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A Systematic Approach to Accident Scenario Analysis: Child Safety Seat Case Study

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체계적 사고 시나리오 분석기법을 이용한 유아용 안전의자 사례연구

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The objective of this paper is to describe a systematic accident scenario analysis method(SASA) adept at creating accident scenarios for the design of safer products. This approach was inspired by the Quality Function Deployment(QFD) method, which is conventionally used in quality management. In this study, the QFD provides a formal and systematic scheme to devise accident scenarios while maintaining objectivity.

SASA consists of three key stages to be broken down into a series of consecutive steps:(1) developing an accident analysis tableau,(2) devising the accident scenarios using the accident analysis tableau,(3) performing a feasibility test, a clustering process and a patterning process, and finally(4) performing quantitative evaluation of each accident scenario. The SASA was applied to a case study of child safety seats. The accident analysis tableau devised 2828(maximum) accident scenarios from all possible relationships between the hazard factors and situation characteristics. Among them, 270 scenarios were devised through the feasibility test and the clustering process. The patterning process reduced them to 29 patterns representative of all accident scenarios. Based on an intensive analysis of the accident patterns, design guidelines for a safer child safety seat were recommended. The implications of the study on the child safety seat case were then discussed.

Keywords: accident scenario, child safety seat, accident analysis tableau, product safety

1. Introduction

A prerequisite to understanding how a user and product contributes to an accident is examining the etiology of accidents and analyzing the detailed sequence of events that caused the accident. This can be accomplished by applying the accident scenario analysis method. This method is the process of

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understanding, analyzing, and describing the behavior patterns of the products' user and the accident process through the use of published sources, focus groups, questionnaires, and personal interviews (Cushman and Rosenberg, 1991). The method has been applied to investigations of industrial accidents and accidents of consumer products in ergonomic research fields(Laugery and Brems, 1985; Kreifeldt, 1987). Drury and Brill (1983) devised a limited number of accident scenarios with descriptions of the actors(victims), the props(products), the scene (environment), and the action(task). These scenarios were used to structure intelligent' accident investigation questionnaires for several products such as chain saws, riding toys, ranges and ovens, swimming pools, etc. Through this method, Godfrey *et al.*(1986) found through 86 household interviews that ingestion accidents involving children under the age of five happen to children not closely monitored by their parents. Cohen and Lin(1991) categorized 10 hazard patterns for accidents involving ladder falls based on the review of 123 accident cases.

The accident scenario analysis can be used to provide a clear picture of accidents that arise from user and product interactions. This method also provides clues to building better accident prevention strategies. But, although much work has been done to apply scenario analysis to accidents, there is still no systematic and formal methodology with which to identify, generate, analyze, and verify product use accident scenarios, in our view. The lack of such a methodology raises questions of accuracy and objectivity; i.e. the systematic reflection of the interaction between the user and product is not employed. Since the validity of the accident scenario analysis can also be subjective because of its dependence on the personal experiences of the analysts, this method is not widely used in analyzing product use accidents. Therefore a new method, one which is more systematic as well as objective, is needed to better identify and give a clearer picture of the accidents arising from the interaction between the user and product.

The objective of this paper is to propose a systematic accident scenario analysis(SASA) method for the design of safer products. This methodology is inspired by the Quality Function Deployment(QFD) method, which is traditionally used in quality management. In this study, the QFD method provides technique for producing accident scenarios. It also guarantees systematic process and objectivity while keeping subjectivity to a minimum.

We will first explain the framework of accident scenario analysis step by step, and finally, show the advantages of the SASA through a case study on the child safety seat.

2. The Systematic Accident Scenario Analysis Method

The QFD method contains one or more matrices called House of Quality'(Hauser and Clausing, 1988), termed QFD matrix for convenience. It displays the customers' needs along the left and the development team's quality requirements along the top. The QFD matrix consists of several sub-matrices joined together in various ways e.g. relationship matrix, market evaluation matrix, and roof matrix.

The SASA was developed based on a modified QFD matrix. We replaced the customer's needs and quality requirements on the QFD matrix with hazard factors and situation characteristics. However, we kept the meanings for the relationship matrix and roof matrix the same. The market evaluation matrix and technical matrix are neglected in our method. The SASA adopted the modified QFD matrix as a tool for devising accident scenarios. There are seven key steps.

Step 1: Identifying the hazard factors

This step is probably the most important in that it can pinpoint the safety problems of a product design; only a successful identification of the problems can lead to improved and safer products. In our study, identification of the hazard factors, as defined by product failures and foreseeable user negligence contributing to an accident, is carried out mainly by gathering consumer data on a product. Consumer data includes consumer complaints, accident injury information, and recall and product liability lawsuit cases. Though we do not use these in our case study, a series of hazard evaluation approaches such as PHA, FMEA, and FTA can also be used in the identification.

Step 2: Determining the situation characteristics

Situation characteristics are the characteristics and circumstances surrounding a product use accident. An epidemiological study shows that a product use accident involves the interaction between a product, a user, a task and an environment(Drury and Brill, 1983). Accordingly, we classified the situation characteristics as such: user, task, product, and environmental characteristics.

User refers to the victim's characteristics. Gender, age, height, weight, injured body parts, and injury types are used to describe user characteristics. Age, height and weight are grouped into intervals. Injured body parts are sub-divided into the head, neck, shoulders, arms, hands, knees/legs, and feet. Injury types are sub-divided into amputations, avulsions, burns/scalds, punctures, dislocations, strains/sprains, etc.

Task describes the user's action surrounding an accident. For more specific task descriptions, task analysis techniques such as hierarchical task analysis, charting and network technique, and decomposition method(Kirwan and Ainsworth, 1992) can also be used.

Product characteristics describe product configuration, operating mode, and qualities such as weight, size, shape, color, age, and material, which could have contributed to the accident. Finally, environmental characteristics involve the events and conditions surrounding a product accident. These can be accident location, temperature, humidity, lighting, ventilation, etc.

Step 3: Evaluating the hazard factors and their relationship with the situation characteristics

On the basis of frequency analysis of various consumer data, such as accident figures, consumer complaints, and recall and product liability lawsuit cases, the SASA rates the importance of the hazard factors and evaluates the relationship between the hazard factors and situation characteristics. That is, the most frequent hazard factor contributing to the accident is assigned the highest weight. The relationship between the hazard factors and situation characteristics is evaluated in the same manner.

Accident data can be obtained from product injury data collection systems, such as the National Electronic Injury Surveillance System(NEISS) in the US, the Home Accident Surveillance System(HASS) in Britain, and the National Injury Reporting System (NIRS) in Japan. Among these, the NEISS, carried out by the CPSC, provides the most comprehensive accident data. The NEISS collects product-related injury data associated with 15,000 consumer products from 101 selected hospital emergency departments throughout the country. Its database is comprised of the age and gender of the patient, injured body part, accident location, type of injury, accident type, severity of the injury, etc. The CPSC reports the results of investigations identifying in-depth the factors of a product use accident. The reports include victim / witness interviews, product and on-site investigations, product documentation review, and perusal of relevant medical records. Although these in-depth investigations usually do not contain statistical data, the reports offer a wide range of information about victims, products, and accident conditions not available in the NEISS data. The NEISS data combined with in-depth investigation reports would, therefore, improve the accuracy of rating the importance of the hazard factors and their relationship with the situation characteristics.

A review of various literature shows that in the QFD method, the ratings are generally weighted on 1 to 5 or 1 to 9 scales with the larger number indicating greater importance or stronger relationship. There is no established scientific basis to determine the superior rating system(Sivaloganathan and Evbuomwan, 1997). In the study, the SASA adopts the 1-to-5 rating scale, meaning a hazard factor weighted '1' indicates the least important, and '5' the most important. The relationship between the hazard factors and situation characteristics is weighted '5' if the relationship is strong, '3' if moderate, and '1' if weak.

Step 4: Devising the accident scenarios

<Figure 1> shows a complete scheme for devising accident scenarios. The scheme, 'accident analysis tableau,' creates scenarios from a matrix of all the possible relationships; the relationship of each hazard factor with its corresponding situation characteristics. For example, if any hazard factor is related to four user characteristics, two task characteristics, three product characteristics, and one environment charac

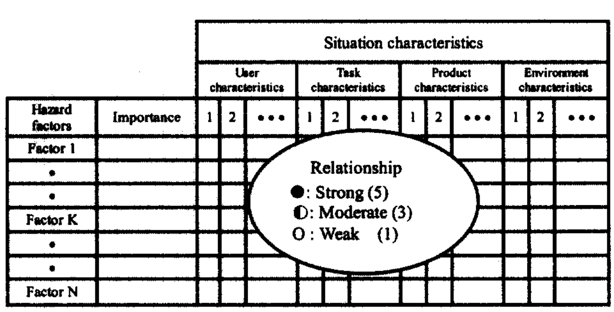


Figure 1. Accident Analysis Tableau.

teristic, the accident analysis tableau can devise a total of twenty-four accident scenarios. The details are described in case study.

Step 5: Testing the feasibility of the relationships between the situation characteristics

The SASA filters out infeasible relationships between elements of the situation characteristics, therefore, mitigating the need to devise and analyze the accident scenarios. For example, consider the user characteristics, 'injured body parts' and 'injury types'. Injured body part, 'face' and/or 'arm', can not be diagnosed with injury type 'anoxia'. In the same context, 'internal organs' can not be related with the injury types, 'contusion' or 'laceration'. Therefore, the accident scenario including these terms is classified as infeasible. A more detailed explanation of this step is in the case study.

Step 6: Calculating the total weight

After the accident scenarios are created, the total weight is calculated to determine the prominence of accident scenarios. To calculate the total weight for each accident scenario, the importance of the hazard factor is multiplied by each of its corresponding situation characteristics and then added together to get the total. The accident scenarios for each hazard factor are prioritized by their relative rankings based on total weights. The highest ranked scenario describes the accident situation that occurred most frequently in a specific hazard factor case.

Step 7: Clustering and patterning the accident scenarios

As mentioned above in step 4, the accident analysis tableau devises the accident scenarios based on all the possible relationships between the hazard factors and situation characteristics. The process may create too many accident scenarios to be dealt with. Though the infeasible scenarios are excluded from the feasibility analysis in step 5, the large number of feasible scenarios may still make it difficult to have a clear overview of the accident situation. In order to understand the accident situation thoroughly, the clustering and patterning processes are introduced. These processes will make the SASA an easier and simpler accident analysis method. Details of this step are presented in the case study.

3. The Case Study: Child Safety Seats

3.1 Child Safety Seats

Child safety seats have proven to be an effective device for protecting children in car accidents. NHTSA(1997) reports that child safety seats reduce the risk of fatal injury by 69% for infants under the age of one and by 47% for those between the ages of one to four. There are three basic types of child safety seats: infant-only, convertible and booster seats. The infant-only seat is designed for newborn babies to those children weighing up to 9 kg(20 lbs). The seat is typically a one-piece shell equipped with a handle for carrying ease, a snap-in pad, buckle, harness and slots for the car's safety belt. It also acts as a rocker and infant carrier that can be used with shopping carts. In a car, it is rear-facing only and can be used until the baby's head reaches the top of the shell(approximately one year old); the baby is then moved to convertible seats. This particular seat is designed for babies from birth to 18kg(40 lbs). The seat is incorporated with a slot for carrying ease, buckle, T-bar or overhead shield, and harness strap with three or five point adjustment. All convertible seats should face the rear of the car for infants under 9 kg and the front for toddlers 9kg to 18kg(40 lbs). It is used until the child's ears reach the top of the back or before the child's shoulders get too broad(approximately 4 years of age). The booster seat is designed for the child who has outgrown an infant-only or convertible seat. There are various types such as belt-positioning booster, shield booster, and built-in booster. They are generally used with a lap/shoulder safety belt.

3.2 Limitations of the Case Study

In our case study, there are three limitations. First, only infant-only and convertible safety seats are included in our case study because most pre-school children weighing between 18 and 27kg — the main users of booster seats — are restrained by the car's safety belt and do not use child safety seats(Decina and Knoebel, 1997). Second, we do not classify the accident scenarios according to child safety seat type because the various consumer data we used do not provide such detailed information. However, we can infer the seat type by the hazard factors in the devised accident scenarios. For example, the hazard factor 'carrying handle' relates to infant-only seats because convertible seats do not have this feature.

Likewise, the accident scenarios including the hazard factor 'shield' indicate a convertible seat. Finally, we ruled out fatal accident cases involving motor vehicles because such cases include variables not related to safety seats. For example, the type of impact(i.e. side, frontal, rear) must be identified to determine whether a defect in the child safety seat was the cause of death(Harcourt, 1995). Accident cases related to airbags are excluded in the same context. Therefore, 'at the time of car accident' in our scenarios indicates not fatal, but injury-only accidents.

3.3 Accident Analysis Tableau

A total of 594 pieces of consumer data such as consumer complaints, accident injury information, and recall cases were reviewed to identify the hazard factors, the situation characteristics and their relationships. Among them, 193 pieces of data were obtained from the NEISS and accident investigation reports of the CPSC from 1996 to 1997(CPSC, 1998). 299 cases of consumer complaints were collected from the complaint database of the NHTSA during the 4-year data collection period from 1995 to 1998(NHTSA, 1998a). And, finally 102 recall cases were sourced from the NHTSA's child safety seat recall campaign list covering January 1988 through July 1998(NHTSA, 1998b) and from the Product Safety and Liability Reporter of the Bureau of National Affairs(BNA), Inc. from 1991 to 1997(BNA, 1997).

<Table 1> shows 12 hazard factors classified into two groups: product failures and foreseeable user negligence. Hazard factors in product failures are the 'carrying handle', 'buckle', 'harness strap', 'padding material', 'shield', 'seat frame', etc. An examination of the accident data revealed the 'carrying handle' and buckle' as the most frequent causes of accidents. Therefore our rating scale assigned a '5' to them. The next most dangerous are the 'harness strap' and seat frame,' which we rated a '4'.

<Table 1> also shows 4 hazard factors in foreseeable user negligence. The importance of these hazard factors was evaluated in the same manner. The accident data revealed 'not or improperly buckling the child with the seat safety strap' as the most frequent cause of accidents, which is rated a '4'.

As shown in <Figure 2>, the situation characteristics consist of the user, task, product, and environment characteristics in this case study. The relationships between the hazard factors and situation characteristics are also evaluated. The SASA performs the rating based on the accident frequency that relates the hazard factor to each situation characteristic. If the frequency of an accident between the hazard factor and situation characteristic is equal to or larger than 70%, the relationship is interpreted as strong and rated a '5'. The relationship is moderate and gets a '3' if the frequency is between 40% and 69%. For 10% to 39%, the relationship is weak and assigned 1. The relationship is, however, ignored if the frequency is less than 10%. For example, in this case study, there is a strong relationship between 'carrying handle' and 'being unlatched', making it rate a '5'(<Figure 2>). But since the relationship between 'carrying handle' and 'being broken' is weak, a '1' is given.

<Figure 2> shows a complete accident analysis tableau on child safety seats. There are 12 hazard factors and 47 situation characteristics resulting in 564 cells in the accident analysis tableau.

Table 1. Hazard Factors and Importance

Hazard factors	Frequency	Importance
Product failure		
Carrying handle	108	5
Buckle	99	5
Harness strap	70	4
Padding material	40	3
Shield	42	3
Seat frame	72	4
Unstable safety seat	39	3
Warning label	8	1
Sub-total	478	
Foreseeable user negligence		
Lifting the safety seat	23	2
Not or improperly buckling the safety seat with the cars safety belts	12	1
Nor or improperly buckling the child with the seats safety strap	62	4
Placing the safety seat on unstable objects	19	2
Sub-total	116	
Total	594	

3.4 Accident Scenario

The SASA devised accident scenarios for the hazard factors based on the accident analysis tableau described in the previous section. In this section, we

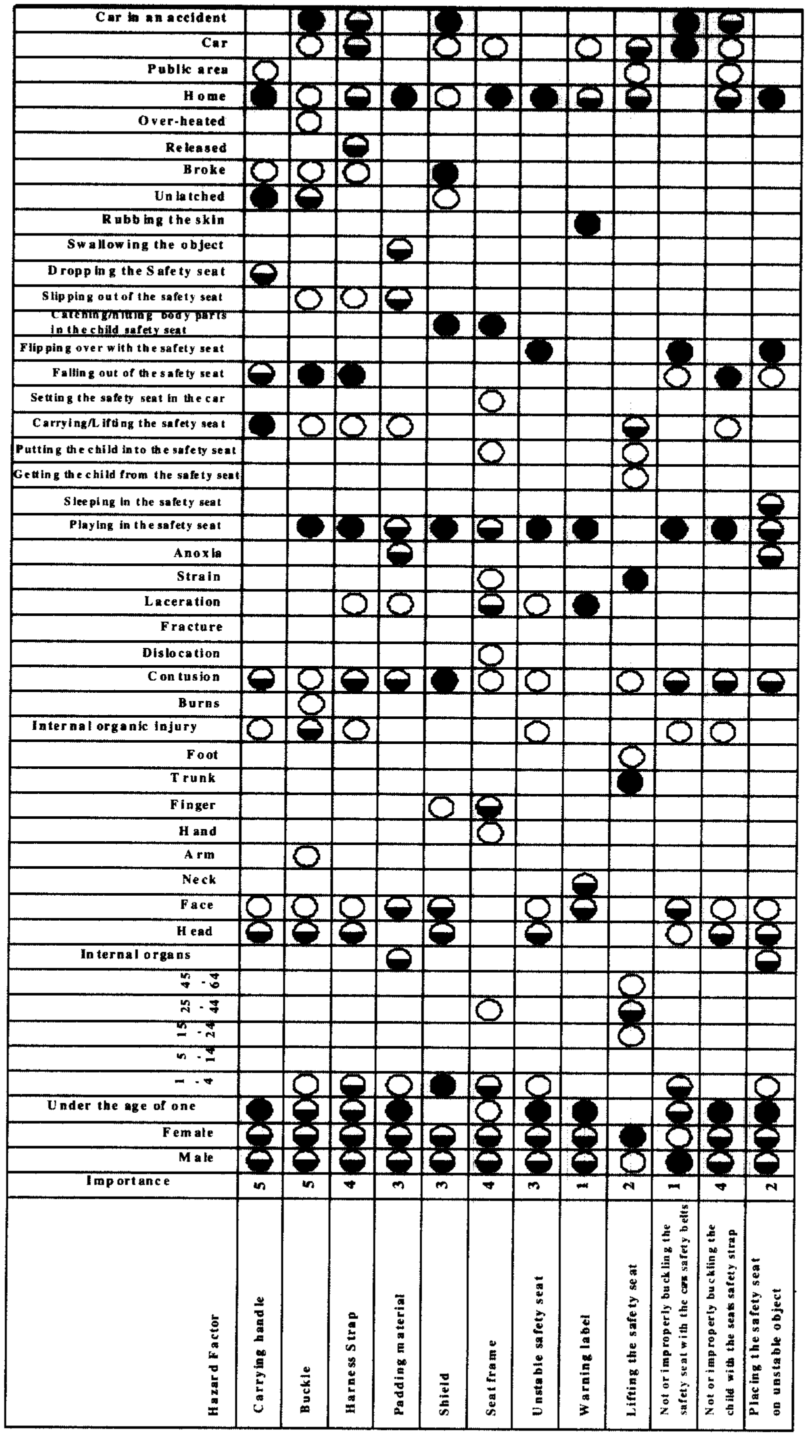
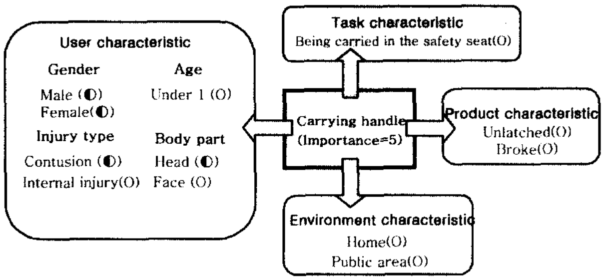


Figure 2. Accident Analysis Tableau in Child Safety Seat Case.

used the hazard factor 'carrying handle' as an example to demonstrate our process. The 'carrying handle' has a maximum of 64 accident scenarios when examining all the possible relationships with the situation characteristics as shown in <Figure 3>. Sixteen scenarios, however, were filtered out due to infeasible relationships between situation characteristics. For example, the injury type 'internal injury' is not compatible to the injured body part 'face'. As such we have excluded the following infeasible relationship from further analysis:

- Males under the age of one suffering an internal face injury from the safety seat falling from the carrier after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home.



Number of all possible accident scenarios=2(gender)×1(age)×2(injury type)×2(body part)×2(accident type)×1(task characteristic)×2(product characteristic)×2(environment characteristic)=64

Figure 3. Relationships Between the Carrying Handle and Situation Characteristics.

The total weights were calculated for the remaining feasible scenarios. The top ranked accident scenarios are listed as follows:

- Males under the age of one suffering a head contusion from the safety seat falling from the carrier after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home(total weight=160);
- Females under the age of one suffering a head contusion from the safety seat falling from the carrier after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home(total weight=160);
- Males under the age of one suffering a head contusion from falling out of the safety seat after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home(total weight=160);
- Females under the age of one suffering a head contusion from falling out of the safety seat after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home(total weight=160).

The difference between each accident scenario is the gender and accident type, with the rest being the same. They are clustered into one accident scenario as follows:

- Infants under the age of one suffering a head contusion from the safety seat falling from the carrier or from falling out of the safety seat after the carrying handle unlatched. The carrying handle unlatched as they were being carried at home (average total weight=160).

The clustering process, which combines the many feasible scenarios—those with the same total weight—into one makes analyses much easier. In the clustering process, the average total weight is calculated to determine the prominence of clustered scenarios. The higher the average total weight, the more important the clustered scenario is. To calculate the average total weight, the sum of the total weight of a clustered scenario is divided by the number of combined feasible scenarios in each clustered scenario.

3.5 Results

The accident analysis tableau resulted in a maximum of 2828 accident scenarios from all possible relationships between the hazard factors and situation characteristics. Among them, however, 1200 scenarios were found to be feasible. The clustering process reduced them to 270 scenarios. However, the large number of scenarios is still a barrier to getting a clear overview of the accident situations. In order to fully understand the accident situations, we performed the patterning process by grouping the clustered accident scenarios using an equality and/or inequality symbol while maintaining the feasibility of the scenarios. For example, 'males=females' indicates that there is no gender difference in the accidents. Therefore, we describe 'males=females' as infants or adults in the scenarios. 'At the time of car accidents>at home=in a car' indicates that the accidents occur more frequently at the time of car accidents than at home or in a car. However, no difference exists between at home and in a car. <Table 2> shows a total of 29 accident scenario patterns for the child safety seat case.

Situation characteristics classify accident scenarios into several patterns. Two patterns are found for hazard factors such as 'carrying handle', 'padding material', 'unstable safety seat', 'not or improperly buckling the safety seat with car's safety belts', and 'placing the safety seat on unstable objects'. The patterns are categorized by user characteristics such as injury type and injured body parts. For example, the accident scenarios for 'carrying handle' are grouped by injured body parts 'head' and 'face'. The accident scenarios for 'seat frame' have two patterns. The patterns are, however, classified by the task characteristics, 'playing in the safety seat' and 'putting the child into the safety seat or setting the safety seat'. The accident scenarios show four patterns for the hazard factors of 'harness strap' and 'not or improperly buckling the child with the seat's safety strap'. They are grouped by user, task, and environ-

Table 2. Patterns of the Accident Scenarios

Hazard factors	Patterns	ATW	Rank
Product failure			
Carrying handle	• Infants under the age of one suffering a head(contusion>internal injury) from (the safety seat falling from the carrier=falling out of the safety seat) after the carrying handle(unlatched>broke). The carrying handle (unlatched >broke) as they were being carried(at home>in a public area).	135	1
	• Infants under the age of one suffering a face contusion from (the safety seat falling from the carrier=falling out of the safety seat) after the carrying handle(unlatched>broke). The carrying handle(unlatched>broke) as they were being carried(at home>in a public area).	130	2
Buckle	• Infants(under the age of one>between the ages of one to four) suffering head(internal injuries>contusion) from(falling>slipping) out of the safety seat after the buckle(unlatched>broke). The buckle(unlatched>broke) as they were playing in the safety seat(at the time of the car accident>at home =in a car).	112	3
	• Infants(under the age of one>between the ages of one to four) suffering head(internal injuries>contusion) from(falling>slipping) out of the safety seat after the buckle(unlatched>broke). The buckle(unlatched>broke) as they were being carried at home.	85	10
	• Infants(under the age of one>between the ages of one to four) suffering (face=arm) contusion from(falling>slipping) out of the safety seat after the buckle(unlatched>broke). The buckle(unlatched>broke) as they were playing in the safety seat(at the time of the car accident>at home=in a car).	97	5
	• Infants(under the age of one>between the ages of one to four) suffering (face=arm) contusion from(falling>slipping) out of the safety seat after the buckle(unlatched>broke). The buckle(unlatched>broke) as they were being carried in the safety seat at home.	70	16
	• Infants(under the age of one>between the ages of one to four) suffering arm burns from an overheated buckle frame. The buckle overheated as they were playing in the safety seat(at home=in a car).	55	22
	• Infants(under the age of one>between the ages of one to four) suffering arm burns from an overheated buckle frame. The buckle overheated as they were being carried at home.	50	23
Harness strap	• Infants under the age of four suffering a head(contusion>laceration =internal injury) from(falling>slipping) out of the safety seat after the strap retainer clip(loosened>borke). The strap retainer clip(loosed>broke) as they were playing in the safety seat(at home=in a car=at the time of car accident).	95	7
	• Infants under the age of four suffering a head(contusion>laceration= internal injury) from(falling>slipping) out of the safety seat after the strap retainer clip(loosened>borke). The strap retainer clip(loosed>broke) as they were being carried at home.	79	13
	• Infants under the age of four suffering a face(contusion>laceration) from (falling>slipping) out of the safety seat after the strap retainer clip(loosened >broke). The strap retainer clip(loosed>broke) as they were playing in the safety seat(at home=in a car=at the time of car accident).	88	9
	• Infants under the age of four suffering a face(contusion>laceration) from (falling>slipping) out of the safety seat after the strap retainer clip (loosened >broke). The strap retainer clip(loosed>broke) as they were being carried in the safety seat at home.	64	20

(□=Average total weight)

Table 2. Patterns of the Accident Scenarios(continued)

Hazard factors	Patterns	ATW	Rank
Padding material	• Infants(under the age of one>between the ages of one to four) suffering a face(contusion>laceration) from slipping out of the safety seat because the seat padding was so slippery. The infants were(playing>being carried) in the safety seat at home.	63	21
	• Infants(under the age of one>between the ages of one to four) suffering asphyxiation from swallowing the seats pad. The infants were(playing> being carried) in the safety seat at home.	66	18
Shield	• Infants between the ages of one to four suffering a(head=face>finger) contusion from hitting the shield after the shield(broke>unlatched). The shield(broke>unlatched) as they were playing in the safety seat(at the time of the car accident>at home=in a car).	92	8
Seat frame	• Infants(between the ages of one to four>under the age of one) suffering(finger>hand)(laceration>contusion=dislocation=strain) from getting their(fingers>hands) caught/hit in the safety seat frame. The infants were playing in the safety seat(at home>in a car).	78	14
	• Adults between the ages of twenty-five to forty-four suffering(finger >hand)(laceration>contusion=dislocation=strain) from getting their(fingers> hands) caught/hit in the safety seat frame. The adults were(putting the child into the safety seat=setting the safety seat)(at home>in a car).	66	18
Unstable safety seat	• Infants(under the age of one>between the ages of one to four) suffering head(internal injury=contusion=laceration) from flipping over with the safety seat because the seat was not stable. The infants were playing in the safety seat at home.	75	15
	• Infants(under the age of one>between the ages of one to four) suffering a face(contusion=laceration) from flipping over with the safety seat because the seat was not stable. The infants were playing in the safety seat at home.	69	17
Warning label	• Infants under the age of one suffering a(neck=face) laceration from rubbing the skin; the surface of the warning label was rough. The infants were playing in the safety seat(at home>in a car).	28	27
<u>Foreseeable user negligence</u>			
Lifting the safety seat	• (Females>Males)(between the ages of twenty-five to forty-four>between the ages of fifteen to twenty-four=between the ages of forty-five to sixty-four) suffering(back>foot)(strain>contusion) when they(lifted the safety seat>got the child from the safety seat=put the child into the safety seat)(from their car=at home>in a public area).	29	26
Not or improperly buckling the safety seat with the cars safety belts	• (Males>Females) under the age of four suffering a face contusion from(flipping over with the safety seat>falling out of the safety seat) because the seat was not or improperly fastened with the cars safety belts. The(males>females) were playing in the safety seat(at the time of the car accident=in a car).	25	28
	• (Males>Females) under the age of four suffering a head(contusion>internal injury) from(flipping over with the safety seat>falling out of the safety seat) because the seat was not or improperly fastened with the cars safety belts. The(males>females) were playing in the safety seat(at the time of the car accident=at car).	22	29

Table 2. Patterns of the Accident Scenarios (continued)

Hazard factors	Patterns	ATW	Rank
Not or improperly buckling the child with the seats safety strap	• Infants under the age of one suffering a head(contusion>internal injury) from falling out of the safety seat because they were not or improperly strapped. The infants were playing in the safety seat(at the time of the car accident=at home> in a public area=in a car).	100	4
	• Infants under the age of one suffering a face contusion from falling out of the safety seat because they were not or improperly strapped. The infants were playing in the safety seat(at the time of the car accident=at home> in a public area=in a car).	96	6
	• Infants under the age of one suffering a head(contusion>internal injury) from falling out of the safety seat because they were not or improperly unstrapped. The infants were being carried(at home> in a public area).	84	11
	• Infants under the age of one suffering a face contusion from falling out of the safety seat because they were not or improperly strapped. The infants were being carried(at home>in a public area).	80	12
Placing the safety seat on unstable objects	• Infants(under the age of one>between the ages of one to four) suffering asphyxiation from(flipping over with the safety seat>falling out of the safety seat) because the seat was placed on unstable objects such as a bed or a couch. The infants were(sleeping in the safety seat=playing in the safety seat) at home.	46	24
	• Infants(under the age of one>between the ages of one to four) suffering a(head>face) contusion from(flipping over with the safety seat>falling out of the safety seat) because the seat was placed on unstable objects such as a bed or a couch. The infants were(sleeping in the safety seat=playing in the safety seat) at home.	44	25

ent characteristics.

In the case study, the accident scenarios for 'buckle' failures have the most varying patterns. There are six patterns grouped by a large number of situation characteristics related to the hazard factor; i.e. the interaction between the user and product is very complicated. On the contrary, accidents from the 'shield', 'warning label', and 'lifting the safety seat' are grouped into only one pattern. This implies that the accident causation between the hazard factors and situation characteristic is simple.

The average total weight for each accident pattern, as shown in <Table 2>, was calculated in the same manner as in the clustering process. The accident pattern for 'carrying handle' had the highest average total weight of 135 among all the accident patterns in product failure and foreseeable user negligence cases. This accident pattern is composed of 32 feasible scenarios(that is, 2(male=female)×1(under the age of one)×1(head)×2(contusion>internal injury)×2(the carrier dropping the safety seat=falling out of the safety seat)×2(unlatched>broke)×2(at home>in a public area)=32).

The accident pattern for 'carrying handle' informs us that the victims are infants under the age of one suffering head contusions or internal head injuries. They were injured when the seat was dropped while they were in the seat or by falling out of the safety seat. An unlatched or broken handle caused the accidents while the seat was being carried at home or in a public area. In this accident pattern, there are no gender and accident type differences but the accidents caused more head contusions than internal head injuries, and occurred more frequently at home than in a public area.

The accident pattern for 'not or improperly buckling the child with the seat's safety strap' showed the highest average total weight of 100 in foreseeable user negligence cases(<Table 2>). This accident pattern has 16 feasible scenarios, which tells us that the victims were mostly infants under the age of one. They suffered head contusions or internal head injuries from falling out of the safety seat. They were playing in the safety seat at the time of a car accident, at home, in a public area, or in a car. In this accident pattern, there is no gender difference but the accidents caused more head contusions than internal head injuries, and occurred more frequently at the time of car accident than in a public area or in a car. However, there was no difference between at the time of car accident and at home.

Through a detailed analysis of the accident patterns, general guidelines and principles of design can be recommended for a safer child safety seat. To avoid carrying handle' failure, for example, the handle must not only be made of durable and hard materials but also must be equipped with a firm latching mechanism. And to avoid accidents from 'padding material', the padding must be made of non-slippery materials to eliminate accidents from slipping out of the safety seat. Appropriate warnings and instructions for padding materials should be provided to inform the user of any hazards from the ingestion of a harmful substance. Warnings and instructions are also necessary to prevent accidents from foreseeable user negligence. For accidents caused by 'lifting the safety seat', proper lifting postures should be detailed, while the seat itself must be made of lightweight materials. The design of a convenient lifting mechanism is another requirement for lifting the seat safely.

Design strategies for protecting the child's head should be provided as well because accidents from the child safety seat cause mostly head injuries. An accident pattern of accident scenarios relating to head injuries was found for the various hazard factors, except for 'padding material', 'seat frame', 'warning label', and 'lifting the safety seat'. The NEISS data showing that about 6195 head injuries were suffered by infants under the age of four in accidents related to child safety seats from 1996 to 1997 supports our result(CPSC, 1998). Head injuries were 38% of total injury cases. Therefore, as part of an ongoing effort, the manufacturer should conduct an in-depth design study to reduce child safety seat-related head injuries. Furthermore, in addition to the overall design change, instructions on wearing head protection equipment such as a helmet are also strongly recommended.

4. Discussion and Conclusion

We believe that a systematic analysis methodology using user-product accident scenarios will help design safer products. According to Warne(1982), information about accidents associated with particular products should be of value to manufacturers for a number of different reasons: First, it will help identify the obvious manufacturing and design defects contributing to an accident; Second, it will highlight patterns of misuse which can lead to personal injury; Last, it will identify the environment in which accidents occur. Most product injury data collection systems provide information about the types of accidents and their environment. Due to the lack of detailed descriptions on the interaction between a user, a task, a product, and an environment, however, such accident data are insufficient for understanding the actual accident process.

The SASA deals with the accident scenarios in foreseeable misuse of products. In the case of the child safety seat, much work has been done to identify the misuse patterns(Bull *et al.*, 1988; Decina and Knobel, 1997; Block et al. 1998). Most of the previous studies have relied on observational methodologies and noted specific types of misuse such as seat direction, attachment of the safety seat to seat belt, and harness strap mechanism. In addition to these misuse patterns, the SASA reveals that 'lifting the safety seat' and 'placing the safety seat on unstable objects' identified in this case study should also be added to the possible misuse type.

Aside from the advantages mentioned above, the SASA is superior to the traditional scenario analysis method: the SASA can identify, generate, analyze, and verify product use accident scenarios while maintaining objectivity and accuracy. Through identifying the hazard factors and situation characteristics, the accident analysis tableau, including all the possible relationships between them, was developed. This tableau inspired by the QFD matrix stresses systematic process while keeping subjectivity to a minimum. The tableau created accident scenarios through the feasibility and clustering processes. The SASA can analyze scenarios quantitatively as well as qualitatively. The total weight ranks frequency of occurrence of the accidents scenarios, which helps us to build more timely and better accident prevention strategies.

The key to any safe product design is identifying all design solutions for reducing and preventing accidents, and then properly implementing them in the product design and development process. Kanis and Weggel(1990) suggest that design solutions for a specific product be extracted from the detailed descriptions of accidents. Based on a thorough analysis of accident scenarios, the SASA recommends design guidelines for a safer product. Ideally, these guidelines should be translated into a new design. However, if it is impossible or unjustifiable to implement due to technological or financial reasons, instructions and warnings should be labeled elsewhere on the product to alert the user. Therefore, the SASA provides effective measures for reducing and preventing product liability lawsuits and improving consumer satisfaction.

The use of the SASA is limited to the redesign of defective products or the design of similar ones with better quality. Despite these limitations, the SASA is still useful when adopting a systematic approach to designing new products. As a result, it will contribute to a reduction in product related risks.

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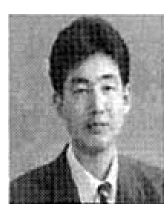

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