Presenting Potential Injury Risk by Biomechanical Simulation Based on Bodygraphic Injury Data

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ABSTRACT

Injury prevention is one of the most important and urgent issues in children's health since the primary cause of death of children is unintentional injury. Injury prevention requires making safe products as well as safe environments by evaluating the risks. This paper proposes a system for presenting and evaluating potential risk of injury by using a biomechanical simulation based on bodygraphic injury data collected in hospitals. To prove the effectiveness of the proposed system, this paper describes the application of the system to the risk analysis of a playground swing in a park. The potential risk of head injury around the swing equipment was calculated by using a physical simulator consisting of a multi-body model, a finite element model of a child's head, and an injury database.

Categories and Subject Descriptors

K.4.1 [**COMPUTERS AND SOCIETY**]: Public Policy Issues—*Human safety*; I.6.3 [**SIMULATION AND MODELING**]: Applications; I.6.8 [**SIMULATION AND MODELING**]: Types of Simulation—*Combined*

General Terms

Human Factors

Keywords

Hazard identification, Injury prevention, Injury surveillance, Impact biomechanics, Injury informatics

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1. INTRODUCTION

Recently, childhood unintentional injuries have been recognized as a social problem in Japan as well as in other countries. Table 1 shows the leading causes of death among children in Japan[1]. As shown in this table, unintentional injuries are the primary cause of death among children of ages 1 to 14 years.

Table 1: Causes of Death among Children in Japan

Age	First	Second	Third	Fourth	Fifth
0	Birth defect / Chromosomal aberration (37.0%)	Respiratory disturbance / Angiopathy (13.3%)	Sudden death syndrome (5.2%)	Unintentional injury (4.5%)	Fetal hemorrhagic disorder (4.3%)
1-4	Unintentional injury (18.0%)	Birth defect / Chromosomal aberration (16.1%)	Malformation neoplasma (8.7%)	Heart disease (6.1%)	Pneumonia (6.0%)
5-9	Unintentional injury (27.2%)	Malformation neoplasma (17.4%)	Pneumonia (6.7%)	Birth defect / Chromosomal aberration (6.5%)	Heart disease (5.6%)
10-14	Unintentional injury (23.2%)	Malformation neoplasma (20.8%)	Suicide (8.8%)	Heart disease (6.7%)	Birth defect / Chromosomal aberration (5.2%)

This trend is common throughout the world. According to the world report on children injury that was published by the World Health Organization (WHO) in December 2008 [2], unintentional injury is a major killer of children under the age of 18 years and is responsible for approximately 950,000 deaths. After the age of 1 year, unintentional injuries are significant contributors to the deaths of children and teenagers. Due to the present awareness of this subject, WHO has formulated a 10-year global strategy for child injury prevention by promoting research and preventive activities in all countries [3].

In the industrial world, the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) prepared ISO/IEC Guide 51 to provide guidelines on the safety aspects in standards [4]. This guide presents the process of risk assessment (risk analysis and risk evaluation) for reducing the risk in the use of products. The term "risk" here is defined as a com-

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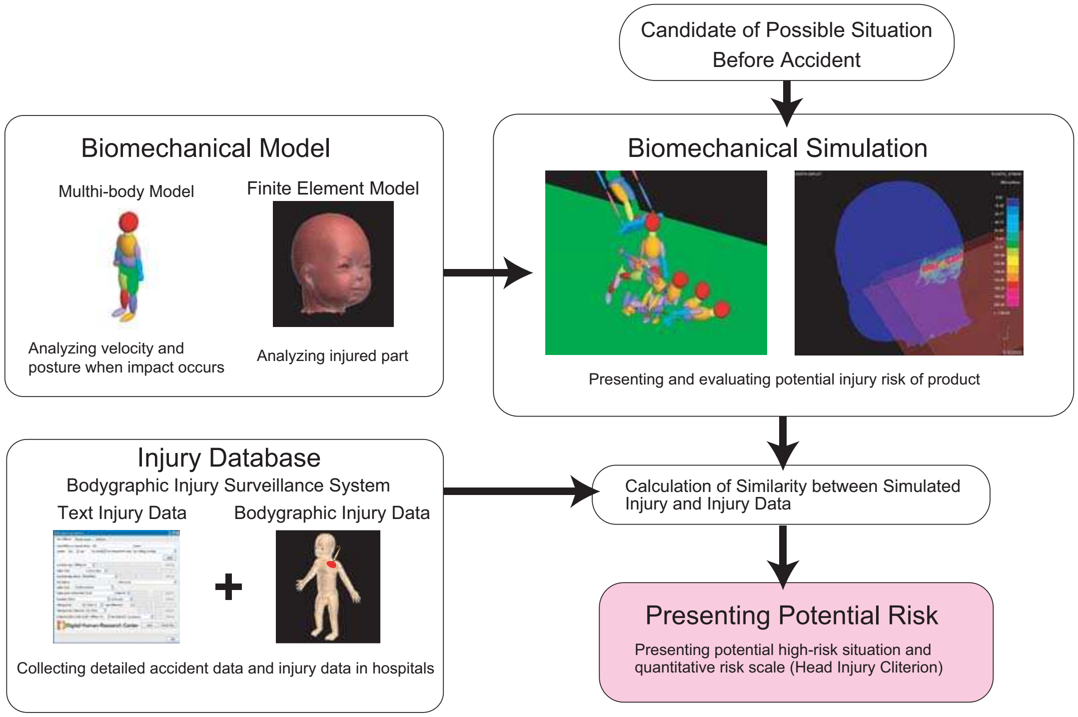

Figure 1: Configuration of the Proposed System

bination of the probability of occurrence of harm and the severity of that harm. In addition, the guide describes the indispensability of risk assessment, although it only presents the concept and abstract process and does not provide any concrete solutions. The conventional risk assessment has been carried out subjectively by product manufacturers. In addition, usage of a product in a way that manufacturers are not intended is recognized as misuse. This is especially true in children accidents, because they sometimes use products in ways that adults would never think of. This can cause the problem that no measures are taken. Therefore, a function for presenting and evaluating potential injury risk of product is important. This allows us to carry out quantitative risk assessment for injury prevention.

In the impact biomechanics field, many studies have been carried out using a cadaver [5], dummy [6], multi-body model [7], and finite element model [8] to clarify the effects of impacts and the process of injury occurrence when a person is subjected to forces and impacts. However, it is difficult to assess the injury risk of a product by only these technologies. First, it is still difficult to predict the severity of injury using these methods since these technologies provide only impact prediction data without clarifying the relationship between impact prediction and injury. Second, children's behavior before an accident is not considered since how they act or play is unclear scientifically. Consequently, it is difficult to determine the probability of injury occurrence and the severity of that injury, both of which are important factors in risk assessment.

To develop a method for evidence-based risk assessment, we need to collect data on injuries. For injury data, the authors are developing a Bodygraphic Injury Surveillance System (BISS) for continuously collecting detailed accident information in hospitals [9]. Since November 2006, we have operated this system in cooperation with two hospitals and collected more than 6,000 records of injuries on children going to a hospital due to injury. BISS allows statistical analysis of the collected injury data, such as injury statistics and body spatial statistics.

This paper proposes a new system for presenting and evaluating the potential injury risk by using a biomechanical simulation based on both bodygraphic injury data collected in hospitals. To prove the effectiveness of the proposed system, this paper reports the risk analysis of a playground swing in a park as an application of the proposed system.

2. SYSTEM FOR PRESENTING AND EVALUATING POTENTIAL INJURY RISK

Fig. 1 shows the configuration of the proposed system for presenting and evaluating potential injury risk. This system consists of an injury database, a children's behavior model, a biomechanical model and a biomechanical simulation engine. The details are as follows.

2.1 Injury Database

2.1.1 Need for Integration of Injury Database and Biomechanical Simulation

In general, impact analysis by biomechanical simulation can calculate physical quantities such as acceleration and stress, but not the type of injury and degree of severity. Conversely, injury data collected in hospitals do not include physical quantities. Therefore, the relation between injury and the physical quantities indicating the impact force remains to be clarified. Biomechanical simulations have been carried out using various evaluation indicator obtained by experiment with a cadaver[5][10][11][12]. However, only these values do not allow us to answer more definitively how severe injury is caused in a living body. Integrating biomechanical simulations and hospital-based injury surveillance data allows us to associate simulated physical quantities with the type of injury and degree of severity as follows. First, we biomechanically simulate

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injured region by giving some conditions. Second, we compare the simulated injured region with injured region of accidents that the actually occurred, and select the injury data whose injured region is the most similar with the simulation result. The selected injury is likely type of injury and likely degree of severity under the given conditions.

2.1.2 Collecting Injury Data

The authors have been developing BISS for collecting detailed accident information in hospitals. BISS enables us to collect more than 20 kinds of text data, such as type of injury, cause of injury, degree of severity, and person(s) involved in the accident. In addition, the location, shape and attribute data of an external injury is collected by drawing on a three-dimensional human body model with a computer mouse, as shown in Fig. 2. The input injury data is converted to raster data and stored in the database system. Since the standard human body model is used, injury data is normalized.

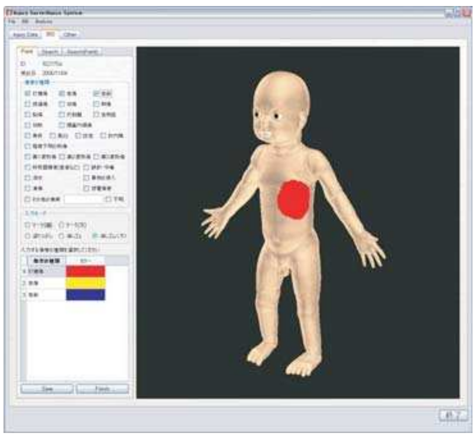

Figure 2: Input of Injury Data by Using a Computer Mouse to Draw a Shape

BISS also allows us to conduct new statistical analyses [13]. As one example of data visualization using BISS, we describe the bodygraphy of injury frequency. Fig. 3 shows the injury frequencies retrieved and visualized with only the necessary data on demand. Since each instance of injury data is expressed in a normalized and structured form in BISS, we can calculate the conditional probability distribution of an injury by counting injury frequencies under given conditions. In the figures shown here, a red color indicates the area with the highest frequency of external injury. Part A of the figure visualizes the bodygraphic frequency of a scald injury, Part B is the frequency of injury due to a fall by children of ages 1 to 2 years, Part C is the frequency of injury due to a playground slide, and Part D is injury due to all kinds of playground equipment.

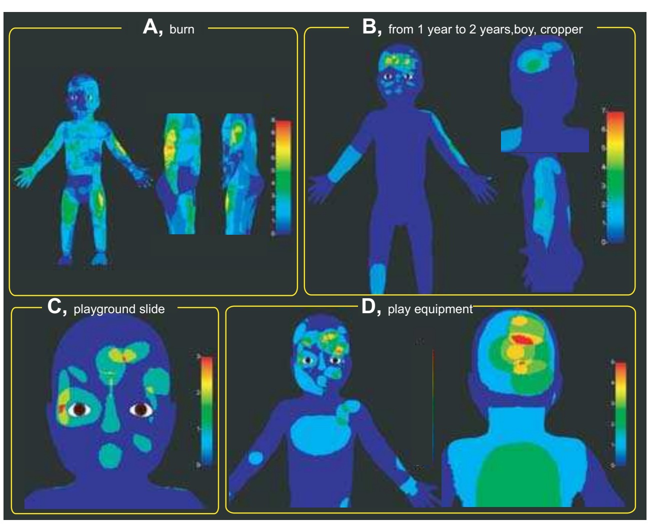

Figure 3: Examples of Injury Retrieval and Frequency Visualization (Conditional Injury Probability Distribution)

In addition to the search function stated above, BISS allows us to clarify the relation among design parameters and injured body regions by Bayesian Network Model[14]. Bayesian Network Model is a probabilistic model which can probabilistically model a structure of a causal relationship among factors. This is constructed automatically by using a stepwise method based on Akaike information criterion (AIC)[15]. In this model, the dependence among stochastic variables is visualized as shown in Fig. 4, and the quantitative relationships among the variables are decided by the conditional probability. That is useful for improving consumer products as follows.

Using Bayesian Network Model, we can represent the consumer products by using various factors consisting of 1) the parameters that we want to control (e.g., injury), 2) the parameters that we can change and operate (e.g., material of products), and 3) the parameters that we cannot change but that are important explaining variables (e.g., child's age). A product designer can find the relationship among the parameters and injury and obtain new knowledge for improving safety of consumer products.

2.2 Biomechanical Simulation

2.2.1 Multi-body Model

The multi-body model, composed of rigid links connected by joints, has the advantages of short calculation time and ease of posture changes. The multi-body model is useful for carrying out a large amount of simulations needed to reproduce the accident situation and present the potential injury risk. As shown in Fig. 5, the multi-body model used in this research is constructed based on the method in Miyazaki et al. [7]. It has the dimensions of Japanese children and consists of 17 ellipsoidal segments and 16 joints. The relationships for contact stiffness are defined by using the data of a Hybrid-III dummy.

By using this model, a large amount of simulations can be carried out to clarify whole body behavior and to provide us with the Head Injury Criterion (HIC) in this research. HIC, calculated from linear acceleration responses at the head's center of gravity (COG), is the tolerance for a skull fracture or brain concussion. The tolerance is 1000.

2.2.2 Finite Element Model

The finite element model allows us to analyze in more detail, although the calculation time is longer than that of the multi-body model. For example, the finite element method (FEM) can evaluate the risks for the occurrence of head injury and display the location of injury by applying the head motion calculated in the multi-body simulation as the boundary condition.

In this research, the three-dimensional human body model of BISS forms the basis for the finite element model of a head, shown in Fig. 6, to integrate the injury model and biomechanical simulation. The mechanical attributes of the model are defined by using the data of a Hybrid-III dummy as well as the multi-body model.

The authors are also proceeding in joint research with the Au-

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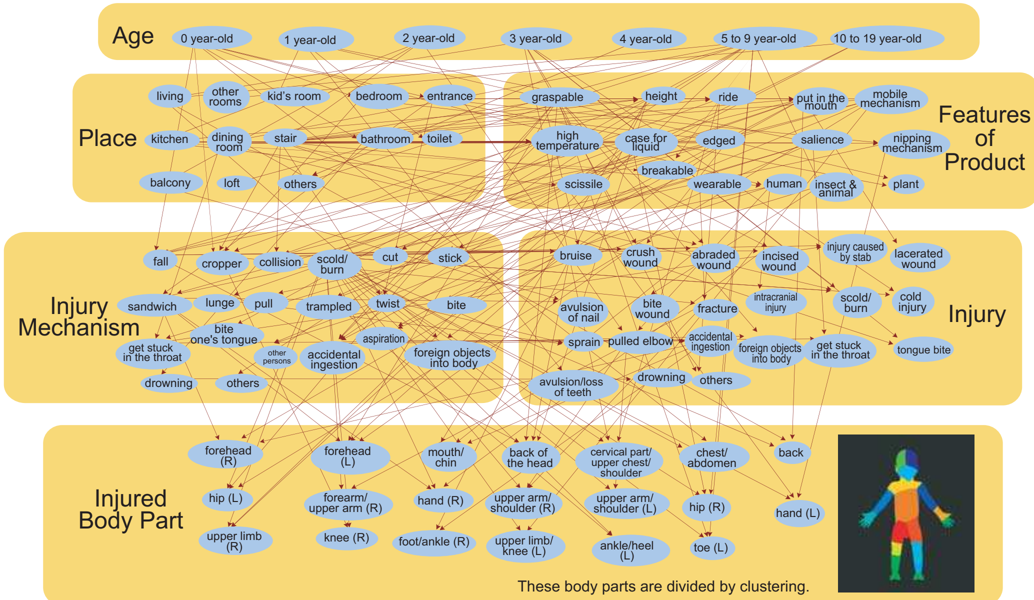

Figure 4: Examples of multiple classification analysis (Bayesian network analysis)

Figure 5: Multi-body Model of a Child

Figure 6: Finite Element Model of a Head

topsy Imaging (Ai) Center at Chiba University Hospital and the Forensic Medicine Class, Chiba University, to investigate the dynamical property of human body tissue to improve the technology with medical expert opinion. In the future, we plan to apply the knowledge obtained in this joint research to injury prevention.

2.3 Simulation Procedure

In this subsection, we describe how the injury database and biomechanical simulation are integrated through the simulation procedure.

2.3.1 Presenting and Evaluating Potential Injury Risk of the Product

We next describe the procedure for presenting and evaluating the potential injury risk of the product. Fig. 7 illustrates the flow.

1. The system produces a candidate of the situation at the time when a child uses a target product and another child plays around the target product.

2. The system simulates the possible accident process caused by the candidate situation before the accident and calculates the posture and velocity immediately before the impact occurs by the multi-body model.

3. The system calculates the injured body part by the finite element model.

4. The system calculates the similarity between the simulated injured part and the actually injured part using the injury database by searching for the most similar injury case from the injury database. This allows us to estimate the type of injury and the degree of severity.

3. APPLICATION OF THE PROPOSED SYSTEM

To prove the effectiveness of the proposed system, this section describes the application of the system to the risk analysis of a playground swing in a park.

3.1 Collection of necessary data for simulation

We conduct the risk analysis of a playground swing in a park. More concretely, we analyze the injury which stems from interactions such as colliding and pushing with the other child as well as

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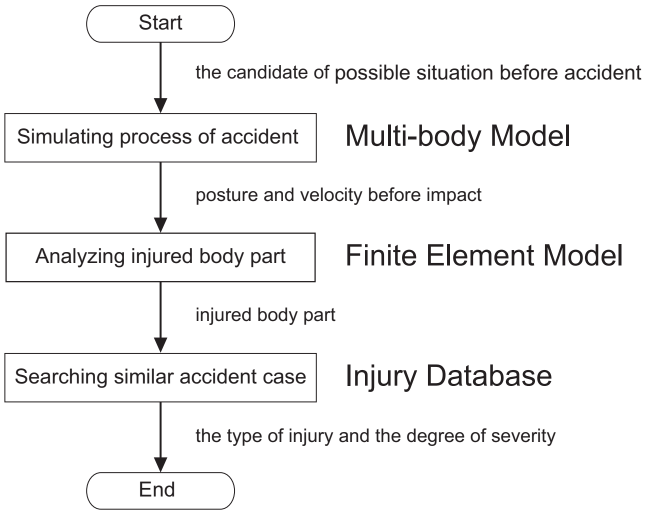

Figure 7: Procedure for Presenting and Evaluating Potential Injury Risk of Product

interactions with the swing equipment itself. First, it is necessary to determine velocity of the swing when the child plays with it as initial condition. In order to obtain the swing velocity data by image processing, we took video pictures of a child playing with a swing equipment in the park, as shown in Fig. 8.

Figure 8: Swing Velocity Data from Video

3.2 Simulation Result

We conducted simulation in accordance with the procedure described in Section 2.3.1. As the first step of the procedure, we made the parameters that express candidates of the situations at the time when a child uses a swing equipment and another child plays around the swing equipment based on the data obtained in Section 3.1.

As the second step, the biomechanical simulation of situation candidates by using the multi-body model was conducted. Fig. 9 shows an example of analyses by the multi-body model. Thus, the system can present possible accidents that have not yet occurred.

As the third step, an analysis of the head injury in the impact case was conducted using the finite element model of the head with the posture and velocity data obtained from the multi-body analysis as the initial conditions. The head injury analysis allows us to obtain the location of the external injury. The coordinate system of this finite element model corresponds to that of the three-dimensional human body model of BISS. Therefore, we can calculate the similarity between the simulated injury area and the actually occurring injury area using the injury database of BISS. This is the forth step of the procedure. In this study, we calculate the distance between the centers of gravity as the similarity. Fig. 10 shows an example of the largest similarity of the position of the actual injury (red area) and that of the simulated injury (blue area) under the given conditions. In this case, the corresponding accident case data is as follows. The injured child was a girl 2 years, 0 months of age, 87 centimeters in height and 11 kilograms in weight. In the park, she was passing behind the playground swing that another child was playing on, and she bumped her face against the seat of the wood swing. Her uncle saw the accident occur. She suffered a bruise on the right side of her face. In this way, we can search for corresponding case data by giving a variety of conditions for a child's behavior before an accident.

In addition, the system allows us to evaluate its risk in terms of the HIC scale. In the case shown in Fig. 9, HIC for a child moving on the ground is 749 and that for a child playing on the swing is 41. The HICs of both children did not exceed the tolerance value. This result means that the possibility of occurrence of fatal head injury is low.

Fig. 11 shows the histogram of 480 calculated HICs. Repeating a large amount of simulations like this is useful for presenting the potential injury risk.

4. CONCLUSIONS

In this paper, we proposed a new system for risk assessment by a biomechanical simulation with a hospital-based injury surveillance database. The system allows a product designer and/or park manager of a municipality to predict the types of injuries that can occur in a daily environment. The developed system can search the candidates of possible situations resulting in serious injuries by using the injury data, and evaluate the risk quantitatively by using the biomechanical simulation (in terms of the head injury criterion (HIC) in our example). To prove the effectiveness of the proposed system, this paper reported the application of the system to the risk analysis of a swing in a playground where multiple children were playing.

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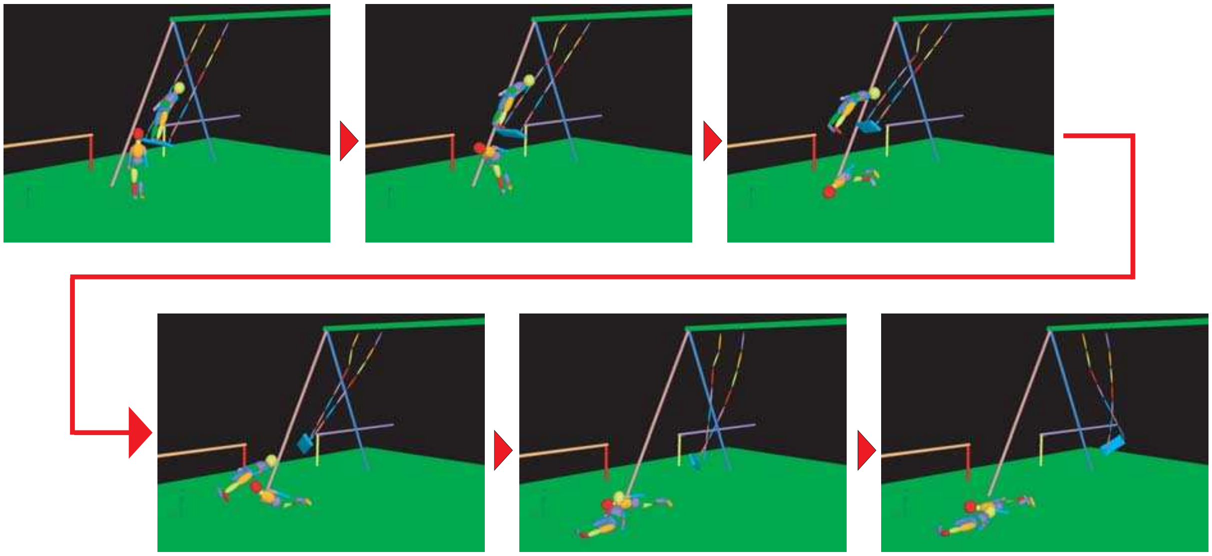
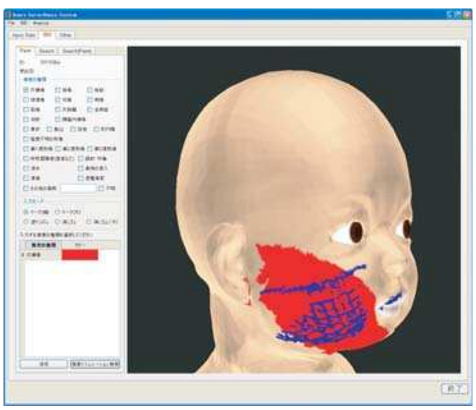


Figure 9: Possible Accident Situations



Red :Injury area accumulated
in Bodygraphic Injury Surveillance System
Blue:Injury area obtained by simulation

Figure 10: Comparative Result of Injury Location

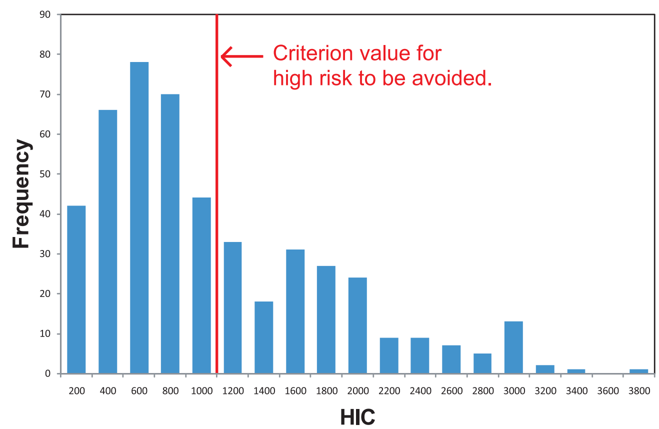


Figure 11: Histogram of HIC

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