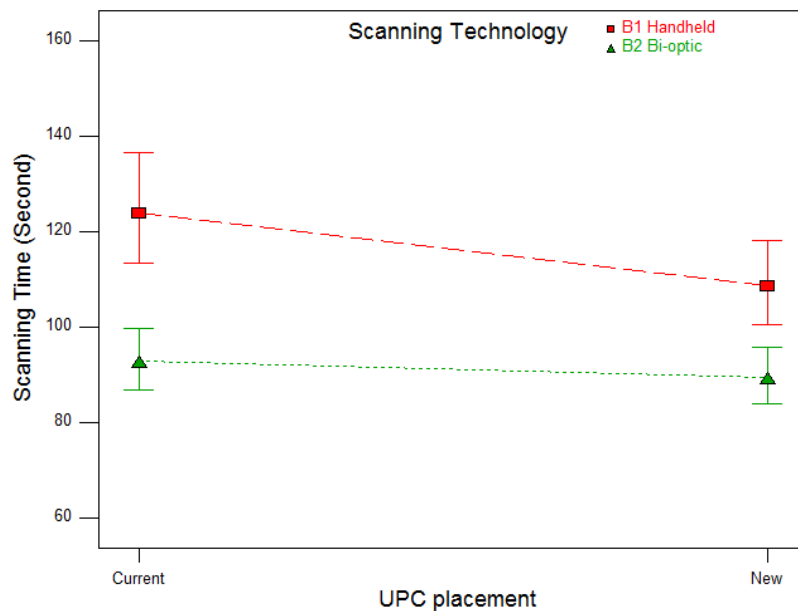
Figure 3-4. The scanning time response under different combinations of the independent variables. The least significant difference (LSD) bars and means are shown.

To further understand the influences of packaging characteristics on the scanning time of individual items, the scanning time was measured and analyzed for the 23 items while being scanned under each combination of independent variables by 8 participants. Multiple mean comparisons using Fisher's least significant difference method have been conducted as shown in Figure 3-5, which shows the means of items' scanning time with the LSD bars indicated.

Table 3-2. The statistical results of the individual items reported using p-values.

Item Number	Scanning Time		Number of wrong flips	
	UPC location (*p*-value)	Scanning technology (*p*-value)	UPC location (*p*-value)	Scanning technology (*p*-value)
1	0.01*	0.35	< 0.01*	0.28
2	0.03*	0.11	0.01*	0.40
3	0.40	0.01*	< 0.01*	0.53
4	0.70	0.11	0.44	>0.99
5	0.39	0.11	0.40	>0.99
6	0.11	0.59	0.02*	0.89
7	0.37	< 0.01*	0.33	0.33
8	0.92	0.04*	0.17	>0.99
9	0.49	0.05*	0.15	0.15
10	0.59	0.03*	0.44	0.44
11	0.02***	0.02*	0.37	>0.99
12	0.30	< 0.01*	0.08**	0.32
13	0.88	0.28	0.82	0.26
14	0.49	0.03*	0.68	0.42
15	0.34	0.09**	0.33	0.33
16	0.55	0.17	> 0.99	0.77
17	0.04*	0.84	< 0.01*	0.71
18	0.16	0.02*	0.07**	0.16
19	0.81	0.01*	0.45	0.45
20	0.63	0.04*	0.64	0.35
21	0.09**	< 0.01*	0.33	0.33
22	0.12	0.60	0.57	0.57
23	0.18	0.26	0.67	0.67

* New UPC/ Bioptic scanner significantly reduce the scanning time or number of wrong flips.
** New UPC/ Bioptic scanner marginally reduce the scanning time or number of wrong flips.
***New UPC/Bioptic scanner significantly increase the scanning time or number of wrong flips.

Comparisons were then conducted between the checked items. Items with no overlapping LSD bars are considered to have significantly different scanning time. In particular, a comparison was conducted on the packaging type basis, since same type packages share approximately same geometry. The following discussion gives more insights into the effect of packaging weight and dimension on the scanning time while controlling the UPC placement and the scanning technology in use.
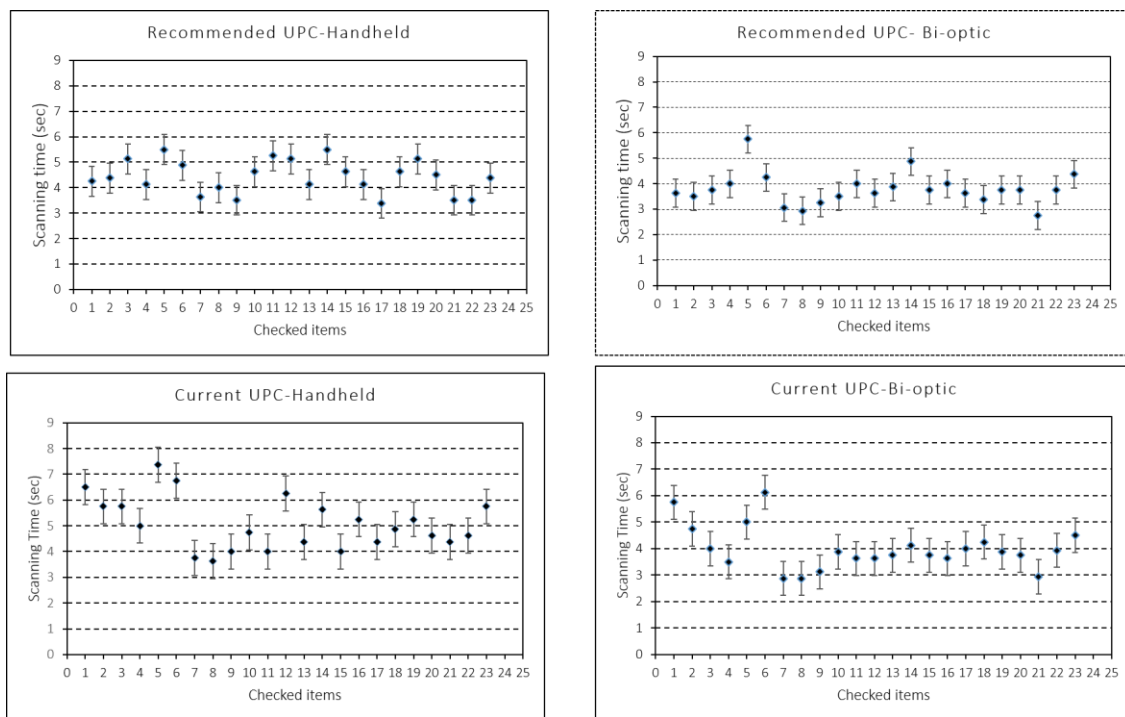
Figure 3-5. The scanning time of the checked items represented using the mean and the LSD bars.

Under the combination of recommended UPC-handheld, it is clear that longer scanning time was recorded when heavier and larger multipack (5) was scanned, compared to smaller and lighter ones (7,8). The same conclusion is obtained when examining the Bottles and Jars group, where a smaller/ lighter item (9) recorded shorter scanning time than larger and heavier items (10, 11, and 12). A smaller and lighter jug (13) has recorded shorter scanning time than

larger and heavier jug (14). Under the combination of recommended UPC-Bi-optic, larger and heavier multi-packs (5, 6) required more scanning time than lighter/smaller multipacks (7, 8). The scanning technology, however, moderated the effect of the package weight and dimension on the scanning time of the groups of bottles and jars and jugs, with no evidence of significant differences found. In general the heaviest and largest items (5, 14) record the longest scanning time compared to most of the other items.

Under the combinations of current UPC-handheld and current UPC-Bi-optic, heavier and larger multipacks (5, 6) required more scanning time than (7, 8), even with variations in the current UPC placements. Complete review of the effects of package characteristics on the scanning time can be conducted through Figure 3-5.

3.4.3. Trunk posture analysis

The trunk posture was analyzed with the aid of Kinovea© software; the videos were analyzed during approaching, grabbing, and scanning the items. The trunk angles, either flexion or lateral bending, were calculated with the total time over the course of the study, and then the percentage of the scanning time during which the trunk was in a non-neutral posture was measured. The results showed that the scanning technology significantly affected the exposure to non-neutral postures $F(1, 24) = 10.4$, $p < 0.01$, $\eta_p^2 = 0.30$. However, changing the UPCs placement did not significantly affect the trunk posture $F(1, 24) = 1.6$, $p = 0.22$. The interaction effect was also not significant $F(1, 24) = 0.71$, $p = 0.41$. Figure 3-6 shows how this percentage changes when the independent variables change. The natural log transformation was used to achieve the normality assumption. This transformation was determined based on Box-Cox method.

3.4.4. Number of wrong flips

The total number of wrong flips/twists can be considered as an indication of the ability to anticipate the UPC locations. The videos were reviewed and the unsuccessful flips /twists, those that did not lead to finding the UPCs, were counted. To attain the normality assumption of the F-test, the data were transformed using the square root function. This transformation was determined based on Box-Cox method. The results showed that the recommended UPC placement resulted in a significant decrease in the total number of wrong flips or twists regardless of the technology used $F(1, 28)= 16.8$, $p < 0.01$, $\eta_p^2 = 0.38$ but the scanning technology did not significantly affect this measure $F(1, 28) = 1.1$, $p = 0.31$. The interaction effect was also not significant $F(1, 28)= 1.41$, $p = 0.25$. Figure 3-7 shows the total number of wrong flips under different combinations of the independent variables.

The number of wrong flips of individual items was also analyzed with the results shown in Table 3-2. The UPC placement has significantly affected this measure of items 1, 2, 3, 6, and 17 ($p < 0.05$), and affected this measure of items 12 and 18 with a marginal significant ($0.05 < p < 0.10$). For these items, the new/recommended placement improved the ability to anticipate the location of the UPCs. The scanning technology did not significantly affect this measure of all the items.

The influences of packaging dimension and weight on the ability to anticipate the UPC location have also been investigated. To that end, the number of wrong flips of individual items has been analyzed utilizing Fisher's least significant difference method. In general, the results revealed that these packaging characteristics did not significantly affect this measure when handheld or bi-optic scanners were used with the recommended placement.
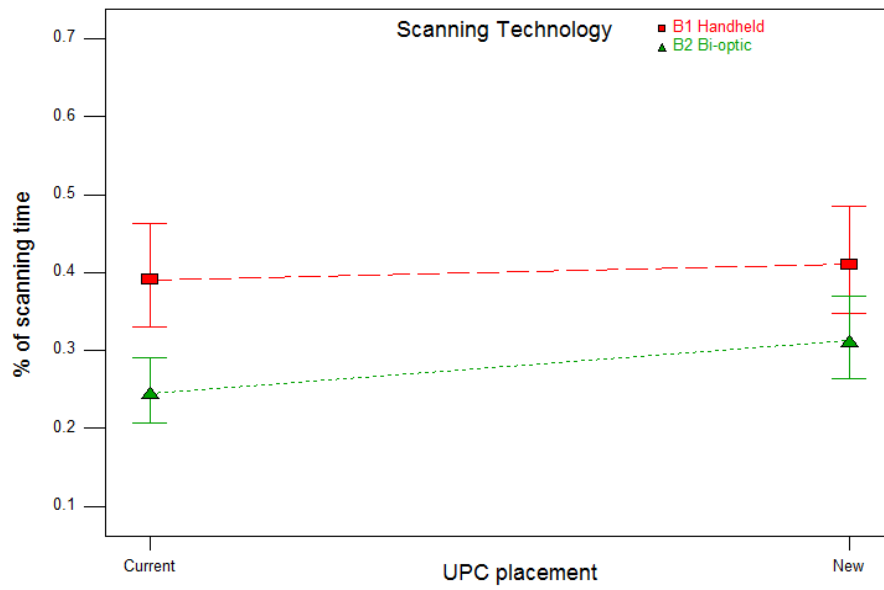
Figure 3-6. The % of the scanning time during which the trunk recorded non-neutral postures, under different combinations of the independent variables. The LSD bars and means are shown.
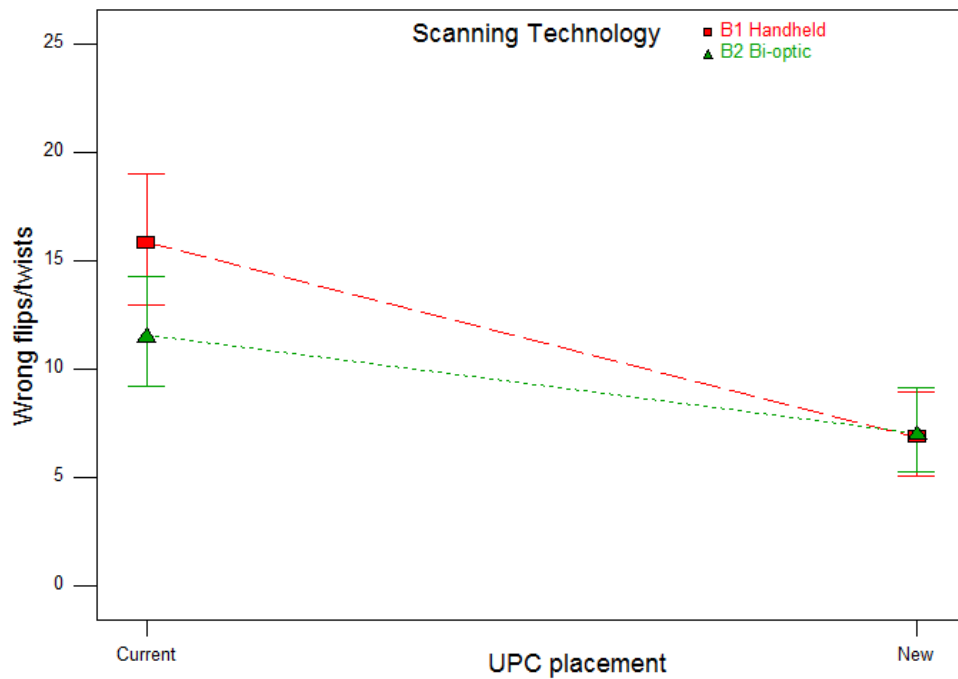
Figure 3-7. The number of wrong flips under different combinations of the independent variables. The LSD bars and means are shown.

3.4.5. Muscle activities

The muscle activities of both the right and left arms of 14 participants were recorded while in session. The muscles of interest were Carpi Radialis and Extensor Digitorum. The percentage of the MVC was measured by dividing the average muscle activities by the maximum voluntary contraction of the participants. The results showed that the task of scanning the items considered in the study did not activate the muscles in a considerable manner; on average it was nearly < 10% MVC for most muscles. Also, the scanning technology and the UPC placement did not significantly affect the muscle activation $F(1,10) <2.0, p > 0.18$ and $F(1,10) <0.60, p>0.45$, respectively. Accordingly, it was decided to not measure the muscle activities of the remaining participants. This decision eliminated the potential restrictions on participants' movements.

3.4.6. Experimental survey

The experimental survey was directly administered after the experiment; a 5-point Likert scale was used to measure participants' perceptions regarding their experience. The results showed that the type of scanning technology used significantly affected the perception of participants regarding the level of randomness with which they checked the items out $F(1, 28) =7.6, p = 0.01, \eta_p^2= 0.21$ Specifically, the participants who used the bi-optic scanner recorded higher Likert scale responses. The perception regarding the effect of the ease of finding the UPC on the checking out time was also investigated. The results revealed that the UPC placement significantly affected this perception $F(1, 28) = 6.5, p = 0.02, \eta_p^2= 0.19$. In particular, the new placement significantly reduced the Likert scale responses for the handheld scanner. These results are shown in Figure 3-8.
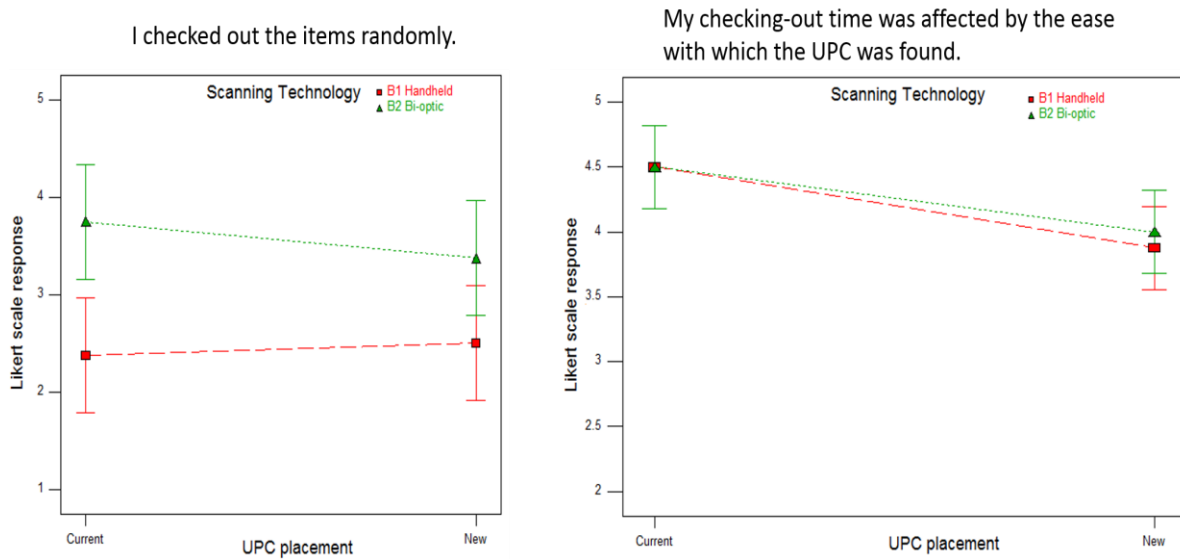
Figure 3-8. Sample of participants' Likert scale responses under different combinations of the independent variables. The LSD bars and means are shown.

3.5. Discussion

While in SCO process, the users interact with the package and the SCO system. To perform the checkout process, the users must find and scan the UPC, usually located on the package, and then they can complete the process of payment and bagging. Accordingly, the scanning technology and the UPC location are considered to be key factors affecting the SCO performance. In this study, the scanning technology, either bi-optic or handheld, and the UPC placement method, either the current or the recommended methods, were tested. To that end, many measures were utilized to study the effect of these factors on SCO performance. These measures were the total scanning time, scanning time of individual items, trunk posture, total number of wrong flips, number of wrong flips of individual items, muscle activities, and user preferences.

The scanning technology demonstrated its ability to significantly affect the total scanning time. The bi-optic scanner in particular, reduced the total scanning time noticeably.

The videos showed that when the bi-optic scanner was used, the users took the advantage of its two-directional scanning capability, since they had the option of scanning the barcodes without locating them. Nonetheless, in the case of the handheld scanner, the users had to locate the UPCs. The UPC placement did not affect the total scanning time significantly. However, Figure 3-4 shows that the scanning time was decreased when the new UPC placement was used, especially when using the handheld scanner. Considering that the users had previous experience with the current placement, and that the new placement was different, the new placement should have the potential for considerably improving the total scanning time of the handheld scanner in the long run.

The UPC placements and the use of scanning technology can affect the scanning time of individual items, and this effect is influenced by the current UPC placement and package characteristics. For light, thin items (1 and 2), changing the location of the UPCs from the current placements to the recommended one has significantly reduced the scanning time of these items. However, changing the UPC placement of item (11) has significantly increased the scanning time, as the new placement was less accessible by both scanners. Changing the UPC placement of a lighter tub (17) to the recommended placement has significantly reduced the scanning time. More items have been affected by the scanning technology as shown in the results section, and this indicates that the contribution of the scanning technology to the total scanning time override the UPCs placement. However, the contribution of the UPC placement is expected to increase over the long run as the users be more familiar with the new placement. Multiple means comparisons (Figure 3-5) showed that package weight and dimension played a role in influencing the scanning time of individual items. Specifically, larger and heavier multipacks (5, 6) required more scanning time than other multipacks, and even other checked

items. Within each group, items with approximately the same size and weight, e.g., 1 and 2 recorded the same scanning time under different combinations of UPC placement and scanning technology in use. Accordingly, these factors should be controlled when determining the proper placement of UPCs of different items.

Also, the scanning technology showed its ability to significantly affect the trunk posture. The bi-optic scanner in particular, resulted in a reduced amount of the exposure to non-neutral trunk posture compared to the handheld scanner, as shown in Figure 3-6. These results are explained by observing the tendency of the handheld scanner's users to bend their trunks to scan the items in the cart, and to stay in this posture while scanning other items. However, in the case of the bi-optic scanner, the users were moving between the cart and the scanner with a combination of flexion and lateral bending postures, so they did not exhibit static trunk postures. The UPC placement had no significant effect on the trunk posture since the users checked the items using the same techniques regardless of the UPC placement used.

Necessity of twisting/flipping the checked out items is considered to be a drawback of the checking out process since it can lead to frustrating users who are trying to find the barcodes. The results showed that the UPC placement significantly affected the total number of wrong flips/twists performed to find the barcodes. The recommended placement has led to a considerable reduction in wrong flips for both scanning technologies, as shown in Figure 3-7. Consequently, the universal location of the UPCs has considerably improved the ability to anticipate the location of the UPCs. On the other hand, users had some difficulties in anticipating the UPCs' locations when the current placement was used because barcodes were placed at different locations even for similar items.

The scanning technology did not significantly affect this measure, but with the current placement the users who used the bi-optic scanner performed fewer wrong flips than those who used the handheld scanner. This is as a consequence of relying on the bi-optic scanner multi-directional scanning capability, since the items can be scanned without detecting the barcodes, while for those who used the handheld scanner, it was required to flip the items to find the barcodes. Yet, with the recommended placement, both the handheld and bi-optic scanners resulted in a smaller number of wrong flips compared to using the current placement, as shown in Figure 3-7. Consequently, the recommended placement has improved the performance of the scanning process for both scanning technologies. It was also shown that both technologies resulted in approximately the same number of flips when the new placement was used.

Packaging characteristics and current UPCs placement can influence the effect of changing the UPCs placement to the recommended ones with respect to the number of wrong flips. The recommended placement has significantly improved the ability to anticipate the UPCs of items 1, 2, 3, 6, and 17. Changing the UPC placements of thin items (1, 2) to the recommended one significantly reduced the number of wrong flips. Changing the UPC location of a small box (3) from its side to the recommended location significantly improved the anticipation of the UPCs, while changing the UPC location of larger and heavier box (4) from the bottom to the same recommended placement did not significantly either improve or degrade the ability to anticipate the UPC location. Changing the UPC location from the top of a multipack (6) to the recommended placement improved the ability to anticipate the location of the UPC, while changing the UPC placement of other multipacks, with different weights and volumes, from the bottom to the recommended placement did not affect this measure. Changing the UPC location of the lighter tub (17) from its side to the recommended placement

improved the anticipation of the barcode, while changing the UPC placement from the bottom to the recommended placement did not significantly affect this measure of a heavier tub (16). It's worth mentioning here that items recorded significant decreases in the number of wrong flips, also recorded significant decreases in the scanning time. This is an evidence of the importance of UPCs anticipation to improve the scanning time.

The total number of wrong flips required can be directly correlated with the scanning time in a positive linear relationship, as shown in Figure 3-9. Simple linear regression was utilized to approximate this relationship, and the following linear equation was generated with a linear correlation coefficient r (32) = 0.68, and $p < 0.01$ for both regression coefficients. This relationship, even though linear, does not have a strong positive correlation, as reflected in the low r value. This can be explained by considering users' practices while looking for the barcodes. In some situations, it was observed that users who flipped the items quickly had a greater tendency toward making wrong flips than those who flipped the items at moderate speed.

Scanning time (second) = 79.2 + 2.4 (wrong flips)   (3-1)
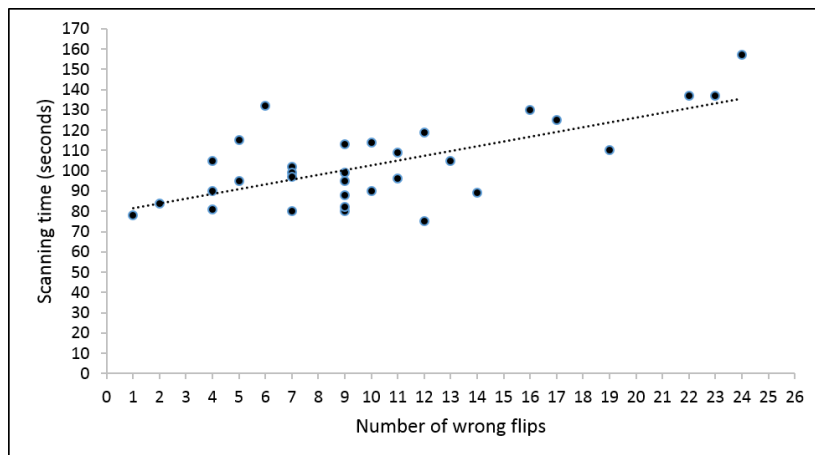
Figure 3-9. Number of wrong flips with the scanning time scatter plot.

Participants were observed during the scanning task to investigate their ability to anticipate the UPCs. In general, the current placement of the boxes and tubs were either on the bottom (4, 16) or on the side (3, 17). The barcodes on the bottom were hard to find and scan, especially when using the handheld scanner. However, the barcodes on the side were unlikely to anticipate when both technologies were used. The current placement of the multipacks were either on the bottom (5, 7, and 8) or the top (6). Placing the UPC on the bottom made it difficult to see and scan the barcode, especially when the hand-held scanner was used. On the other hand, for an item whose UPC was placed on the top, many participants unintentionally covered the barcode with their hands while trying to scan the UPC when using either scanning technology. With respect to thin items, the current UPC locations were either on the middle back (2) or on the edge (1). It was hard to find the UPC located on the edge since this location was not anticipated. Even though many participants had no problem in finding the barcode placed on the middle back, the ability to anticipate this location was degraded when an item with the barcode located on the edge was scanned first. In general, the new placement has led to more accessibility and better anticipation for the UPCs, especially when the handheld scanner was used.

The initial analysis of the arm muscles showed that the scanning task did not significantly activate the muscles because heavy items were not included in this study for reasons of safety. The analysis also showed that neither the choice of scanning technology nor the UPC placement significantly affected the muscle activations. This can be explained by the participants' tendency to grab and hold the items regardless of the scanning technology and UPC placement used.

The results of the experimental survey revealed that the scanning technology has significantly affected the perception of users with respect to the way they checked out the items. The users who used the bi-optic scanner tended to scan the items randomly because the scanned items were moved from the shopping cart into the bagging area. However, when the handheld scanner was used, in general the users scanned the items lying close to one another in a precedence order to make sure they did not forget to scan any item and thus reduce the scanning time. Also, the UPC placement led to a significant change in the user's perception regarding the effect of the ease with which UPCs can be found during self-checking activity. Generally, when the current placement was used the users had the same perception regardless of the scanning technology used. However, when the new placement was used the users' Likert scale responses were lower for both technologies, as shown in Figure 3-8. Accordingly, the recommended placement reduced the users' perception with respect to the dependency of checking-out time on the ease of locating the UPCs. This can be related to the reduced scanning time when the new placement was used; the diminished perception of dependency reflects the reduced contribution of the role of finding the UPCs to the scanning time. Accordingly, the recommended placement has proven to be suitable for both scanning technologies. Furthermore, the participants reported that the arrangement of the items did not significantly affect their performance, in turn supporting the used arrangement.

3.6. Conclusions

In this study two scanning technologies and two UPC placement techniques were tested. Also, the compatibility of the UPC placement with the scanning technologies was investigated. To that end, many measures were utilized including the total scanning time,

individual items' scanning time, the total number of wrong flips, number of wrong flips of individual items, muscle activation, trunk posture, and users' preferences.

In conclusion, the bi-optic scanner has proven itself to be an efficient scanning technology, since it resulted in a considerable decrease in the total scanning time and scanning time of many items. It can also be considered to be an ergonomically friendly scanning technology since the exposure to the non-neutral trunk posture was conspicuously reduced. In general, the resting posture is associated with the highest level of comfort, and as the posture changes toward non-neutral the comfort level declines [38]. Accordingly, reducing the exposure to the non-neutral posture of the trunk is preferred. This conclusion was supported by users' preferences obtained from the general survey toward using the bi-optic scanners when considering SCO.

The recommended UPC placement showed considerable capability for reducing the scanning time of many items. It also improved the capability for anticipating the location of the barcodes, which translated into a significant decrease in the total number of wrong flips regardless of the scanning technology used. In particular, the new placement has considerably reduced the number of wrong flips of many items covering the categories of thin items, boxes, multipacks, tubs, and bags. This result was confirmed by the informal interview responses, since all the participants were in favor of having a universal location of the UPCs on different items. In general, the total number of wrong flips correlates to the total scanning time with a positive linear relationship, and this shows the importance to the checking out performance of anticipating the location of the barcodes. Accordingly, the reduced number of wrong flips associated with the new placement was usually accompanied by a shorter scanning time.

To ensure that an efficient recommendation for the UPC placement is proposed, packaging characteristics, including weight and dimension should be considered as factors affecting the scanning process. The decision of changing the current UPC placement should be made within the context of these characteristics, so the recommended placement can moderate their influences on the scanning process. The effect of changing the UPC is influenced by the current UPC location, so different UPCs locations should be compared with the recommended placement while considering same package.

The scanning practices have been affected by the scanning technology used; the users specifically tended to check the items in a random manner when the bi-optic scanner was used. Also, static trunk posture was experienced when using the handheld scanner. The users adapt their own practices to accommodate the scanning technology and such accommodation is usually affected by the design of the scanning technology and the intention to scan all items quickly. Users may thus involuntarily put themselves into a non-neutral trunk posture.

In general, the bi-optic scanner is recommended for SCO stations, especially when light grocery items are considered. In addition, the new UPC placement technique is recommended, since it will either significantly improve or at least not degrade the overall scanning time and barcode anticipation. The new placement suits both scanning technologies and will have the potential to improve the checking out process, regardless of the scanning technology used, especially after a long time of use. In addition, changing the location of the UPCs is applicable without a considerable cost, especially when there is no need to redesign the graphics of the package.

3.7. Future work

The differences in trunk posture motivate additionally considering the back muscles in future studies because of their potential activation. Also, a multi-criteria decision making model can be built to determine the best combination of the UPCs placement, and scanning technology for specific purposes. Since the study considered light grocery items for SCO, different items with heavier weights might be considered for studies of both self-checking and cashier-related stations. Further investigation of the effect of packaging characteristics on the decision of UPC placement and scanning technology in use can be conducted.

3.8. Further Analysis

To further investigate the effect of the UPC placement and the scanning technology in use on the dependent variables considered in this study, effect size measures were calculated. Effect sizes associated with significant results are represented in terms of partial eta squared (η_p^2) [40]. Values of 0.0099, 0.0588, and 0.1379 indicate low, medium, and high effect sizes, respectively [41]. The previous results showed that the bi-optic scanner has significantly reduced the total scanning time and exposure to non-neutral posture with large effect sizes (η_p^2 = 0.43, and 0.30, respectively). The universal placement of the UPCs has also significantly improved the ability to anticipate their locations with a large effect size (η_p^2=0.38). This indicates the considerable impact of the scanning technology and UPC placement on supermarket self-checkout with respect to the previous dependent measures. The following subsection shows the detailed statistical results of the individual items with the associated partial eta squared values.

3.8.1. Statistical details for individual items

Table 3-2 shows the effect of the UPC placement and the scanning technology on the individual items' scanning time and the number of wrong flips. Additional information is included in Tables 3-3 and 3-4 to show the effect sizes associated with the significant effects of the independent variables of UPC placement and scanning technology.

The UPC placement has significantly affected the scanning time for items 1, 2, 11, 17, and 21 (Table 3-3), with large effect sizes reported in the scanning time of the previous items with exception of 21, which is associated with a medium to large effect size. The new UPC placement has resulted in a significant increase in the scanning time of item 11, which indicates the inappropriateness of the new placement of this item.

The scanning technology has significantly affected the scanning time of items 3, 7, 8, 9, 10,11, 12, 14, 15, 18, 19, 20, and 21 with large effect sizes reported for these items with the exception of item 15, which is associated with medium to large effect size. The Bi-optic scanner has reduced the scanning time for the previous items.

For the number of wrong flips (Table 3-4), the UPC placement has significantly affected this measure for items 1, 2 ,3, 6, 12, 17 and 18, with large effect reported when changing the current UPCs placement for all these items with the exception of items 12 and 18, which are associated with medium to large effect size. The scanning technology has been shown to have no effect on the number of wrong flips for the items under study.

Table 3-3. Detailed statistical results for Table 3-2. Part 1

Scanning Time					
Item Number	UPC location $F(1,28)$	UPC location (p-value)	partial eta squared η_p^2	Scanning technology $F(1,28)$	Scanning technology (p-value)	partial eta squared η_p^2
1	9.17	0.01*	0.25	0.91	0.35	----
2	5.44	0.03*	0.16	2.78	0.11	----
3	0.74	0.40	----	9.45	0.01*	0.25
4	0.15	0.70	----	2.80	0.11	----
5	0.76	0.39	----	2.71	0.11	----
6	2.73	0.11	----	0.30	0.59	----
7	0.83	0.37	----	14.19	< 0.01*	0.34
8	0.01	0.92	----	4.93	0.04*	0.15
9	0.48	0.49	----	4.33	0.05*	0.13
10	0.32	0.59	----	5.06	0.03*	0.15
11	5.83	0.02***	0.17	5.83	0.02*	0.17
12	1.11	0.30	----	14.86	< 0.01*	0.35
13	0.02	0.88	----	1.22	0.28	----
14	0.48	0.49	----	5.54	0.03*	0.17
15	0.96	0.34	----	3.10	0.09**	0.10
16	0.37	0.55	----	2.04	0.17	----
17	4.90	0.04*	0.15	0.04	0.84	----
18	2.08	0.16	----	5.77	0.02*	0.17
19	0.06	0.81	----	6.97	0.01*	----
20	0.56	0.63	----	5.65	0.04*	0.17
21	3.07	0.09**	0.10	13.01	< 0.01*	0.32
22	2.57	0.12	----	2.57	0.60	----
23	1.93	0.18	----	1.34	0.26	----

* New UPC/ Bioptic scanner significantly reduce the scanning time or number of wrong flips.
** New UPC/ Bioptic scanner marginally reduce the scanning time or number of wrong flips.
***New UPC/Bioptic scanner significantly increase the scanning time or number of wrong flips.

In this study, a standardized location for the UPCs was shown to improve the ability to anticipate their locations for many items, as shown in Table 3-2. However, other standardized placements may result in better anticipation. For some items, the new/universal placement may increase their scanning time, while it may decrease the scanning time for other items. Accordingly, the decision of changing the UPC location should be taken with considerations of the current UPC placement, the items' characteristics, and the scanning technology in use to ensure the suitability of these changes. Multiple standardized UPC locations could be tested for each packaging type to produce efficient placement guidelines.

Table 3-4. Detailed statistical results for Table 3-2. Part 2

Number of wrong flips						
Item Number	UPC location $F(1,28)$	UPC location (p-value)	partial eta squared η_p^2	Scanning technology $F(1,28)$	Scanning technology (p-value)	partial eta squared η_p^2
1	21.29	< 0.01*	0.43	1.21	0.28	----
2	8.54	0.01*	0.23	0.74	0.40	----
3	33.35	< 0.01*	0.54	0.41	0.53	----
4	0.62	0.44	----	0.00	>0.99	----
5	0.72	0.40	----	0.00	>0.99	----
6	6.50	0.02*	0.19	0.02	0.89	----
7	1.00	0.33	----	1.00	0.33	----
8	2.00	0.17	----	0.00	>0.99	----
9	2.17	0.15	----	2.17	0.15	----
10	0.61	0.44	----	0.61	0.44	----
11	0.82	0.37	----	0.00	>0.99	----
12	3.35	0.08**	0.11	1.04	0.32	----
13	0.05	0.82	----	1.34	0.26	----
14	0.17	0.68	----	0.67	0.42	----
15	1.00	0.33	----	1.00	0.33	----
16	0.00	> 0.99	----	0.09	0.77	----
17	23.20	< 0.01*	0.45	0.14	0.71	----
18	3.67	0.07**	0.12	2.07	0.16	----
19	0.59	0.45	----	0.59	0.45	----
20	0.22	0.64	----	0.89	0.35	----
21	1.00	0.33	----	1.00	0.33	----
22	0.33	0.57	----	0.33	0.57	----
23	0.19	0.67	----	0.19	0.67	----

* New UPC/ Bioptic scanner significantly reduce the scanning time or number of wrong flips.
** New UPC/ Bioptic scanner marginally reduce the scanning time or number of wrong flips.
***New UPC/Bioptic scanner significantly increase the scanning time or number of wrong flips.

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CHAPTER 4. AN AFFORDANCE-BASED MCDM APPROACH FOR PACKAGING EVALUATION

Modified from a paper submitted to Packaging Technology and Science Journal[1]

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Abstract

Affordances provided by packages determine packaging usability by facilitating interaction between users and packages, so it is important to evaluate packaging designs with respect to their ability to provide particular affordances. This paper introduces a multi-criteria decision-making (MCDM) model for evaluating packaging affordances. Thirty-eight requirements serving as evaluation criteria were elicited from the literature and restated in terms of affordance properties such as intuitiveness, responsiveness, without thought, clear information, and symbols. These properties represent the affordances required to perform tasks of purchasing, storing, opening, reclosing/reopening, handling, unpacking, and disposal of packages. Four experts verified the elicited criteria for four products and then, using the swing weighting method, assessed their relative importance. The overall affordance level for each alternative package was determined, and a sensitivity analysis was conducted to investigate the robustness of the model. A usability testing study with 37 participants was conducted to validate the model. This paper revealed that different products may require different affordances and necessitate exclusive evaluation. The model is an evaluation tool that can be

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used at the early stages of design and can also direct designers' efforts based on affordance importance.

4.1. Introduction

Packaging supports the basic functions of containing, preserving, transporting, and marketing products [1, 2]. The life cycle of a package occurs over a collection of different stages that depend on the contained product and packaging type. During this cycle, users interact with packages as they purchase, check out, handle, open, and dispose of empty packages. In fact, user satisfaction can be affected by package attributes, which benefit both in point-of-sale and the after-purchase instances [3]. Since such satisfaction is ultimately sensitive to occurrences of problems/difficulties experienced over the product life cycle, both negative and positive implications related to products, manufacturers, or other stakeholders are to be expected. This mandates package designers to comprehensively focus on instances in which users interact with their packages to achieve and maintain satisfaction. Packaging designs should thus be evaluated with respect to ensuring user satisfaction over package life cycles.

A package will have both visual and informational components [4] that provide information about the contained product and can affect users during its life cycle. The information obtained from a package is usually linked to affordances stored in a user's long-term memory. The word "affordance" was introduced by Gibson, who stated that an affordance represents an action available in the environment to an individual regardless of its ability to be perceived [5]. Users rely on perceived affordances to decide on actions that should be performed to accomplish specific tasks, and these affordances can guide users to perform specific tasks envisioned by packaging designers at different stages.

Designers strive to design a package that provides users with the characteristics required to facilitate desired tasks. In practice, these requirements can be represented in terms of affordance properties such as intuitiveness, responsiveness, without thought, information clarity, and symbols (Table 4-1). At each stage of the life cycle of a package, various affordance properties should be specified and offered to improve packaging usability. A variety of alternative packages should thus be evaluated against multiple affordance properties that can improve usability. Accordingly, packaging evaluation should be considered as a multi-criteria decision-making (MCDM) problem, one that permits simultaneous consideration of multiple required affordance properties.

This paper introduces an MCDM model for evaluating packaging designs based on affordance properties. The proposed model integrates the simple additive-weighting (SAW) method with the swing weighting method. The latter tool is utilized to assess the relative importance of affordance properties. The model determines overall affordance levels for the alternative packages. The remainder of the paper is organized as follows: The related work is presented in Section 4.2. The proposed methodology is presented in Section 4.3. An empirical application of the proposed model is presented in Section 4.4. Discussion and conclusions are presented in Sections 4.5 and 4.6, respectively.

4.2. Related work

Packaging evaluation has attracted many researchers because of its important impact on user satisfaction and product supply chains. For example, packaging performance has been evaluated by introducing a scorecard model that considered consumers as stakeholders involved in the supply chain [6]. A great deal of work focusing on usability to evaluate packaging through its life cycle has also been done. Opening, using, and discarding stages were

evaluated through a usability survey in which users were provided with a rating scale to convey their experience during each stage [7]. Problems related to packaging usability and safety have also been studied in terms of negative impact on user satisfaction related to the competitive advantages of products. Many packaging problems related to "safety, clarity, legibility, visibility, storability, open-ability, reclose-ability, usefulness, and pleasantness" were reported by users at different stages of interaction [8].

To ensure that a package will be usable for different users representing a variety of capabilities, universal design principles have been applied to packaging design [9]. Different flexible packages based on modified universal design principles, including convenience, perceptivity, conveyance of information, ease of opening, structure and graphic design, and equitability have been evaluated [10]. In addition, a usability survey was created to investigate the compliance of different products, including their packages, with universal design principles [11]. With the aim of increasing awareness of package usability, a standard usability evaluation method was introduced that considered the different stages of interactions [12]. To gain more insight into packaging affordances, an affordance-based model was introduced for use in the design and evaluation of medical packaging [13]. Even after extensive efforts have been applied to improve packaging usability, users still commonly experience problems related to packaging usability. Since the perceived affordances determine usability [14], to reduce the number of such problems, affordances provided by packages at various stages should be evaluated and improved [15].

In fact, the term affordance is abstruse and hard to express, making the evaluation process even more difficult. To facilitate dealing with affordances, typical affordance properties have been elicited from basic descriptions of affordances provided in the literature

and used to evaluate products [16]. The concept of affordances has been utilized in product design to help designers improve product usability [16-19].

4.2.1. Packaging evaluation as an MCDM problem

Packaging evaluation is a multi-dimensional problem because of the many affordance properties that must be achieved, making the selection of a best alternative packaging design even more complicated. MCDM methods for handling complexities associated with such problems in a systematic manner [20] are usually used when among many feasible alternatives only one should be selected based on a set of evaluation criteria. In the case of packaging, affordance properties can serve as evaluation criteria.

Many MCDM methods with varying complexities, characteristics, and applications are available. Examples of popular MCDM methods are the analytic hierarchy process (AHP), SAW, elimination and choice expressing reality (ELECTRE), the technique for order of preference by similarity to ideal solution (TOPSIS), and multiplicative exponent weighting [21]. These methods have been applied in different fields, including but not limited to lean manufacturing [22, 23], facility layout [24] and location [25] selection, economics [26], contractor selection [27], tourism [28], social science [29], health care [30], supply chain [31], supplier [32, 33] and personnel [34] selection, energy planning [35] and many others. With respect to packaging science, a framework was proposed for wine exterior packaging design selection using the stepwise weight assessment ratio analysis method [36]. In another situation MCDM was applied to the problem of selecting a packaging machine [37]. Packaging affordance evaluation has not been systematically targeted by MCDM, even with its potential for improving user satisfaction. It would therefore seem beneficial to support packaging science with a reliable and efficient MCDM method for evaluating packaging designs.

Among various MCDM methods, SAW is one of the most frequently used and best-known methods [38], known for its simplicity, i.e., it employs a weighted average using a simple arithmetic mean. It also achieves an advantage over other MCDM methods by proportionally transforming raw data in a linear fashion and preserving the relative order of standardized scores [34, 39, 40]. Such simplicity underlies its popularity as a classical MCDM method [41]. SAW has demonstrated capability for helping make decisions in different fields, including investment [42], geographical information systems [43, 44], personnel selection [34], food choice problems [40], office purchase problems [45], software industry issues [46], power plants [47], facility location [25], and pharmaceutical industry issues [48]. In a comparitive study among eight MCDM methods that included AHP, TOPSIS, and ELECTRE, SAW was shown to perform better than any of the other methods [21]. An empirical study also showed the superiority of SAW over TOPSIS and weighted-product methods in evaluating airline competitiveness [49].

4.3. Methodology

The evaluation process follows the main operational steps of SAW [40], composed of (1) Evaluation criteria, (2) Relative importance of evaluation criteria, (3) Feasible alternatives, and (4) Rating of alternatives against evaluation criteria [50]. To support making a quality decision, these components should be precisely identified. In this model, the elicited affordance properties represent the evaluation criteria that will be used to evaluate each feasible alternative l_i, $i = 1, ..., n$. They will be weighted using the swing weighting method to represent their relative importance with respect to their corresponding affordance A_j, $j = 1, ..., S$. An affordance property related to an affordance A_j is represented by p_{jm}, $m = 1, ..., M$. The following are the detailed calculations required to perform the MCDM evaluation approach.

Step 1: The evaluation criteria and their relative importance should first be identified. The criteria were elicited from previous packaging usability studies and are presented in terms of affordance properties, as shown in Section 4.3.1. The relative importance of each criterion was determined utilizing the swing weighting method, as shown in Section 4.3.2. The evaluation criteria related to affordance A_j can be represented by the vector P:

$$P = \begin{bmatrix} p_{j1} & p_{j2} & p_{j3} & \dots & p_{jM} \end{bmatrix}^T \qquad (4-1)$$

where p_{jm} is an evaluation criterion related to affordance A_j.

Using the MCDM approach, this vector includes the following entities: symbols, responsiveness, without thought, as shown in Table 4-1. The relative importance of these evaluation criteria can also be represented by the vector shown in Equation 4-2:

$$W = \begin{bmatrix} w_{j1} & w_{j2} & w_{j3} & \dots & w_{jM} \end{bmatrix}^T \qquad (4-2)$$

where W_{jm} is the relative importance of evaluation criterion p_{jm} with respect to affordance A_j, that can be purchase-ability, store-ability, open-ability, reopen/reclose-ability, unpack-ability, or dispose-ability.

Step 2: The feasible alternatives should be identified and then evaluated against the evaluation criteria. A seven-point Likert scale will be utilized to rate the alternatives against the evaluation criteria. The alternatives' rate should then be normalized to obtain dimensionless rates as follows:

$$N_{ijm} = \frac{X_{ij}m}{\text{Max } X_{ijm}} \quad \forall\, i \,, \text{for beneficial criteria} \qquad (4-3)$$

$$N_{ijm} = \frac{\text{Min } X_{ijm}}{X_{ijm}} \quad \forall\, i \,, \text{for cost criteria} \qquad (4-4)$$

where

N_{ijm} is the normalized rate of alternative l_i with respect to p_{jm}.

X_{ijm} is the rate of the alternative l_i with respect to p_{jm}.

Step 3: An alternative's score then can be calculated with respect to each affordance using Equation 4-5:

$$V_{ij} = \sum_{m=1}^{M} w_{jm} N_{ijm} \quad , \forall\, i, j \qquad\qquad (4-5)$$

where

V_{ij} is alternative l_i score with respect to affordance A_j.

w_{jm} is the relative importance of property p_{jm} with respect to affordance A_j.

N_{ijm} is the normalized rate of alternative l_i against property p_{jm} of affordance A_j.

Step 4: The overall affordance score for each alternative then can be calculated.

$$V_i = \sum_{j=1}^{S} w_j V_{ij}, \forall\, i \qquad\qquad (4-6)$$

where

V_i is the overall affordance score of alternative l_i.

w_j is the relative importance of affordance A_j with respect to the overall affordance level.

Step 5: Determine the best alternative V_{Best} associated with the highest overall affordance level.

$$V_{Best} = \text{Max}\,_{i=1}^{n}\, V_i \qquad\qquad (4-7)$$

4.3.1. Evaluation criteria for packaging evaluation

The review of several packaging usability studies [7, 8, 10-12, 15] has revealed about 200 user requirements covering the life cycles of packages. These requirements were combined and reformulated into 38 requirements represented in terms of five affordance properties, as

shown in Table 4-1. These properties express the affordances of purchase-ability, store-ability, open-ability, reopen/re-close-ability, handle-ability, unpack-ability, and disposability. This process resulted in an initial set of evaluation criteria that can be used to evaluate different packages, which was further verified by experts to ensure their suitability for particular products. In this study, the evaluation criteria are considered to be beneficial in which achieving these criteria improves the overall affordance level of packages.

Table 4-1. Affordance properties descriptions [16]

Affordance property	Description
Without thought	Without the need to learn and memorize, the user can interact with the package
Intuitiveness	The package can be used without instructions
Symbols	Symbols used to represent the packaging functions and usage are efficient
Responsiveness	The user can react to the packaging components immediately
Clear Information	The information provided is sufficient and helpful

4.3.2. Weights of importance of the evaluation criteria

After evaluation criteria are identified, they should be assigned weights to represent their relative importance. These weights can either be assigned directly by decision makers or by using a weighting method. In practice, many criteria are expected to be used to evaluate packaging affordances, making the direct assignment of weights impractical. The swing weighting method is one of the most efficient methods that can be used to estimate the weights [51]. It requires a decision maker to assign a score of 100 to the most important criterion and to assign lower scores to the other criteria swinging from worst to best level relative to the most important criterion [52]. The swing method, usually used to calculate relative weights of

the decision criteria when performing multi-attribute value theory [53], can also be integrated with other MCDM methods such as AHP [54].

The operation of the swing weighting method is as follows [55]. To visualize the evaluation problem effectively, it is structured in terms of an objectives hierarchy diagram that organizes relationships in terms of a main goal, objectives, and evaluation criteria considered in the problem. The highest level in this hierarchy represents the main goal of maximizing the overall affordance level, the intermediate level of the hierarchy represents the objectives of maximizing the affordance scores at different stages, and the lower level consists of the evaluation criteria related to the objectives. A presentation of an objectives hierarchy is shown in Figure 4-1.

The evaluation criteria under each objective are then weighted using the swing method to calculate their relative importance. They are initially ranked according to their importance to the corresponding affordances. The first ranked criterion is then assigned a score of 100, while the second ranked should be assigned a value less than 100, indicating its relative importance compared to the first-ranked. As the process continues through the rest of the criteria, the assigned scores decrease. The weights of the criteria are then calculated by normalizing the assigned scores by the total scores as shown in Equation 4-8 [52]:

$$w_{jm} = \frac{z_{jm}}{\sum_{m=1}^{M} z_{jm}} \; \forall \, j \qquad\qquad (4-8)$$

where

w_{jm} is the relative importance of evaluation criterion p_{jm} with respect to affordance A_j, such that $\sum_{m=1}^{M} w_{jm} = 1$ and $0 \leq w_{jm} \leq 1 \; \forall \, j$.

Z_{jm} is the corresponding swing score.

M is the number of the evaluation criteria related to affordance A_j.

The relative importance of the objectives in achieving the main goal of maximizing the overall affordance level should then be weighted using the swing method. The weights of importance are calculated using Equation 4-9:

$$w_j = \frac{Z_j}{\sum_{j=1}^{S} Z_j} \qquad (4-9)$$

where

w_j is the relative importance of affordance A_j , such that $\sum_{j=1}^{S} w_j = 1$ and $0 \leq w_j \leq 1 \ \forall j$.

Z_j is the corresponding swing score.

S is the number of affordances considered in the evaluation.
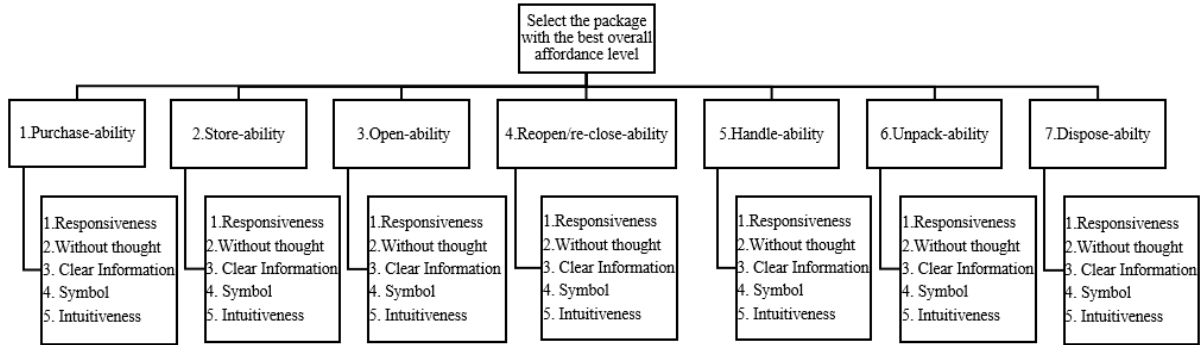
Figure 4-1. A generic hierarchy for packaging affordances.

4.4. Results

The model was applied by experts recruited to verify and properly weigh the evaluation criteria and to evaluate the alternative packages against these criteria. The resulting outcomes of the model were the overall affordance levels for the alternative packages. Furthermore, sensitivity analysis was conducted to investigate the robustness of the model. A usability testing study validated these outcomes to confirm the model's capability for distinguishing between different packages.

4.4.1. Empirical application with experts

The proposed model was applied to four groups of food products with two different packages for each group. The packages under each group were selected to have the same brand name and approximately the same amount of content to diminish the effects of potential biases. Four experts in areas of human factors, human computer interaction, and product and packaging design expertise were invited to an evaluation session. Table 4-2 describes the experts recruited in the evaualtion session. The expert evaluations in the study are considered to have the same weight, and the averages of their inputs were used to evaluate the alternative packages. The study was approved by the human subjects' institutional board (Appendix).

Table 4-2. Experts recruited

Expert	Years of experties	Degrees	Age	Expertise
A	14	PhD	39	Human factors, engineering design, Human computer interaction, Product design
B	4	MSc	24	Human computer interaction, Human factors
C	5	MSc	31	Product design (5 yr) and packaging design (1 yr)
D	3	MSc	25	Human factors

The generic affordance properties elicited from the literature were used to form an initial set of packaging evaluation criteria. For each product, the experts were asked to select the affordance properties that are important with respect to facilitating performing particular tasks during the product life cycle. These properties represent the verified set of evaluation criteria, covering particular affordances, for that product. The criteria corresponding to each affordance were then ranked according to their importance by each expert to facilitate the associated task. Each expert was then asked to assign the maximum score of 100 to the first

ranked criterion and lesser proportional scores to the other criteria as explained in Section 3. Equation 4-8 was then used to calculate the relative importance weights. Table 4-3 shows a sample of the experts' inputs in terms of the resulting weights, and Table 4-4 shows the average relative weights of importance of the affordance properties under each affordance.

To support calculation of the overall affordance level, the experts were asked to weigh the importance of providing affordances using the swing method, as shown in Equation 4-9. Table 4-5 shows the average weights assigned to reflect the relative importance of affordances for each product.

Table 4-3. Swing scores assigned by an expert considering the affordance open-ability for product 3 (Egg)

Evaluation criteria	Swing score (Z_{3m})	Local weight (W_{3m})
Responsiveness	82	0.24
Without thought	70	0.21
Clear Information	100	0.30
Intuitiveness	85	0.25

After determining the evaluation criteria and their relative importance, feasible alternatives were identified and evaluated. Two alternative packages were considered for each product type, resulting in a total of eight different packages. The packages under evaluation are shown in Table 4-6. The experts were randomly assigned to evaluate the alternative packages, and they simulated interaction with the packages at different stages. A seven-point Likert scale was used to rate the alternatives against the evaluation criteria as shown in Table 4-7. The alternatives' priorities with respect to each affordance were then calculated using Equation 4-5. In general, an alternative with a higher priority with respect to a particular affordance is considered to be better than the other alternative relative to that affordance.

Table 4-4. Average weights of importance of affordance properties during products' lifecycles

Elicited requirements	Associated Affordance	Butter	Flour	Egg	Juice
Purchasing	Purchase-ability	Weight	Weight	Weight	Weight
The quantity in the package can be determined and visible.	Responsiveness	0.27	0.32	0.34	0.27
Handle the product properly without reading instructions.	Intuitiveness	0.15	0.24	0.22	0.19
Symbols, labels and pictures listed on the package are comprehensible and helpful	Symbol	0.08	NA	NA	NA
Find the important information; product descriptions, expiry date, nutrition facts, warnings, etc.	Responsiveness	0.26	0.18	0.33	0.25
The information listed on the package is understandable and readable.	Clear Information	0.09	0.12	0.11	0.12
Can understand how to use the product properly without instructions.	Intuitiveness	0.14	0.14	NA	0.18
Storing	Store-ability	Weight	Weight	Weight	Weight
Find the storage instructions and check the expiry date immediately.	Responsiveness	0.21	0.31	0.24	0.34
Can comprehend the storage related symbols.	Symbol	0.13	NA	NA	NA
Can understand and comprehend the storage instructions, before and after first time use.	Clear Information	0.14	NA	0.11	NA
Know the current level of the contained product, "visibility".	Responsiveness	0.21	0.30	0.24	0.31
Can understand how to store this product without reading storage instructions	Intuitiveness	0.20	0.22	0.25	0.19
The package helps me to pay attention during storing tasks	Without thought	0.11	0.16	0.15	0.16
Opening	Open-ability	Weight	Weight	Weight	Weight
Find the opening position and instructions easily.	Responsiveness	0.28	0.30	0.23	0.26
The package helps me to pay attention during opening tasks.	Without thought	0.09	NA	0.20	0.13
Opening instructions and methods are obvious.	Clear Information	0.18	0.21	0.25	0.25
Symbols and pictures related to the opening task are helpful and comprehensible.	Symbol	0.13	NA	NA	0.10
Can understand how to open the package correctly without reading the opening instructions.	Intuitiveness	0.31	0.49	0.32	0.26
Reopening/reclosing	Reopen/reclose-ability	Weight	Weight	Weight	Weight
The package helps me to pay attention during reopening/reclosing.	Without thought	NA	0.19	0.15	0.17

Table 4-4 Continued

Can understand the reopening/reclosing methods without reading instructions.	Intuitiveness	0.28	0.27	0.26	0.29
Symbols and pictures related to reopening and reclosing tasks are helpful and comprehensible.	Symbols	0.19	NA	0.12	NA
Find the reopening/reclosing features immediately.	Responsiveness	0.27	0.30	0.25	0.26
Reopening/reclosing instructions and methods are obvious.	Clear Information	0.26	0.24	0.23	0.27
Handling	Handle-ability	Weight	Weight	Weight	Weight
Can understand how to handle the package without reading handling instructions.	Intuitiveness	0.34	0.39	0.30	0.33
The package helps me to pay attention during handling	Without thought	NA	NA	0.16	0.14
Symbols and pictures related to handling are helpful and comprehensible.	Symbols	NA	0.19	NA	NA
The handling features can be found immediately	Responsiveness	0.39	0.24	0.26	0.23
Handling instructions are obvious	Clear Information	0.27	0.18	0.28	0.30
Unpacking	Unpack-ability	Weight	Weight	Weight	Weight
Can understand how to unpack/use the product without reading instructions	Intuitiveness	0.27	0.29	0.35	0.27
The package helps me to pay attention during unpacking/usage.	Without thought	NA	NA	0.14	NA
The unpacking features can be found immediately	Responsiveness	0.29	0.24	0.19	0.21
Unpacking/ usage instructions are obvious.	Clear Information	0.20	NA	0.12	0.23
Symbols and pictures related to using/unpacking the product are helpful and comprehensible.	Symbols	NA	0.16	NA	NA
Know the current level of the contained product, "visibility" and how much did I take from inside the package	Responsiveness	0.23	0.31	0.20	0.29
Disposing	Dispose-ability	Weight	Weight	Weight	Weight
Segregation, disposal, and recycle instructions, and reuse options are obvious	Clear information	0.32	0.32	NA	0.27
Symbols and pictures related to disposal, recycle and reuse are helpful and comprehensible.	Symbols	NA	NA	0.14	0.19
The disposal, recycle, segregation, and reuse related features can be found immediately	Responsiveness	0.27	0.33	0.33	0.26
Can understand how to dispose, segregate, recycle, or reuse the package correctly without reading the related instructions.	Intuitiveness	0.41	0.35	0.27	0.28
The package helps me to pay attention during segregation / disposal/ reuse /recycle.	Without thought	NA	NA	0.26	NA

Table 4-5. The mean weights of importance of affordances and their standard deviations

Product	Purchase-ability	Store-ability	Open-ability	Reopen/re-close-ability	Handle-ability	Unpack-ability	Disposal-ability
Butter	0.18 (0.11)	0.18 (0.03)	0.14 (0.05)	0.17 (0.03)	0.09 (0.05)	0.16 (0.07)	0.07 (0.05)
Flour	0.14 (0.09)	0.15 (0.03)	0.15 (0.01)	0.17 (0.01)	0.13 (0.03)	0.16 (0.01)	0.09 (0.05)
Egg	0.12 (0.10)	0.18 (0.03)	0.15 (0.04)	0.19 (0.05)	0.11 (0.07)	0.16 (0.02)	0.09 (0.05)
Juice	0.12 (0.10)	0.17 (0.03)	0.16 (0.02)	0.17 (0.02)	0.15 (0.03)	0.16 (0.07)	0.07 (0.06)

Table 4-6. Alternative packages
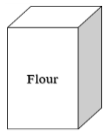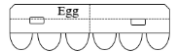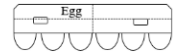
Product	Package #	Packaging description	Dimensions L*W*H (cm)	WEIGHT (g)	Presentation
1. Butter	1.1	A folding carton box	14*13.5*4	453	
	1.2	A lidded plastic tub	13.5*10.5*9	425	
2. Flour	2.1	A plastic dispenser	18.5*13*25.5	2270	
	2.2	A folded paper bag	15.7*10.9*22.1	2270	
3. Egg	3.1	A foam carton	21* 11*7.5	680	
	3.2	A plastic thermoformed carton	21.5* 11.5*8.5	680	
4. Juice	4.1	A plastic jug	11.5*11.5*27.5	2000	
	4.2	A plastic square bottle	10.5*10.5*25.5	1900	

Table 4-7. The Seven-point Likert scale [56]

Definition	Scale of preference
Very poor	1
Poor	2
Fair	3
Good	4
Very good	5
Excellent	6
Exceptional	7

The overall affordance level of each alternative was then calculated using Equation 4-6, and the package with the highest score was considered the best. Table 4-8 shows the affordance scores for the packages under evaluation.

Table 4-8. Results of the Model

Product	Alternatives	Overall Affordance Raw score	Overall Affordance Normalized score	Overall Affordance Ideal score	Ranking
1.Butter					
	Package 1.1	0.68	0.41	0.69	2
	Package 1.2	0.99	0.59	1.00	1
2.Flour	Package 2.1	0.99	0.61	1.00	1
	Package 2.2	0.62	0.39	0.63	2
3.Egg	Package 3.1	0.91	0.49	0.95	2
	Package 3.2	096	0.51	1.00	1
4.Juice	Package 4.1	0.99	0.54	1.00	1
	Package 4.2	0.83	0.46	0.85	2

The results of the model show the ranking of the alternative packages on the basis of their overall affordance levels. According to the model, Package 1.2 outperformed Package 1.1 with more affordance level recorded. This indicates its capability to provide the affordances required to facilitate the interaction between users and packages. This package recorded higher affordance scores for the individual affordances leading to a higher overall affordance level. For flour, package 2.1 obtained higher overall affordance level and was ranked the first. This package recorded higher scores at all affordances. For eggs, packages 3.1 and 3.2 recorded

affordance levels with a small margin difference. However, Package 3.2 was ranked the first because of having a higher affordance level score. This package recorded higher scores for purchase-ability, store-ability, unpack-ability, and dispose-ability, while package 3.1 recorded higher values for open-ability and reopen/reclose-ability. Packages of juice were also evaluated with the higher affordance level recorded for package 4.1. Table 4-9 shows the detailed affordance scores of the alternative packages.

Table 4-9. Affordance scores

Product	Alternatives	Purchase-ability	Store-ability	Open-ability	Reopen/re-close-ability	Handle-ability	Unpack-ability	Dispose-ability
1.Butter	Package 1.1	0.85	0.71	0.66	0.42	0.68	0.80	0.70
	Package 1.2	1.00	1.00	1.00	1.00	1.00	0.97	1.00
2.Flour	Package 2.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Package 2.2	0.76	0.62	0.73	0.48	0.59	0.66	0.53
3.Egg	Package 3.1	0.82	0.85	0.98	0.98	0.99	0.88	0.89
	Package 3.2	1.00	1.00	0.90	0.93	0.98	0.98	0.98
4.Juice	Package 4.1	0.99	0.93	0.99	1.00	1.00	0.99	1.00
	Package 4.2	0.76	0.76	0.96	0.95	0.85	0.78	0.68

4.4.2. Sensitivity Analysis

Sensitivity analysis is an important part of any MCDM process that relies on decision makers' weights to rank alternatives. This provides a greater understanding of the behavior of the alternatives' ranking as these weights change. Variations between the experts' weights would be expected to cause variations in the resulted affordance scores, so to account for these variations, sensitivity analysis was conducted to investigate the effect of changing the relative importance of the affordances and their properties on the overall affordance level. Sensitivity analysis was conducted for each product, and it was determined that the outcomes of the decision analysis were robust to moderate increases/decreases in the weights on key

affordances and affordance properties. Figure 4-2 shows a sample of sensitivity analysis plots

for product 3 (Egg).
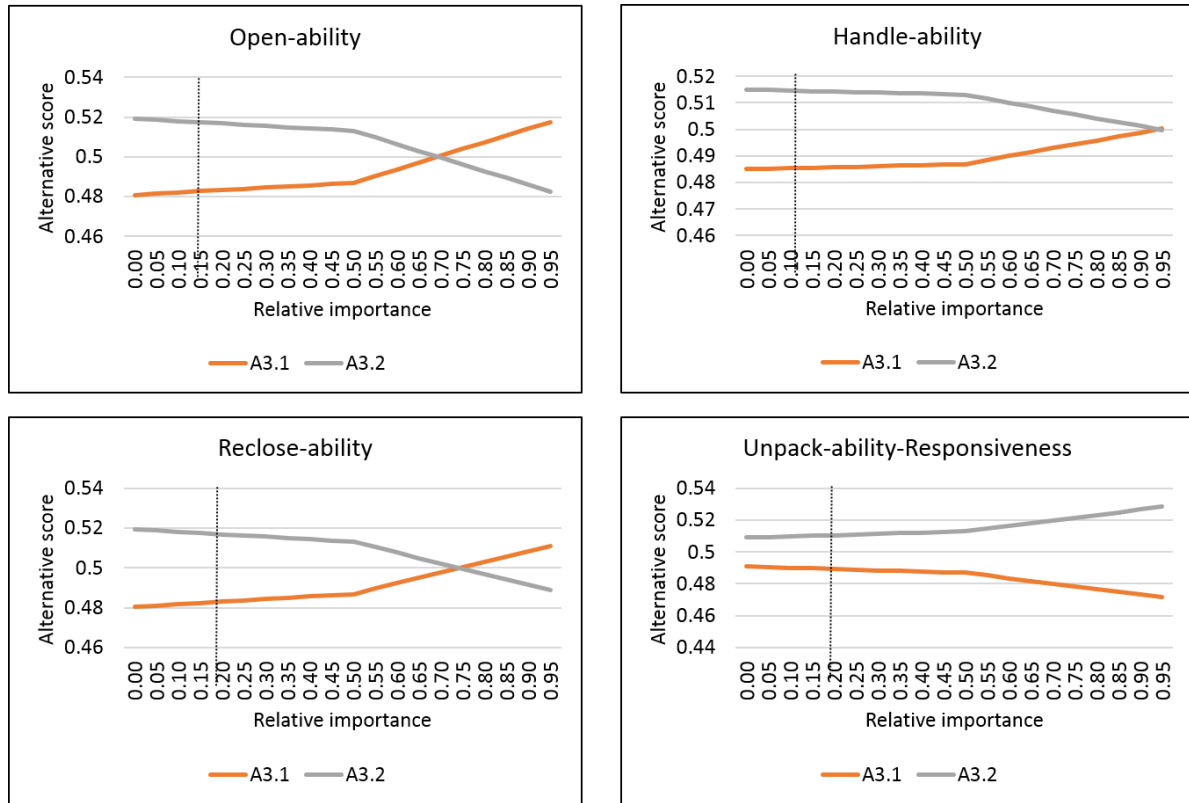
Figure 4-2. Sample of the sensitivity analysis for product 3 (Egg)

The affordance levels of the egg alternative packages were explored as the weights

assigned by the experts change. Changing some weights resulted in changing the alternatives'

affordance level, however, these changes were minimal with exception for open-ability and

reclose-ability. When increasing the weight of open-ability, the affordance level of alternative

3.1 increases till it outperforms alternative 3.2. This indicates the superiority of this alternative

with respect to open-ability. When increasing the weight of importance of handle-ability the

two alternatives approach same affordance levels. Increasing the weight of importance of

reclose-ability leads to an increase in the affordance level of alternative 3.1, while it decreases

for alternative 3.2. In general, the overall affordance scores were shown to change when

changing the weights, these changes, however, did not lead to switching the alternatives' ranking in most cases. Rankings of all products' alternatives were found to be insensitive to moderate changes in experts' weights.

4.4.3. Usability testing study

While affordance scores of the alternative packages were obtained from the model, these outcomes should be validated to ensure the capability of the model to distinguish among different packages. To this end, a usability testing study was conducted. 37 subjects (15 males and 22 females) voluntarily participated in the study and were compensated with extra credit for their time. They all were more than 18 years old (mean = 23.8, SD = 5.4), and seven of them were left-handed. They had frequently (1-3 times a week or more) visited shopping districts and used products independently. No participants had osteoarthritis or rheumatoid arthritis affecting their hands, and none had previous experience as cashiers or in other supermarket-related work. These conditions ensured the representative nature of the study. The study was approved by the human subjects' institutional board (Appendix).

Participants were seated while presented with the packages on a round table. For each product group, two alternative packages were introduced and each participant asked to perform specific tasks, i.e., purchasing, storing, opening, reopening/reclosing, handling, unpacking, and disposal, to simulate normal interaction at different stages. Figure 4-3 shows the main steps of the usability study. At the completion of each task, participants were asked to respond to a statement reflecting their capability related to understanding how to perform that task. A seven-point Likert scale in which 1 was strongly disagree and 7 was strongly agree was used to express their relative agreement to the provided statement. The packages were introduced in a random and counterbalanced manner to ensure the randomness of the experiment.

Participant responses were analyzed using the paired t-test, at 0.05 significance level, to determine the significance of differences between the packages in each group, with results of the analysis shown in Table 4-10. For each product, alternative packages with ≤.05 p-value for a task were considered to be significantly different in terms of their ability to facilitate that task. Comparing these results with the model outcomes permitted investigating the capability of the model in predicting the performance of the packaging designs.
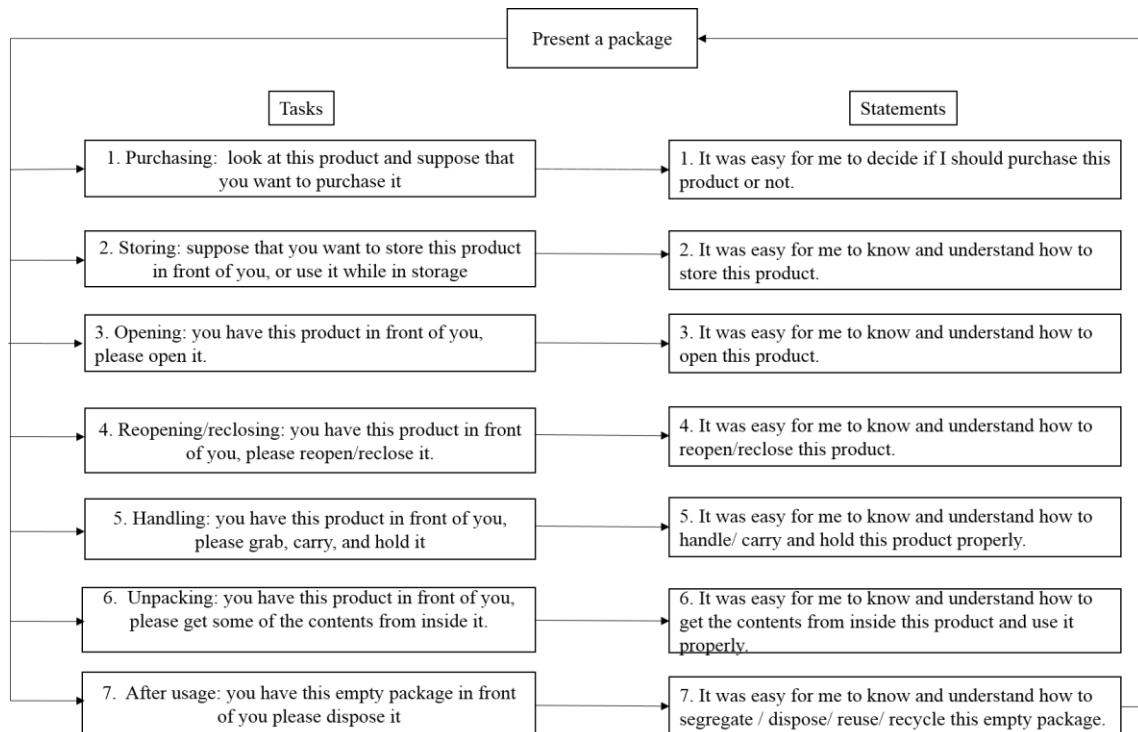
Figure 4-3. Usability testing study flow chart.

4.4.4. Limitations

User requirements were elicited not directly from users but rather from previous packaging usability studies. While these requirements were associated with the affordance properties used to create the initial set of evaluation criteria, these were verified by experts to ensure their suitability. The usability study included young students and was a simulation study conducted in a controlled environment, representing the essential condition of including users

with similar experience in performing similar tasks. Also, the subjects did not perform the

whole chain of the tasks of purchasing, storing, unpacking, and disposing. Food packages were

used as a case study to demonstrate the model. Since these particular packages covered most

of the stages of user packaging interaction, they were selected to ensure generality of the

model.

Table 4-10. Results of usability testing study- means and p-values (standard deviation in parentheses)

Product	Alterna-tives	Purchas-eability	Store-ability	Open-ability	Reopen/re-close-ability	Handle-ability	Unpack-ability	Dispose-ability	Overall
1.Butter	Package 1.1	4.92 (1.4)	4.24 (1.5)	4.95 (1.5)	3.62 (1.7)	5.51 (1.3)	4.81 (1.4)	5.16 (1.7)	4.51 (1.3)
	Package 1.2	5.92 (1.0)	5.39 (1.6)	6.67 (0.5)	6.81 (0.5)	6.17 (1.0)	6.03 (1.3)	5.53 (1.5)	6.20 (0.9)
	P-value	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*	0.24	< 0.01*
2.Flour	Package 2.1	5.95 (1.1)	6.03 (1.6)	6.51 (1.0)	6.54 (0.8)	5.97 (1.2)	6.35 (0.9)	6.00 (1.2)	6.14 (1.0)
	Package 2.2	5.57 (1.4)	5.41 (1.3)	5.35 (1.2)	3.92 (1.9)	4.08 (1.7)	4.89 (1.6)	4.08 (2.1)	4.61 (1.6)
	P-value	0.09	0.06	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*	< 0.01*
3.Egg	Package 3.1	5.76 (1.2)	5.43 (1.6)	6.11 (1.0)	6.49 (0.7)	5.32 (1.4)	6.43 (0.6)	3.41 (1.7)	5.72 (0.8)
	Package 3.2	6.00 (1.1)	6.22 (1.1)	5.62 (1.3)	6.08 (1.1)	5.41 (1.4)	5.84 (1.1)	3.84 (1.7)	5.73 (1.2)
	P-value	0.32	< 0.01*	0.09	0.04*	0.69	< 0.01*	0.13	0.91
4.Juice	Package 4.1	5.57 (1.3)	6.03 (1.1)	6.61 (0.5)	6.57 (0.6)	6.65 (0.5)	6.54 (0.6)	4.81 (1.8)	6.35 (0.8)
	Package 4.2	5.92 (0.9)	6.30 (1.0)	6.32 (0.8)	6.59 (0.5)	4.35 (1.4)	6.08 (0.9)	3.32 (1.4)	5.65 (0.9)
	P-value	0.23	0.15	0.04*	0.79	< 0.01*	< 0.01*	< 0.01*	< 0.01*

Missing data points resulted in a sample size of 35 or 36 for some measures.

4.5. Discussion

This paper proposes an MCDM model for assessing the affordances of products'

packaging. The functionality of the model was demonstrated by evaluating four different

products, each with two alternative packages. Experts with product and packaging usability

expertise participated in an evaluation session, during which they evaluated the alternative

packages. This session resulted in establishing the relative importance of the affordances and their related properties and the priorities of the alternatives under evaluation. Sensitivity analysis was further conducted to understand the effect of changing the weights assigned by the experts on alternatives' ranking.

Traditionally, packaging usability studies focus on packaging open-ability, even though other aspects are undoubtedly important to packaging usability. Store-ability and unpack-ability have particularly been shown to be relatively associated with a high level of importance, as shown in Table 4-5. This in fact supports the utilization of the MCDM approach to handle the multi-dimensional packaging evaluation problem, which involves many affordance properties.

Variations observed in the relative importance of affordances supported the fact that different product types have different importance of affordances, and the relative importance of affordances can be linked to the differences in the contained products. For example, the importance of handle-ability varies among the products under evaluation. For the product Juice the highest importance is for handle-ability, explained by its importance in performing tasks of pouring and carrying a fluid product. The importance of this affordance was also high for product Flour, because this product has a 2.27 kg weight and its handling is critical in performing tasks of opening and unpacking without creating a mess or spillage. The product with the lowest importance of handle-ability was Butter, which even though it is relatively small, it has been assigned high importance for purchase-ability and store-ability. With respect to product Egg, store-ability was associated with a high level of importance because this product should be stored in a refrigerator under specific conditions to keep it fresh and safe. In general, dispose-ability recorded the lowest importance for all products, possibly explained by

the small size of the products under evaluation. Dispose-ability is expected to acquire a higher level of importance when large or toxic products are involved.

For each affordance, a set of properties were elicited from previous studies and further assigned weights of importance by the experts. These properties served as evaluation criteria used to evaluate alternative packages. The weights of these properties represent the relative importance of including them to support particular affordances. The results showed that these weights vary among the products under evaluation in such a way that, if a property is of importance to a particular product, it may not be required or associated with lower importance when considering another product. Accordingly, what applies to one product may not apply to others. For example, the property of symbols is important to support the affordance of purchase-ability of Butter, since symbols indicate its usage and purpose, even though symbols may not be required for other products whose usage is straightforward. A property of clear information is also required to support the affordance of store-ability of Eggs and Butter since they must be stored under specific conditions in a refrigerator; this property is not required for other products for which no strict storage conditions are required.

Prioritizing the affordances creates a road map for their improvement. Designers should focus first on the affordances with the highest weights of importance, and work on properties with high importance to them. For example, the affordance reopen/reclose-ability has the highest level of importance when considering Flour, so this affordance should be given the highest priority when considering improving Flour packaging. To improve this affordance, the property of responsiveness should be the starting point of improvement since it, followed by the property of intuitiveness, will have the greatest impact on this affordance.

Among the affordance properties, intuitiveness, responsiveness, and clear information have the highest level of importance to support the affordances considered in the evaluation. These properties are directly related to the capability of interacting with a package to perform specific tasks without needing to read related instructions, the ability to find related information, and the readability and comprehensibility of such information. The affordance level of packages can therefore be considerably improved if these properties are provided to support affordances with highest importance.

The priorities of alternatives were presented and a sensitivity analysis was conducted to account for the variations among experts' weights. Affordance scores were calculated using the proposed model, as shown in Table 4-9, and differences in affordance properties were responsible for the differences in affordance scores. These scores were used to calculate the overall affordance level of packages, with results showing the ranking of the alternative packages.

The model's rankings were compared to the rankings of the usability testing study to examine its capability for evaluating packages. Alternatives' rankings resulting both from the model and from the usability testing study are shown in Table 4-11. For each group of products, the rankings of alternative packages on the basis of overall affordance level are reported. The overall affordance level rankings of the alternative packages were completely confirmed by the usability testing rankings except for eggs packages. The results of the usability testing study indicate no evidence of significant difference between the two alternative packages. This could be related to the tight defference between the two alternatives' affordance levels as shown in Table 4-8.

Table 4-11. Alternatives' rankings from the model and usability testing study

Product	Alternatives	Model Ranking	Usability testing RankingRanking
1.Butter	Package 1.1	2	2
	Package 1.2	1	1
2.Flour	Package 2.1	1	1
	Package 2.2	2	2
3.Egg	Package 3.1	2	Not distinguishable
	Package 3.2	1	Not distinguishable
4.Juice	Package 4.1	1	1
	Package 4.2	2	2

4.6. Conclusions and future work

An affordance-based MCDM model was introduced as a comprehensive tool for inclusively evaluating package affordances. The evaluation process followed the main structure of the SAW method while incorporating a swing weighting method to determine the weights of importance of evaluation criteria, and these weights then used to determine the priorities of the alternative packages. The functionality of the model was demonstrated on eight different packages representing four products. The rankings of the alternatives resulting from the model were compared to the rankings generated from a usability testing study. The model was able to predict the rankings of the alternative packages except for alternatives 3.1 and 3.2. However, these two alternatives recorded close affordance scores resulted from the model and the usability testing study, indicating no considerable differences between them. In general the model was capable of distinguishing between packages with different affordance levels.

The application of the MCDM concept to packaging evaluation is required to support consideration of multiple aspects of packaging design. Structuring the evaluation problem as an MCDM problem facilitated the consideration of 38 affordance properties representing seven main affordances.

This is the first study of its kind to evaluate packaging based on affordance properties. Using this model will allow tracking affordance properties provided by packages and tracing their effects on affordance level. While the model is suitable for packaging designers because it can be conveniently used for improving and evaluating different packages, it requires proper identification and weighting of the affordance properties. The proposed model is general enough to be applied to any packaging type without the need for significant changes. It is particularly useful for improving usability of a novel and smart package that may be problematic for users. The model may also help in achieving a systematic design of frustration-free and user-centric packages, since it allows incorporating user requirements with respect to multi-packaging perspectives.

Because of the potential impact of packaging affordances on usability, their management and evaluation are important at different points during product life cycles. To ensure building an efficient packaging design, different product life-cycle stages should be considered as sources for providing needed affordance properties. Different characteristics of the contained products may yield different properties that may vary in importance, so exclusive evaluation of alternative packages is recommended for particular products, since what applies to one product may not be applicable to others.

Prioritizing affordances and their properties can direct attention of designers to important aspects of packaging. Designers should direct more resources to improving affordances with high levels of importance. For example, the affordance of reopen/reclose-ability for the Egg is associated with the highest level of importance, so improving this affordance would have a significant impact on the overall affordance level. The resources assigned to improve this affordance could then be distributed to improve various properties

based on their weights of importance. Intuitiveness is associated with the highest level of importance and this necessitates directing more resources to its improvement. This ensures the proper assignment of the resources dedicated to improving packaging design.

The focus of the model was on affordances provided by packaging designs. To ensure the comprehensibility of the model, capability of performing packaging tasks should be further considered. The model can be used as an attention-directing tool during early stages of design by predicting the affordance levels of different packaging designs. The connection between affordance properties and packaging features can be structured by using an affordance structure matrix. This would allow an affordance-based packaging design.

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CHAPTER 5. A DESIGN FOR AFFORDANCES FRAMEWORK FOR PRODUCT PACKAGING: FOOD PACKAGING CASE STUDY

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Abstract

Since affordances provided by packaging features play a major role in facilitating user packaging interaction, it is important to integrate the concept of affordances into the packaging design process and to understand the interrelationships between packaging features and affordances. A framework is proposed for linking user requirements to packaging design features utilizing the concept of affordances. The framework is accomplished in two main steps; first, determine the affordances required to facilitate performing packaging-related tasks, and second, link these affordances to packaging features. Previous packaging usability studies were reviewed to elicit requirements in terms of affordance properties such as intuitiveness, responsiveness, and clarity of information. The elicited properties represent the affordances of purchase-ability, store-ability, open-ability, reopen/reclose-ability, handle-ability, unpack-ability, and dispose-ability. An affordance structure matrix (ASM) was built to link user requirements, represented by affordance properties, to packaging features, and to appraise the links between them. To demonstrate its functionality, the framework was applied to assessment

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of a food packaging design. Further, a usability study conducted with 37 users agreed with the framework outcomes. The framework systematically incorporates user requirements for affordances into the design stage, thereby allowing modifications of packaging features to improve packaging designs based on affordance measures.

5.1. Introduction

Product packaging is a growing global industry that supports logistical and marketing functions of business. It at present is unlikely to find products without packaging because of packaging's role in supporting a product supply chain and providing end users with protected and safe products. Packaging is perceived as an added-value element of products, even though it may contribute considerably to a product's cost. Roles of packaging have evolved as a response to evolutionary changes in manufacturing technologies, regulations, and lifestyles. In general, an ideal package should contain, protect, transport, and market products [1, 2], while presenting no significant usability difficulties.

The life cycle of product packages is comprised of several different phases determined by the product's nature. Users are expected to be involved with these packages and perform specific tasks during these phases, including buying, opening, handling, and storing, and a user's perception may be affected by problems and difficulties experienced during these phases. User satisfaction can therefore be improved by suitable facilitation of the tasks performed during the product lifecycle.

A package is comprised of both physical and informational features [3] such as size, shape, color, brand, surface texture [4], typography, illustrations, graphics [5], materials, geometry, symbols, labels, and signs. Such features provide information about the contained

product and can affect the ease of use during its life cycle. Specifically, the information conveyed by these features can determine user actions when interacting with packages.

In practical terms, interaction between users and packages can be characterized by four main elements: the user, the task to be performed, packaging features, and the information obtained from these features as follows [6]. To perform a specific task, users first observe information characterized by various packaging features such as size, shape, labels, color, and warnings. This information is then used as input to senses such as vision, touch, and hearing, then processed and transformed into internal representations. After then, users begin to recognize and assign meanings to the transformed information; internal presentations are usually associated with perceived affordances stored in a user's long-term memory. The implications of using the packaging features are then compared to the intended user's task. Finally, users' thoughts are translated into actions to accomplish the intended task, with this cycle repeated till the task is performed.

Interaction can be described as a system comprised of a user who uses the information provided by different packaging features to perform specific tasks. Figure 5-1 represents the user packaging interaction model with main elements. It is clear that packaging features convey different messages about the contained product, and can guide users to use packages as envisioned by product designers, and that the suitability of the information provided by these features can determine the quality of the perceived affordances. Such features are therefore considered to be main drivers of users' actions and important determinants of packaging usability.

Designers strive to design a package that provides users with the requirements essential to facilitate the completion of their tasks. These requirements can be represented in terms of

affordance properties (Table 5-1) expressing the affordances provided by packaging features. A package has many features that can be manipulated; for instance, the transparency, shape, size, and material of the package can all be changed with possible impact on users. Changing these features should be based on user requirements, or else the design will probably not be suitable for them. A packaging design framework is thus required to ensure the existence of the features required to support user requirements.
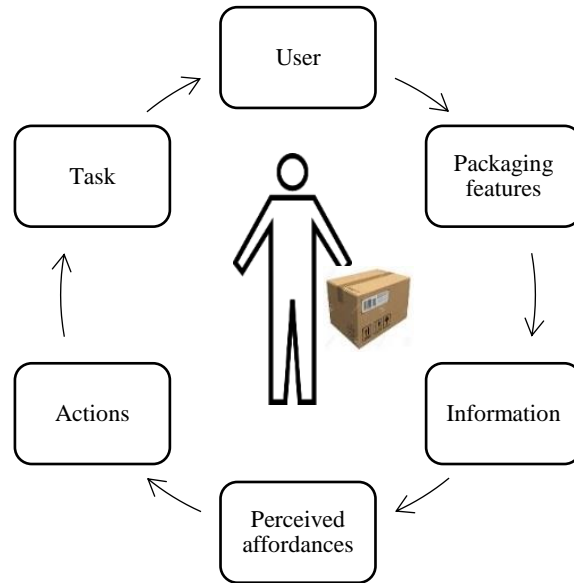
Figure 5-1. An illustration of user packaging interaction model
; based on [6]

This work proposes an affordance-based design framework for product packaging. It links packaging features to user requirements through associated affordance properties elicited from previous usability studies and further verified by experts. The proposed framework uses an affordance structure matrix (ASM) to construct the relationships between affordance properties and packaging features. The framework's effectiveness was demonstrated though a usability testing study conducted on a product packaging.

5.2. Related work

While packaging design has evolved to help users overcome many difficulties experienced while performing different tasks, users still experience problems related to product packaging usability, including clarity, safety, visibility, and accessibility [7]. In fact, this type of negative experience has potential for affecting user satisfaction while performing such tasks [8].

Because of the potential impact of packaging usability on user satisfaction, a great deal of work has been directed toward its evaluation and improvement. For example, a usability survey was used to evaluate product packages by considering opening, usage, and after-usage stages, with a scale used to quantitatively express user experience [9]. Universal design principles have also been used to ensure product packaging usability for different users. For example, flexible product packages were evaluated based on universal design principles such as delivery of information, ability to open, and package design [10]. A survey for affirming the conformance of package designs to universal design principles has also been proposed [11], and a usability survey was introduced to evaluate package usability [12].

While previous packaging usability studies have been able to evaluate packages at different stages of their life cycles, these methods do not indicate the root causes of usability problems nor do they provide systematic suggestions for improving packaging design. In general, while such studies may conclude that there are difficulties in opening, disposal, or unpacking, they usually provide insufficient detail regarding the features actually responsible for such problems.

Many frameworks have been proposed for improving the packaging design process. For example, a method has been introduced to match user capabilities to packaging design

variables while adequately maintaining basic packaging functions [13]. Furthermore, an optimization approach was applied to finding an optimal alternative packaging design among many alternatives generated through users' collaborations [14]. These studies established connections between packaging features and users' perceptions and accessibility, even though the connection between these features and the other aspects of packaging usability requires more attention.

In general, the aforementioned work can be divided into packaging usability and packaging design studies. Because usability studies focus on the interaction between users and packages with little effort applied to establish connections between packaging features and usability, they have been limited in capability for identifying the responsibility of different packaging features with respect to usability problems. On the other hand, previous packaging design studies have focused on aspects of accessibility and connections established mainly between packaging features and ability to open packages. Accordingly, there is a necessity to link aspects of packaging usability to packaging features to achieve a better understanding of potential improvements in packaging design. The concept of affordances can be utilized to construct this link and trace usability problems to particular packaging features. A design methodology has been proposed to ensure the existence of required affordances when considering packaging design [15].

One approach to improve packaging usability is to understand the affordances provided by packaging features [16], since these affordances are strongly related to usability [17]. " The term affordance refers to the perceived and actual properties that determine just how the thing could possibly be used" [18], and it can be expressed by a word ending in ability [19]. In practice, it is hard to convey the meaning of the term affordance, although typical affordance

properties, including intuitiveness, responsiveness, and information clarity can be used to express affordances [20].

Designers have utilized affordances to improve different products' usability. For example, usability evaluation has been used to study the effect of affordance quality on user-product interaction [21] and various methods have been introduced for affordance documentation and evaluation [22]. An online evaluation model reflecting the importance of affordance properties was also introduced to evaluate affordances associated with a product [20]. A design for affordance framework was also developed to ensure that design features provide the affordances required to facilitate interaction between users and products [23].

To utilize the concept of affordance, a mapping tool connecting affordances to packaging features should be utilized. An affordance structure matrix (ASM), an extension of a design structure matrix (DSM), can link requirements presented as affordances to physical features [22]. ASM represents an affordance-based tool in which affordances depend on design features, allowing designers to identify relationships between affordances and features [24, 25]. An ASM specifically correlates design features with affordances and allows designers make comparisons between designs using the links between features and affordances [26]. Each feature considered in the ASM can be described as being positively, negatively, or not affecting each affordance [24, 27]. To build an ASM, user requirements should be translated into affordances that in turn may be affected by features [28].

This work proposes a design framework for helping designers improve packaging usability through the concept of affordances. The proposed framework can be incorporated into the design process of product packaging. Specifically, by supporting systematic incorporation of users' requirements and determination of relationships between packaging

features and affordances. Accordingly, modifications on packaging features can be performed during the packaging design phase by evaluating their effects on the affordances. Overall, this paper tries to make the packaging design process more systematic and provide the advantage of considering different aspects of packaging at early design stages.

5.3. Methodology

The proposed framework utilizes the concept of affordance to map users' requirements to packaging features. The overall structure of the proposed framework allows an affordance driven package design through linking users' requirements for affordances and packaging features, as shown in Figure 5-2.
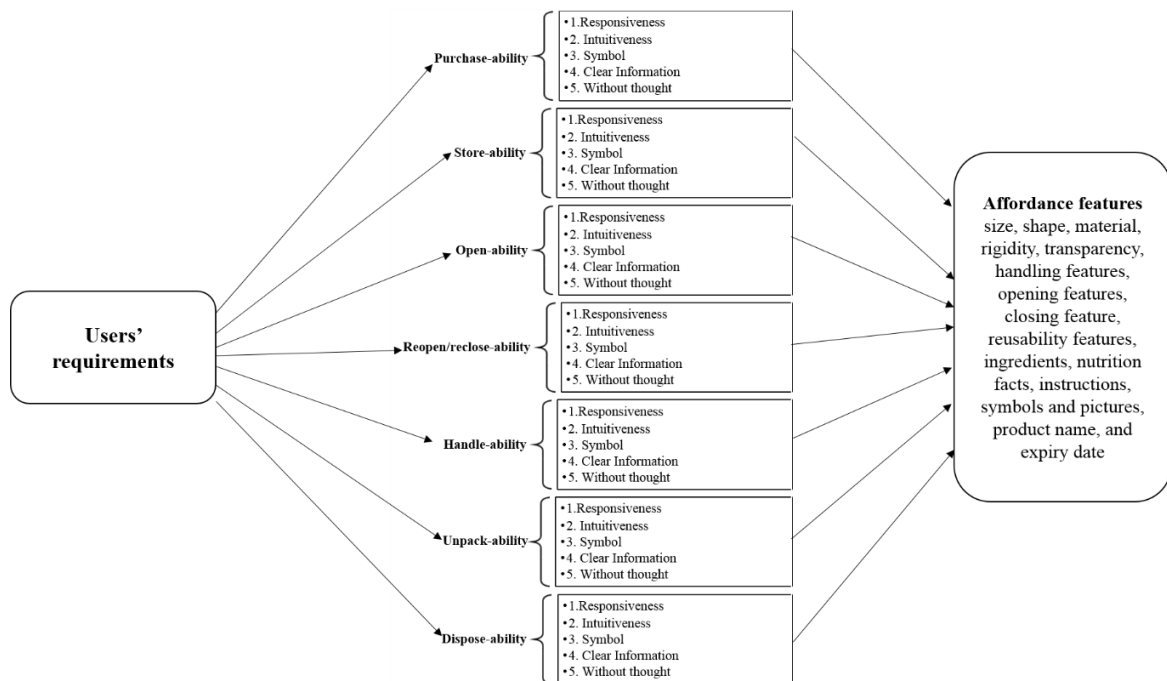

Figure 5-2. User requirements and packaging features linked through affordances.

Generally, there is a wide variety of user requirements rooted from the fact that products vary in terms of types, users, characteristics, and usage. These variations in user requirements reduce or eliminate the possibility of designing packages based on the same set

of requirements, complicating the packaging design task, so providing the packaging community with a generic design framework that can be applied to different packaging types is required. To this end, affordance properties can be elicited from generic user requirements and further verified to suit particular packages.

5.3.1. Design Framework

The design framework can be outlined in five steps; eliciting affordance properties, selecting a product of interest, affordance features identification, building an ASM, and calculating metrics.

Eliciting affordance properties

The first step of the framework is to elicit affordance properties from user requirements. To do so, packaging usability studies were surveyed to obtain user requirements, producing about two hundred requirements [7, 9-12, 16]. These requirements were reviewed and then combined, based on their similarities, into thirty-eight distinct requirements. These requirements were then associated with the five basic affordance properties [20] as shown in Table 5-1. The elicited properties express affordances related to the tasks of purchasing, storing, opening, unpacking, reclosing, handling, and disposing of packages.

Table 5-1. Affordance properties related to open-ability.

Elicited Requirements	Associated affordance property
The package helps me to pay attention during opening tasks.	Without thought
Can understand how to open the package correctly without reading the opening instructions.	Intuitiveness
Symbols and pictures related to the opening task are helpful and comprehensible.	Symbols
Find the opening position and instructions easily.	Responsiveness
Opening instructions and methods are obvious.	Clear Information

Selecting product of interest

The proposed framework can be applied to different products because it relies on the same initial set of user requirements. Once particular product is selected, the context of use, tasks performed by users, and product characteristics should be enumerated to determine the requirements from the initial set that should be considered.

Affordance features identification

Packaging features providing affordances are called affordance features [23]. These features can be classified into physical and verbal features. The physical features can be in form of size, shape, material, rigidity, transparency, handling features, opening features, closing features and reusability features. The verbal features can be represented by ingredients, nutrition facts, instructions, symbols and pictures, product name, and expiration date. These features convey information about the product/package throughout its lifecycle and guide users in performing packaging related tasks. Features associated with one affordance property at least are considered to be affordance features with potential impact on the corresponding properties, and such associations can be constructed based on observational studies [13].

Building an ASM

The ASM concept can be utilized in constructing the link between packaging features and affordance properties. ASM helps in systematically defining relationships between features and affordance properties. The main components of an ASM are affordance properties (in the rows), affordance features (in the columns), and relationships between affordances and features (the interior elements of the matrix). Three types of relationships between the affordance properties and features can be defined in ASM, i.e., helpful (+1), harmful (-1), or

no relationship (0) [24]. Table 5.2 shows the basic components of an ASM that can be used for product packaging design.

Calculations

Different evaluation metrics can be extracted from the ASM to evaluate relationships between affordance properties and their related features. The total number of helpful and harmful features with respect to a particular property, the total number of properties for which a feature has helpful or harmful relationships, and the percentage differences are considered the basic metrics [24].

In this framewrok, each affordance is presented by the term A_i , $i = 1, ..., I$. An affordance property related to affordance A_i is represented by p_{im} , $m = 1, ..., M$. A packaging feature with a relationship to a property p_{im} is represented by F_{imk} , $k = 1, ..., K$. This relationship can be represented by the term X_{imk} as follows:

$$X_{imk} = \begin{cases} -1, & \text{if feature } F_{imk} \text{ doesn't support property } p_{im} \\ 0, & \text{if feature } F_{imk} \text{ is not related to property } p_{im} \\ 1, & \text{if feature } F_{imk} \text{ supports property } p_{im} \end{cases}$$

The package under study can be evaluated according to its ability to support the required properties through use of different packaging features. The features related to affordance properties are assigned scores according to the following rules: if the package has the feature and supports a property, it is assigned a score of (1). If the package has the feature and does not support the property, a score of (-1) is assigned. If a package lacks a feature required to support an affordance property, a score of (-1) is also assigned.

For each affordance property, the percentage difference can be calculated using Equation 5-1. The percentage difference of an affordance can be calculated using Equation 5-

2, while Equation 5-3 can be used to calculate the overall percentage difference of the packaging design. The percentage difference of a feature can be calculated as shown in Equation 5-4. The highest possible value of these metrics, 100%, represents the ideal case in which no packaging design modifications are required since the affordance properties will be fully supported by the related features.

Table 5-2. ASM structure; updated from [24]

Affordan-ce	Propert-ies	F_{im1}	F_{im2}	F_{im3}	F_{imK}	Total harmful	Total helpful	Total	Percentage harmful	Percentage helpful	Percentage differe nce
A_1	P_{11}										
	P_{12}										
	P_{13}										
	P_{1M}										
$A2$	P_{21}										
	P_{22}										
	P_{23}										
	P_{2M}										
$A3$	P_{31}										
	P_{32}										
	P_{33}										
	P_{3M}										
AI	P_{I1}										
	P_{I2}										
	P_{I3}										
	P_{IM}										

$$P_{im}^D = \frac{P_{im}^+}{\sum_{k=1}^{K} |X_{imk}|} - \frac{P_{im}^-}{\sum_{k=1}^{K} |X_{imk}|} \; \forall \, i, m \qquad\qquad (5-1)$$

Where

P_{im}^D is the percentage difference score for a property p_{im} of affordance A_i

$P_{im}^+ = \sum_{k=1}^{K} X_{imk}$, $X_{imk} > 0$

$P_{im}^- = \sum_{k=1}^{K} |X_{imk}|$, $X_{imk} < 0$

$$D_i = \frac{D_i^+}{\sum_{m=1}^{M}\sum_{k=1}^{K}|X_{imk}|} - \frac{D_i^-}{\sum_{m=1}^{M}\sum_{k=1}^{K}|X_{imk}|} \quad \forall\, i \qquad (5-2)$$

where

D_i is the percentage difference score of an affordance A_i

$$D_i^+ = \sum_{m=1}^{M}\sum_{k=1}^{K} X_{imk},\; X_{imk} > 0$$

$$D_i^- = \sum_{m=1}^{M}\sum_{k=1}^{K} |X_{imk}|,\; X_{imk} < 0$$

$$D = \frac{D^+}{\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{k=1}^{K}|X_{imk}|} - \frac{D^-}{\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{k=1}^{K}|X_{imk}|} \qquad (5-3)$$

where

D is the overall percentage difference score of a packaging design.

$$D^+ = \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{k=1}^{K} X_{imk}, X_{imk} > 0$$

$$D^- = \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{k=1}^{K} |X_{imk}|, X_{imk} < 0$$

$$F_{imk}^{D} = \frac{F_{imk}^{D+}}{\sum_{i=1}^{I}\sum_{m=1}^{M}|X_{imk}|} - \frac{F_{imk}^{D-}}{\sum_{i=1}^{I}\sum_{m=1}^{M}|X_{imk}|} \quad \forall\, k \qquad (5-4)$$

where

F_{imk}^{D} is the percentage difference of a feature F_{imk}.

$$F_{imk}^{D+} = \sum_{i=1}^{I}\sum_{m=1}^{M} X_{imk}, X_{imk} > 0$$

$$F_{imk}^{D-} = \sum_{i=1}^{I}\sum_{m=1}^{M} |X_{imk}|, X_{imk} < 0$$

The resulting scores can be considered as measures of the gap between a current and an ideal packaging design [24]. Affordances with scores greater than 0% and less than 100% indicate that the corresponding affordance features have more positive than negative relationships. Affordances with a 100% score are considered to be satisfied with no need for further modification of the associated affordance features. A score $< 0\%$ for an affordance indicates that the corresponding features have more negative than positive relationships.

Features with low percentage difference scores do not support the related affordance properties in a proper manner. To improve the affordance scores, the features with negative relationships should be reviewed and modified.

5.4. Case Study: Flour Package

This framework was applied to food packaging due to the fact that users are in daily contact with food packaging which accounts for most of the packaged products [9]. In particular, 2.27 kg Flour packages were examined by focusing on the link between packaging features and affordance properties. A part of the data collected in section 4.4.1 was utilized in this study. Four experts with human factors and other expertise (Table 4-2) were invited to participate in an experimental session where they were asked to verify the initial set of affordance properties to ensure their suitability for flour products. The experts selected 27 affordance properties from the 38 comprising the initial set of properties as shown in Table 5-3.

A part of the the data obtained from the usability testing study shown in section 4.4.3 was utilized in this paper. Thirty-seven participants, 22 females and 15 males, all age 18 or older, participated in a controlled usability experiment. They were asked to perform specific tasks to simulate normal interaction during the product life cycle. These tasks included purchasing, storing, opening, unpacking, reclosing, handling, and disposing of flour packages consisting of a folded paper bag and a plastic dispenser as shown in Figure 5-3. The packages were introduced to the participants in a counterbalanced manner to ensure experimental randomization. The participants were observed while performing the aforementioned tasks to determine interrelationships between affordance properties and packaging features. Fifteen packaging features were identified and associated with affordance properties. After identifying

the affordance properties and their associated affordance features, the ASM was constructed. Features related to each affordance property were appraised according to their ability to support that property.

A folded paper bag
Dimensions : 15.7*10.9*22.1 cm
Weight (kg): 2.27 kg

A plastic dispenser
Dimensions: 18.5*13*25.5 cm
Weight (kg): 2.27 kg

Figure 5-3. Flour packages; Package 1(left) and
Package 2 (right).

For some affordance properties, association with particular affordance features was clear. For example, to facilitate the task of purchasing, the quantity in the package should be determined and visibly identifiable, and package transparency, size and information are affordance features that affect the property "Responsiveness" associated with this requirement. For other properties, the affordance features were identified based on user actions and common-sense reasoning. For example, to perform the task of opening, users had to grasp the package and find and utilize an opening feature. The size, shape, rigidity, and handling features induce a grasping action, while material and opening instructions and features induce the action of opening. Just as for the after-usage stage, the size, shape, material, rigidity, after usage, and instructions features affect user actions when dealing with empty packages. These features

were associated with the corresponding affordance properties and the packaging evaluations were based on the determined relationships.

Table 5-3. Elicited requirements with their associated affordance properties

Elicited requirements	Associated Affordance
Purchasing	*Purchase-ability*
The quantity in the package can be determined and visible.	Responsiveness
Handle the product properly without reading instructions.	Intuitiveness
Find the important information; product descriptions, expiry date, nutrition facts, warnings, etc.	Responsiveness
The information listed on the package is understandable and readable.	Clear Information
Can understand how to use the product properly without instructions.	Intuitiveness
Storing	*Store-ability*
Find the storage instructions and check the expiry date immediately.	Responsiveness
Know the current level of the contained product, "visibility".	Responsiveness
Can understand how to store this product without reading storage instructions	Intuitiveness
The package helps me to pay attention during storing tasks	Without thought
Opening	*Open-ability*
Find the opening position and instructions easily.	Responsiveness
Opening instructions and methods are obvious.	Clear Information
Can understand how to open the package correctly without reading the opening instructions.	Intuitiveness
Reopening/reclosing	*Reopen/reclose-ability*
The package helps me to pay attention during reopening/reclosing.	Without thought
Can understand the reopening/reclosing methods without reading instructions.	Intuitiveness
Find the reopening/reclosing features immediately.	Responsiveness
Reopening/reclosing instructions and methods are obvious.	Clear Information
Handling	*Handle-ability*
Can understand how to handle the package without reading handling instructions.	Intuitiveness
Symbols and pictures related to handling are helpful and comprehensible.	Symbols
The handling features can be found immediately	Responsiveness
Handling instructions are obvious	Clear Information
Unpacking	*Unpack-ability*
Can understand how to unpack/use the product without reading instructions	Intuitiveness
The unpacking features can be found immediately	Responsiveness
Symbols and pictures related to using/unpacking the product are helpful and comprehensible.	Symbols
Know the current level of the contained product, "visibility" and how much did I take from inside the package	Responsiveness
Disposing	*Dispose-ability*
Segregation, disposal, and recycle instructions, and reuse options are obvious	Clear information
The disposal, recycle, segregation, and reuse related features can be found immediately	Responsiveness
Can understand how to dispose, segregate, recycle, or reuse the package correctly without reading the related instructions.	Intuitiveness

The results of the ASM reflected some issues with Package 1. It didn't fully satisfy the affordances where all recorded negative percentage differences with exception for purchase-ability, open-ability, and dispose-ability. The ASM specifically showed that many features such as transparency, handling, reclosing, and information and instruction were associated with negative difference percentages. Improving features with such negative relationships is expected to help recovering the related affordances. This indicates a need for package redesign to ensure the existence of the required positive relationships.

An ASM was built for Package 2 to determine the effect on the percentage difference scores of having a package with different characteristics. The results showed that Package 2 satisfied most of the affordance properties and, as shown in Figure 5-4, achieved positive scores for all affordances. Since it has good transparency, handling, after usage, and reclosing features, as well as information, this package supports the affordance properties with the required features, making this package differ from Package 1. The overall percentage differences of the two packages were also calculated, with results showing the superiority of Package 2, with a score of 83%, compared to the 10% score of Package 1.

After performing each of the tasks, the users were asked to respond to a statement about the ease of interaction with the package. In general, the statement was in the form of "It was easy for me to know and understand how to (Task) the product/package (Figure 4-3). A seven-point Likert scale was utilized to express the level of agreement with the provided statements, with 1 being strongly disagree and 7 strongly agree.

A paired t-test was used to examine the significance of the differences between the scores of the two packages, and the results showed that the scores of Package 2 were significantly higher than that of Package 1 with respect to the tasks of opening,

reopening/reclosing, handling, unpacking, and disposal. Participants were also asked to respond to a statement about the overall design of the package. Package 2 achieved a significantly higher number of Likert scale points, as shown in Figure 5-5, a superior result explained by Package 2 being perceived as more informative than Package 1.

5.4.1. Limitations

Although the case study was a simulation study in which participants did not perform the whole range of tasks of purchasing, unpacking, storing, and disposing, this was not found to significantly affect the results since the focus was on the affordances and the information provided by the packages and not ability to perform the actual tasks. Affordance features of any particular property were assumed to have the same importance to that property and a simple scale was used to evaluate relationships. This seemed reasonable because the framework was meant to be attention-directing tool.
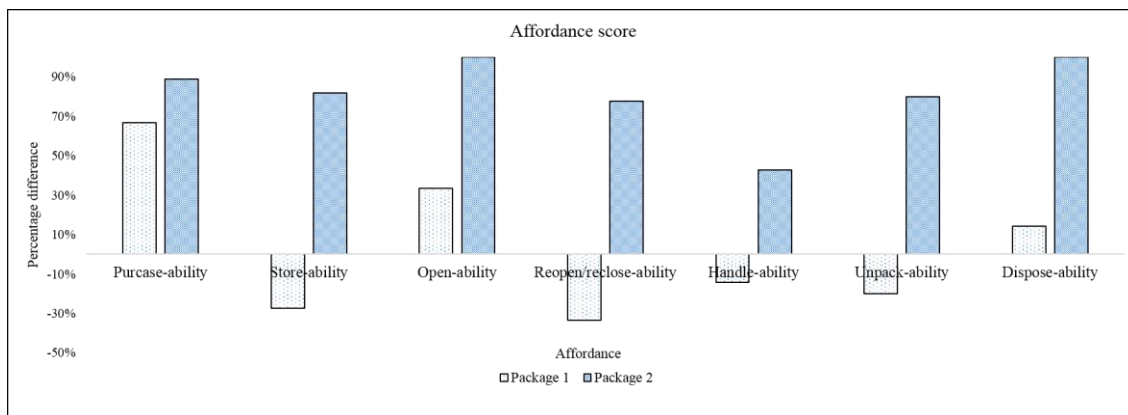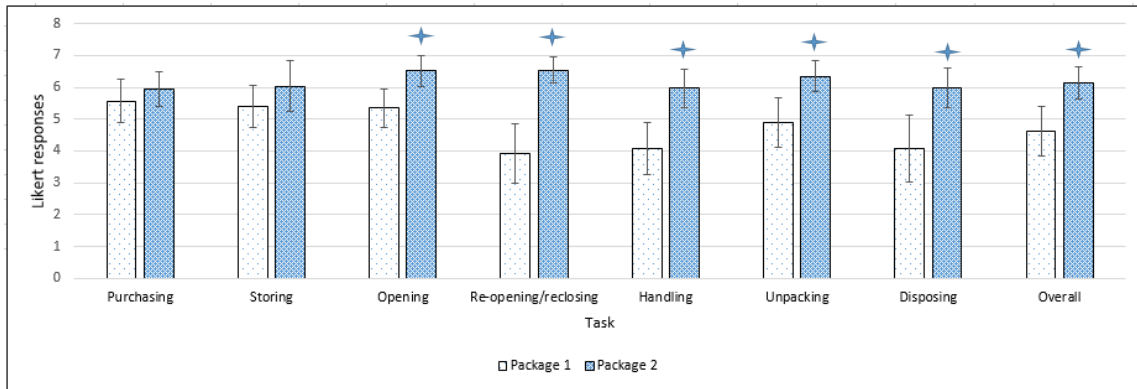

Figure 5-4. Results of the ASM

Figure 5-5. Results of the evaluation of the packages under study. N=37, except for the overall measure =36.(✦P-value < 0.05)

5.5. Discussion

This paper proposed a design framework based on the fact that affordances are dependent on design features. The framework was developed to help designers apply modifications during the design stage, with subsequent consideration of the potential effects of such modifications on packaging affordances. The framework was demonstrated using a Flour product in a case study. Two Flour packages were appraised with respect to the ability of their features to support the required affordance properties. The framework facilitated the identification of packaging features needing modification to improve affordances.

The results showed the superiority of Package 2 over Package 1 because it satisfied most of the required affordance properties through the flour product life cycle. In general, Package 2 outperformed Package 1 because of its transparency, rigidity, handling, reclosing, and reusability features, and its superior instructions. The usability testing study, wherein Package 2 obtained more Likert scale points than Package 1 with respect to different tasks, supported the framework's results. Overall, Package 2 was perceived to be significantly better than Package 1.

The ASM showed that more relationships than those only resulting from verbal features were specified between affordance properties and physical packaging features, indicating the potential impact of physical features on packaging affordances for this particular product. The features associated with the largest number of affordance properties were information and instructions, size, transparency, rigidity, shape, material, handling, and opening features. These features should be considered critical to the packaging design process of the Flour product because of their significant impact on many affordance properties. More efforts should be directed toward ensuring the suitability of such features at the design stage. The lack of such features will have significant negative impact on the affordances provided by the package, while features with no significant impact on affordance properties can be considered noncritical with respect to the affordances provided by the package.

The ASM visualizes the relationships between the required affordance properties and packaging features and it can locate problems of packaging design that lead to low affordance scores. For example, Package 1 has a low open-ability score and this could be explained by the low percentage of difference recorded for the properties related to ability to understand how to open the package without instructions, i.e., "Intuitiveness", and those related to finding and comprehending the opening instructions, i.e., "Responsiveness and Clear information". Features related to these properties with negative relationships should also be reviewed. For example, Package 1 lacks a handling feature and opening instructions and information, resulting in negative relationships. Providing these features would improve the percentage difference of the associated properties as well as the open-ability score.

5.6. Conclusion

This paper describes construction of a design framework based on a user packaging interaction model. The framework was developed to allow affordances-driven design that takes into account requirements for affordance properties. A food-packaging design case study was introduced to illustrate the functionality of the framework. Two packages were presented to show how packages with different features will produce different affordance scores. According to the framework, Package 2 has higher affordance scores than Package 1, and this rating was supported by the higher Likert scale responses obtained from the participants in the usability study. Package 2 supported the required affordance properties, and it was perceived to be more informative than Package 1; it provided the users with information required to perform the tasks considered in the study.

Applying this framework will help a designer understand relationships between packaging features and affordances and receive early feedback about a design. Expressing the affordances in terms of affordance properties facilitated associations between affordances and features, helping in building the connections between affordance features and properties at early stages of a packaging design.

ASM utilization has the advantage of supporting the visualization of relationships between user requirements for affordances and packaging features, and it can also be used to appraise packaging designs with respect to their ability to support required affordance properties through packaging features. Application of the framework provides insights into possible roadmaps for improvement guided by affordance scores and the links between affordances and packaging features.

The framework is an attention-directing tool for locating problems that should be fixed. It can be used to create alternative packaging designs through understanding of affordance properties and their associated features. It focuses on affordances, embracing the different types of information provided by a package. Given the importance of providing a user-friendly package, the physical capabilities of users should also be integrated into the framework to ensure that users understand how to deal with their packages, and are capable of performing the required physical actions. The framework is suitable for use by packaging designers in designing various product packages, e.g., for medications. The cost of packaging was not considered in this framework, and in future work packaging cost could be introduced as an additional metric for evaluating packaging designs. More consideration should also be directed toward understanding the effect on other properties of supporting a particular property.

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CHAPTER 6. CONCLUSION AND FUTURE WORK

6.1. Conclusions

In this dissertation, the UPI field has been considered as a system of users who interact with packages and other elements at different instances during product lifecycle. This facilitated the integration of systems and human factors engineering concepts to improve the field of UPI. This integration allowed systematic process improvement at a stage of interaction with both operational and ergonomic measures of interest. It also resulted in a model with capabilities to evaluate human factors aspects of UPI utilizing a decision support tool. This model is practical and accessible by researchers from different fields as it accounts for instances of interaction all the way from the point of purchase to the point of disposal. A design framework is also introduced to translate human factors related requirements to packaging design features to ensure meeting users' needs. This framework is considered as a system engineering tool which is capable to visualize and quantify the interrelationships between packaging features and user's requirements. In fact, this work is the first of its kind to consider both systems and human factors engineering concepts in UPI in a structured and systematic manner. The following is a description of the main conclusions and contributions of this dissertation.

Chapter 2 describes an effort applied to structure the field of UPI through an extensive literature review. This is the only available review in the field of UPI, which has been organized with a unique structure, representing the UPI as a system of users who interact with packages and other elements at stages of interaction. This resulted in a platform which is accessible to researchers with different interest in packaging science. The platform is unique in its nature since it covers UPI over product life cycles with comprehensive suggestions to solve the

problems experienced by users at different stages. The review process revealed issues with the state of the art of UPI related to users, packaging and product types, comprehensibility of the conducted research, and the distribution of the related articles. These issues present potential future work to improve the research structure of UPI field.

In Chapter 3, a systematic process improvement effort has been applied to improve self-checker performance while at the checkout stage. Particularly, the focus was on the features of UPC, weight, and size of packages, and the type of the used scanning technology. This study is unique in terms of giving recommendations to improve the self-checkout experience based on empirical results, focusing on users, packages, and scanning technologies in use. These recommendations are applicable and approved to affect UPI with operational and ergonomic impacts. The study demonstrates the importance of introducing systems engineering principles to the UPI field, in which each stage of interaction should be considered as a system of users, packages, and other components affecting each other.

Chapter 4 proposes a decision support model for evaluating packaging affordances required to facilitate users' tasks. This is the first model of its kind to utilize MCDM to evaluate packaging based on affordance properties. The model can eventually determine the overall affordance level and detailed affordance scores for alternative packages. Packaging designers can use these scores to compare and rank alternative packaging designs. In general, the model is capable of distinguishing between packages with different affordance levels.

Chapter 5 introduces an affordance-based design framework. This framework is built based on the UPI model, which entails that packaging features are considered to have the role of providing the information required to facilitate the interaction between users and packages. The framework links users' requirements associated with affordances with packaging features.

This framework is new to the field of packaging design, with advantages to visualize and assess the interaction between packaging features and affordances through an ASM. Designers can determine if a packaging feature should be added or modified to support particular affordances.

This dissertation is the first to officially coin the term UPI and integrate systems and human factors engineering concepts to its improvements. It introduces a new approach to improve the field of UPI relying on the system view of the interaction, which should replace the currently adopted approach that relies on partitioned efforts of improvements. This way of thinking resulted in applicable and accessible improvement, evaluation, and design techniques. The dissertation paved the way for researchers from the fields of human factors and systems engineering to augment UPI. This work is expected to benefit users, manufacturers, and other stakeholders who rely on packaging as a tool to support their business.

6.2. Future works

1. Interaction between users and secondary and tertiary packages will be investigated. This interaction requires greater attention because of the potential impacts on users, manufacturers, distributors, and retailers.

2. Systematic process improvement efforts will be directed to consider stages of interaction with potential operational and ergonomic impacts.

3. Because of having many stakeholders involved in product packaging with different objectives, the evaluation and design models will be extended to consider aspects of manufacturing, distribution, and marketing.

4. The concept of design for X will be utilized to ensure the suitability of packaging designs. This technique will ensure the suitability of a packaging design with respect to different aspects and solve potential conflicts at the early stages of design.

APPENDIX. INSTITUTIONAL REVIEW BOARD APPROVAL

[IRB#15-690 approval]

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
1138 Pearson Hall
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515-294-4566
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Date: 1/22/2016

To: Ahmad Mumani
4325 Todd Drive Unit 207
Ames, IA 50014

CC: Dr. Richard T Stone
3004 Black Engineering

From: Office for Responsible Research

Title: Universal Product Code (UPC) Location: An ergonomic study

IRB ID: 15-690

Approval Date:	1/21/2016	**Date for Continuing Review:**	1/20/2018
Submission Type:	New	**Review Type:**	Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp**.

- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.

- **Obtain IRB approval prior to implementing <u>any</u> changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.

- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.

- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.

- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 1138 Pearson Hall, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

[IRB#15-690 modifications approval]

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

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1138 Pearson Hall
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Title: Universal Product Code (UPC) Location: An ergonomic study

IRB ID: 15-690

Approval Date: 3/3/2016   **Date for Continuing Review:**   1/20/2018

Submission Type: Modification   **Review Type:**   Expedited

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[IRB#17-198 approval]

IOWA STATE UNIVERSITY
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Institutional Review Board
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To: Ahmad Mumani
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CC: Dr. Richard T Stone
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From: Office for Responsible Research

Title: Validating an evaluation model for consumer packaging interaction

IRB ID: 17-198

| **Approval Date:** | 7/13/2017 | **Date for Continuing Review:** | 7/12/2019 |
| **Submission Type:** | New | **Review Type:** | Expedited |

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

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[IRB#17-198 modifications approval]

IOWA STATE UNIVERSITY
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Date: 9/22/2017

To: Ahmad Mumani   **CC:** Dr. Richard T Stone
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From: Office for Responsible Research

Title: Validating an evaluation model for consumer packaging interaction

IRB ID: 17-198

Approval Date:	9/21/2017	**Date for Continuing Review:**	7/12/2019
Submission Type:	Modification	**Review Type:**	Expedited

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- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.