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Establishment of 3D-printed Child Manikins Using Anthropometric Data of 6- and 10-year-old ASEAN Children

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Abstract – *The New Car Assessment Programme for Southeast Asian Countries (ASEAN NCAP) has been working hard to increase vehicle safety levels in the ASEAN region. To ensure a significant impact on the ASEAN community, few enhancements need to be made to their test methodology and facilities. As an example, ASEAN NCAP is using child manikins with generic build in their vehicle safety assessment. Meanwhile, vehicle manufacturers and product developers are also using these generic references in their product designs such as the seat restraint system, child seat design, etc. For the improvement of vehicle safety especially for the ASEAN region, dedicated manikins with ASEAN anthropometric measurements are necessary. This paper aims to describe the development of 3D-printed manikins based on anthropometric data of ASEAN children aged 6 and 10 years old. The completed prototypes will be tested using a selected vehicle safety assessment (i.e., Child Restraint System installation) and intended to be applied for design refinement of vehicle safety systems.*

Keywords: Anthropometry, ASEAN population, children, ASEAN NCAP, 3D-printed manikins, vehicle safety assessment, Child Restraint System (CRS) installation

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1.0 INTRODUCTION

The New Car Assessment Programme for Southeast Asian Countries (ASEAN NCAP) is using Q1.5 and Q3 dummies from Humanetics as children surrogates in their frontal-impact crash testing. Similar dummies (representing children aged between 6 and 10 years old) are also used for Child Restraint System (CRS) installation assessment procedure (ASEAN NCAP, 2018a and 2018b). These dummies were developed based on anthropometry parameters (stature & bodyweight) representing the universal population. With the rapid growth of human populations throughout the globe, physical characteristics of human body composition may have significant variation, particularly in terms of height, weight, and body mass index (BMI) (Pheasant & Haslegrave, 2006; Tesedo Nieto et al., 2011; Dawal et al., 2012). These variances are subjected to human diversity factors such as age, genetics, ethnicity, health, diet intake, and lifestyle (Hsu et al., 2016; Taifa & Desai, 2017). Another survey conducted on the Chinese population found that both the statures and body weights were relatively lower than the reference values of these dummies, indicating a mismatch of anthropometric measures between the populations of the two worlds most populated nations (i.e., USA and China) (Cao et al., 2016). Anthropometric variations between these two populations resulted in some design issues. Without the use of accurate anthropometric data, the performance of product design is limited.

With the view to enhance vehicle safety aspects in ASEAN, the need to establish dummies or test manikins according to the ASEAN anthropometric data is crucial. In April 2019, ASEAN NCAP together with a group of researchers from Universiti Teknologi Malaysia, King Mongkut's University of Technology North Bangkok, and Institut Teknologi Bandung, embarked on a project to collect body measurements across Malaysia, Thailand, and Indonesia for the development of ASEAN anthropometric database. Part of the collected data is presented in Mohd Zaki et al. (2020a and 2020b). These data are utilized in this work for the development of ASEAN test manikins for ASEAN NCAP's future use.

Apart from ASEAN NCAP as the main beneficiary, various organizations could benefit significantly from this work especially in fulfilling specific considerations towards the ASEAN NCAP requirements. Relevant stakeholders such as automotive manufacturers may want to consider utilizing the newly established ASEAN test manikins to develop their new products (especially related to vehicle safety applications such as CRS, restraint system, etc.) in the future. Nonetheless, it is also essential to utilizing the ASEAN test manikins to achieve the ergonomic design of products, design for vehicle safety (such as blind-spot reduction), and general vehicle design applications. This paper describes the development of 3D-printed manikins of ASEAN children aged 6 and 10 years old. The developed prototypes will be tested at the Malaysian Institute of Road Safety Research (MIROS) and ASEAN NCAP using selected vehicle safety assessments.

2.0 BACKGROUND STUDY

This section details the background study conducted in this research. Tables 1 and 2 outline basic references that have been studied from previous researches on ASEAN children's anthropometric data and anthropometric manikin. Meanwhile, Table 3 tabulates additional references relating to product development and design analysis approaches. Based on these tables, it can be concluded that there are limited works on the anthropometric database that can represent the ASEAN children's population. Additionally, these references give input on suitable criteria for design consideration, key points for manufacturing approaches and appropriate design analysis to be performed in developing the manikins.

3.0 METHODOLOGY

The workflow of this research incorporates five phases as illustrated in Figure 1 which include:

i. Phase 1: Development of detailed 3D-model of ASEAN manikins
ii. Phase 2: 3D-models optimization for Additive Manufacturing
iii. Phase 3: Fabrication of ASEAN manikin's body parts using 3D printer
iv. Phase 4: Product validation
v. Phase 5: Establishment of ASEAN children manikins

Based on Figure 1, three objectives of this study, which are – (i) to establish the detailed design of ASEAN children manikins; (ii) to develop full-sized 3D-printed ASEAN children manikins (6 and 10years old), and (iii) to validate using ASEAN NCAP CRS installation methodology, are expected to be achieved after completing Phase 2, Phase 3 and Phase 4, subsequently.

The details for each phase are as follows.

Phase 1: Development of detailed 3D-model of ASEAN manikins

In this study, three-dimensional (3D) Computer Aided Drawing (CAD) models of ASEAN manikins were developed using Fusion 360/Solidworks based on the established database as presented by Mohd Zaki et al. (2020a and 2020b). Each of the manikin's body parts was detailed up, and proper joints were established to ensure proper attachment of body parts during assembly. Various types of joints were studied, including the Lego joints.

Phase 2: 3D-models optimization for Additive Manufacturing

Once detail design was established, Fusion 360 Additive Manufacturing was used to further optimize the model. This phase is crucial to ensure minimum cost and waste during 3D printing while producing good quality manikins.

Phase 3: Fabrication of ASEAN manikin's body parts using a 3D printer

Optimized 3D models will then be used for the fabrication of the manikin's body parts using a 3D printer. The quality of the products will be monitored, and further modifications will be performed if needed.

Table 1: Previous works on ASEAN children's anthropometric data

Title/ Author	Subjects	Age Group	Area	Parameter	Measuring Equipment	Findings
Development of Anthropometric Database for ASEAN NCAP: A Case Study of Malaysian Children Aged 6 Years Old *Mohd Zaki et al.* (2020a)	143 Malaysian children aged 6 years old samples	6 years old	Malaysia	42 anthropometric parameters	Height and weighting scale, ruler and measuring tape	The developed database shows significant differences in anthropometric measurements (mainly on the weight, stature, sitting height, shoulder, breadth, and knee-length) to the existing manikins used by the industry. The mismatch of anthropometric data between different human populations in the world raises concern on product design aspects relating to many applications such as vehicle safety and ergonomics.
Anthropometric Status among 6–9-Year-Old School Children in Rural Areas in Hai Phong City, Vietnam *Hoang et al.* (2018)	2334 school children (boys and girls)	6 – 9 years old	Vietnam	3 parameters	Direct measurement method (i.e. weight scale and measuring tape)	The study aims to estimate the prevalence of undernutrition and overnutrition among primary school children in rural areas of Vietnam and sociodemographic factors associated with the population.
Indonesian Anthropometry Update for Special Populations Incorporating Drillis and Contini Revisited *Hartono* (2018)	498 children (boys and girls)	7 - 12 years old (children)	Indonesia	36 parameters	Direct measurement method (i.e., anthropometric tape, small stool, and weighing scale meter)	The research provides a comparative study between elderly and children anthropometry using Drillis and Contini approach to update special populations in Indonesia incorporating Chinese and non-Chinese ethnic groups.
Anthropometric Data of Primary School Children in Malaysia for School Chair Design *Yuhaniz et al.* (2018)	2400 school children (boys and girls)	7 – 11 years old	Malaysia	6 parameters	Direct measurement method (i.e. custom-made anthropometer and stadiometer)	The main purpose of the study is to compare the dimension of the existing school chair with the newly proposed design chair in order to prove the need for having anthropometric data as a basis in designing furniture.
Evaluation of the Indonesian National Standard for elementary school furniture based on children's anthropometry *Yanto et al.* (2017)	1146 elementary school children (boys and girls)	6 - 12 years old	Indonesia	7 parameters	Direct measurement method (i.e. anthropometer, ruler, calipers and measuring tape)	This study aims to examine whether the current national standards for elementary school furniture dimensions issued by the National Standardization Agency of Indonesia match the up-to-date Indonesian children's anthropometry.

Title/ Author	Subjects	Age Group	Area	Parameter	Measuring Equipment	Findings
Mismatch Between Furniture Dimension and Anthropometric Measures Among Primary School Children in Putrajaya *Yusoff et al.* (2015)	100 elementary school children (boys and girls)	7 & 12 years old	Malaysia	7 parameters	Direct measurement method (i.e. Martin type anthropometer set, SECA body meter, and SECA weighing scale)	The aim of this study is to determine the mismatch between the furniture dimension and anthropometric parameters among primary school children in Putrajaya.

Table 2: Previous works on anthropometric manikin

Title/ Author	Scope	Parts	Findings	Review
Development of the Q10 10 Year-Old Child Crash Test Dummy *Paul Lemmen et al.* (2013)	Q10 dummy	Ball joint	• The shoulder concept with ball joint on an oblique pin, issues arise related to cross talk, non-linearity and hysteresis. • Specifies a P10 dummy (Stature 1.38 m, mass 32 kg, approximately 50th percentile 9.4 YO)	• The ball joint on the shoulder will create some design issues (e.g., alignment) due to its free direction. • This dummy is non-representative to ASEAN population.
Validation of Finite-Element Model of Thor-Nt Lower Abdomen *Desbats et al. (2013)*	Frontal impact crash test dummy	Lower Abdomen	• The dummy was positioned on a plane surface, its back tangent to a vertical plane surface. No gravity was applied. • The dummy was positioned on a plane surface with outstretched legs. • 9° between lumbar bracket and pelvis bracket.	• The sitting position of this dummy is rigid; it will be more accurate and aligned.
Child Dummy Finite Element Models Development: A Review *Rafukka, I. (2016)*	Finite Element Modelling	Full Body	• The model was developed using data from CT scans of a child and Computer-Aided Engineering software. • Finite element (FE) modelling has become the most efficient method for its repeatability and low cost compared to the physical crash dummies. • It is strongly recommended that dummies should be designed using anthropometric data of developing countries.	• The finite element was a very useful method before or during product development to get full visualization of the product for some consideration. • The finite element and multi-body models could be used repeatedly without damage and at a low cost compared to physical ones.
Development and Validation of Dummies and Human Models Used in Crash Test *Tao Xu et al.* (2018)	Dummies and human models	Full Body	• Limitations on the damage prediction of other regions. • Each country should work hard to develop a crash test dummy that meets the human characteristics of its national conditions. • Most of the existing dummies and models are based on the male body. • Commercial mechanical dummies are expensive and consume huge during crash tests.	• Crucial to establishing cost-effective and practical dummies to suit specified applications

Table 3: Product development and design analysis

Title/ Author	Scope of study	Method	Findings	Review
Effective Use of 3D Printing in the Innovation Process *Candi and Beltagui* (2016)	Production (Research and Development)	3D-printed; build directly from a digital model	• Three-dimensional printing (3DP) is touted as a core element of a new industrial revolution. • Effective coordination between IT and manufacturing functions can intensify the benefits of using 3DP. • 3DP in innovation is more likely to be effective for businesses that face greater turbulence in their operating environment.	• 3DP very recommended for product development or custom made product which is needed very specific demand and currently in the market. • Flexibility and environmental uncertainty by testing the moderating influence of the external force of technological turbulence. • 3DP in innovation will give high impact for this IT era especially in Industrial Revolution 4.0.
On the 3D Printing of Recycled ABS, PLA and HIPS Hermoplastics for Structural Applications *Kumar et al. (2018)*	Material; 3D-printed	Tensile testing, pull-out testing	• 3DP has the potentials to be a milestone in rapid manufacturing (RM), customized design and structural applications. • This can be a potential tool for fabrication of multi-material component at minimum cost. • ABS is amorphous in nature and having high impact resistance. Low thermal conductivity, heat resistance and toughness, bio-degradability and biocompatibilities are the key advantages of PLA	• 3DP very recommended for product development or custom made product which is needed very specific demand and currently in the market. • This method also no need to have the mould to make some product, which it will make a very minimum cost. • ABS material in 3DP is a very friendly handle on 3DP device and it biocompatibility also toughness for kind of manikin test.
Mechanical Strength of Adhesively Bonded Joints using Polymeric Additive Manufacturing *Spaggiari and Denti* (2019)	Joint, Design of Experiments	Mechanical strength; Tensile Test & epoxy resin	• Beneficial effect of combining the additive manufacturing techniques, such as fused deposition molding, and structural adhesives, to obtain strong and reliable bonded structures.	• Combining the additive manufacturing techniques, such as fused deposition moulding, and structural adhesives, to obtain robust and reliable bonded structures, will give very flexible and various options during product development.
Redesain Kontruksi Meja Laser Marking Menggunakan Metode Design for Manufacture and Assembly (DFMA) *Yamin Lubis and Jeffrey* (2018)	Manufacturing	Design For Manufacturing and Assembly	• Before fabrication process, a software-based design should be carried out in order to obtain an efficient and economical design. • Use of the DFMA method in designing a construction is very helpful for improve efficiency and product quality. • Shorter time and the number of components more effectively according to function	• By using DFMA method, product can be easily produce and faster for fabrication. • Also more critically systematic in term of design for manufacturing.
Design for Manufacturing and Assembly Methodology Applied to Aircrafts Design and Manufacturing *Barbosa & Carvalho* (2013)	Aircrafts design and manufacturing	Design for Manufacturing and Assembly	• Optimization and simplicity of product; • Increase of productivity and quality. • Easiness for manufacturing and assembly. • Reduction of product cost. • Waste minimization on production. • Improves healthy and ergonomics issues. • Instrument of training for DFMA methodology. • Contributes with the increase of competitiveness	• As a guideline during the product development and it can also be used as a training tool. • As tool for checklist of progress work and for product effectiveness.

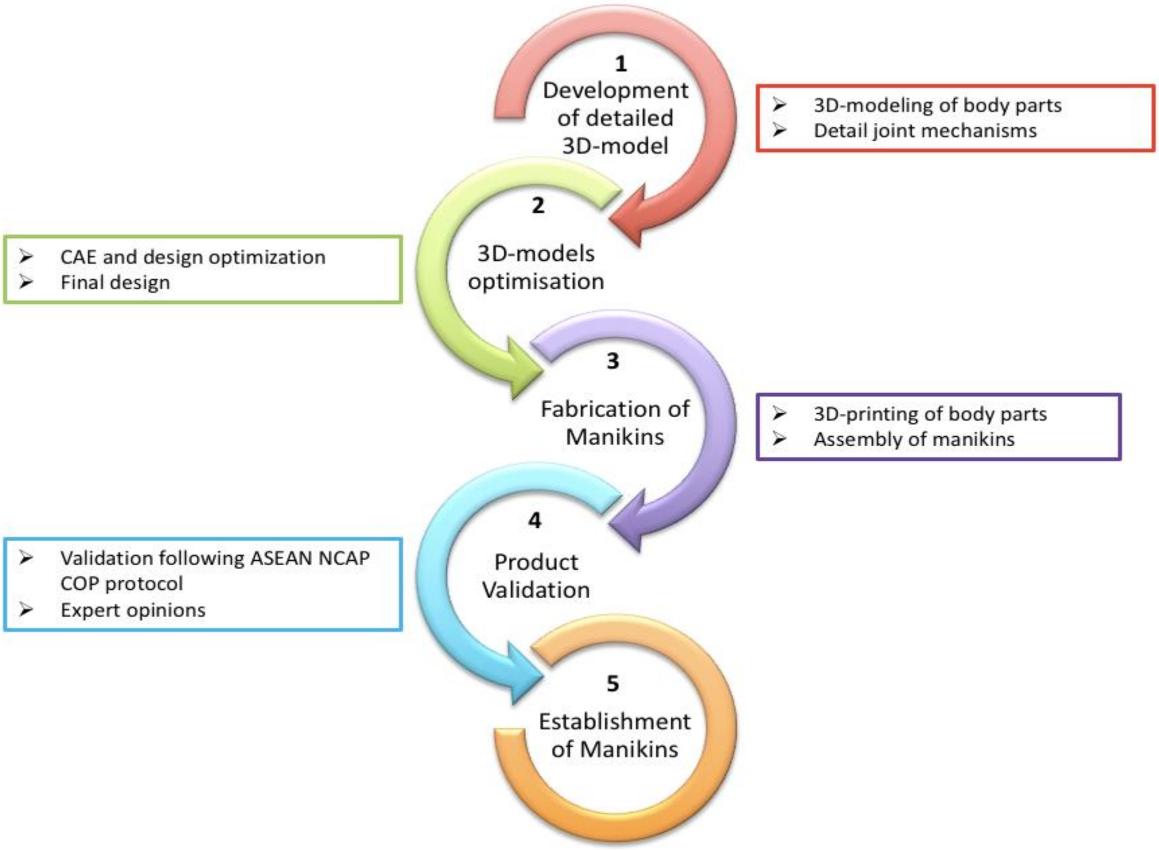


Figure 1: Research flow for the establishment of ASEAN children manikins

Phase 4: Product validation

ASEAN manikin prototypes will be assembled; there will be two categories of prototypes: 6- and 10-year-old child manikin. Minor modifications shall be conducted to ensure good prototypes are produced before validation work following the ASEAN NCAP vehicle assessment protocol. Once validation is achieved, the prototypes are ready for future utilization in ASEAN NCAP's vehicle assessment procedure.

Phase 5: Establishment of ASEAN children manikins

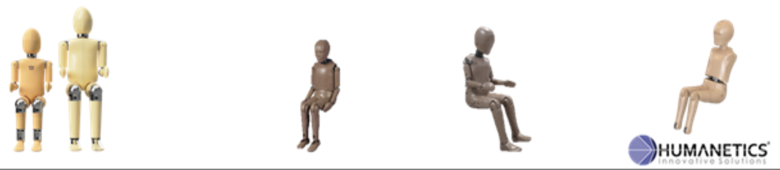
The ASEAN children manikins will be established in full-sized dimensions, together with their installation manuals and packaging.

4.0 RESULT AND DISCUSSION

4.1 Detail Design of ASEAN Children Manikin

The ASEAN children manikins are designed specifically for the ASEAN region, which generally can be utilized for any product development for this regional market. Table 4 shows the comparison between ASEAN children manikin, Anthropometric Test Devices (ATDs), and JASPER by Humanetics - the only manufacturer that produces manikins for the automotive industry. In the table, these manikins are further categorized into two age groups - 6 and 10 years old. It is expected that the ASEAN manikins will be cheaper compared to the other manikins while able to perform similar functions.

Table 4: Comparison between ASEAN children manikin, children ATDs and JASPER



	ASEAN Children Manikins		Children ATDs		JASPER
Age	6 years old	10 years old	6 years old	10 years old	6 years old
Anthropometry Data	ASEAN		NHTSA		
Size	ASEAN size		Non-ASEAN size		Non-ASEAN size
Weight	19.6 kg	30 kg	23.5 kg	35 kg	20.4 kg
Stature Height	114.5 cm	137 cm	115 cm		
Sitting Height	61 cm	70.5 cm	63.5 cm	72 cm	63.9 cm
Construction	3D-printed, ABS, hollow case, weight-ballast, part-by-part assembly		Vinyl skin, rubber parts, metal frame, springs, cables & instrumentation		3D-printed, UV cured liquid polymer
Applications	Installation checks, design reference, demo set		Crash tests		Static Test, Safety Belt Fits, Design reference
Practicality	Flexible, detachable, appropriate for CRS installation checks		Over-spec for CRS installation purpose		Static, appropriate for CRS installation checks
PRICE	Significantly cheaper		Highly expensive		Significantly Cheaper

Figure 2 provides the detailed design process of manikin development that includes body part modeling, Computer-Aided Engineering (CAE), design optimization and detail joint mechanisms. Appropriate design analyses involving kinematic analysis, correct weight distribution for each body part, design of joints and their fasteners, static stress analysis on critical areas, and design refinement and optimization were performed during the development stage to ensure functionality and quality of the product are appropriate.

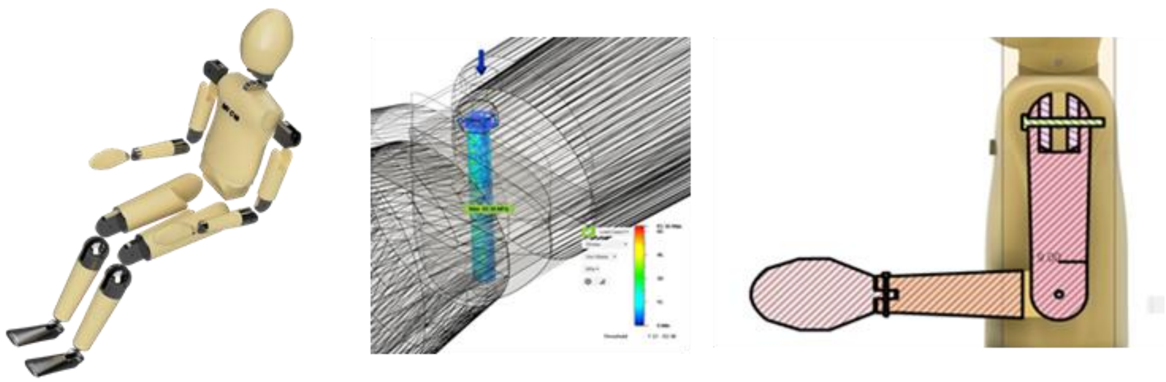


Figure 2: Detail design process of manikin development

4.2 Development of 1:5 Scaled-model and Full-scaled Functional Model of 3D-printed ASEAN Children Manikins (6 and 10 Years Old)

The 1:5 scaled-model and full-scaled functional model of 3D-printed ASEAN children manikins (6 and 10 years old) are shown in Figure 3. Currently, design verification is being conducted to ensure consistent measurement to the ASEAN anthropometric data, while checking dedicated functions, flexibility, and proper construction of the prototypes are achieved. The overall look of the manikin is shown in Figures 4 and 5.

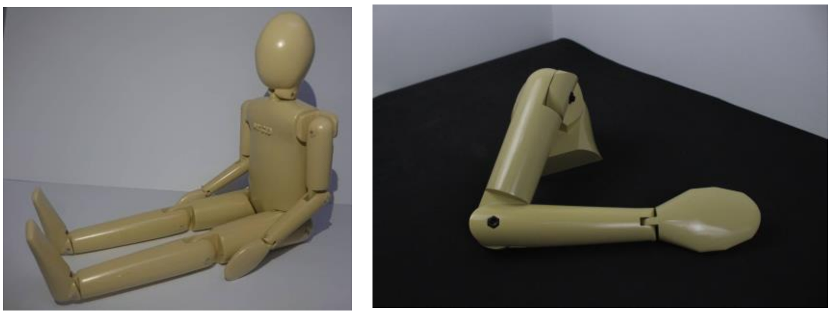


Figure 3: (Left) Scaled-model of manikin, and (right) full-scaled functional model

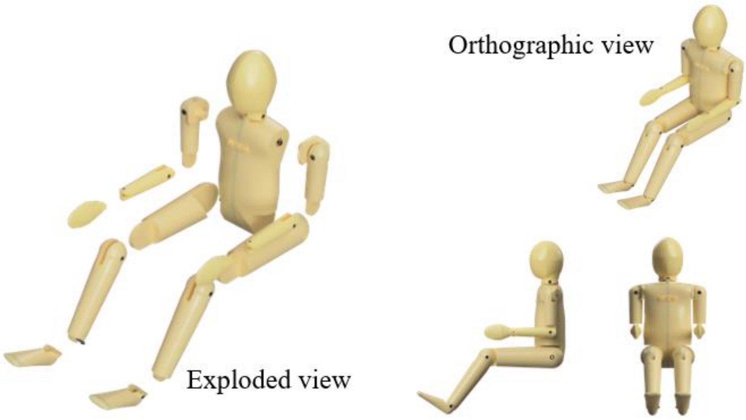


Figure 4: Exploded view (left) and orthographic view (right)

Figure 5: Overall look of 3D-printed manikin

Since these manikins need to be robust and resistant to crack, acrylonitrile butadiene styrene (ABS) is selected for its durability and resistant performance compared to other 3D printing materials. In order to obtain the balance of weight, the model is filled with clay and metal to ensure proper weight distribution is established. In addition, the coating is required for the protection of the outer surfaces from wear and tear, scratches, skin melting, and fading. After several studies on different types of coating, epoxy resin was selected since it could provide chemical resistance, corrosion resistance, high strength, low moisture absorption, adhesive and high viscosity. In addition, epoxy resin is also suitable for large surfaces application.

4.3 Future Work

The full-scale manikins of ASEAN 6- and 10-years old children will be established according to design and measurements using 3D-printing. Then, validation of the prototypes will be performed using ASEAN NCAP's CRS installation methodology after the completion of prototypes fabrication. These prototypes will be mainly used as a replacement to existing children manikins in the CRS installation assessment. The final output of the project will include the full-scaled manikins (6 and 10-years old), along with their installation manual and dedicated packaging as shown in Figure 6. The installation manual serves the purpose of a guideline for assembling/disassembling manikins. Meanwhile, the dedicated packaging acts as protection during storage and transportation from one place to another.

Figure 6: Installation manual and packaging

5.0 CONCLUSION

Currently, ASEAN NCAP is using existing ATDs to perform its CRS installation assessment procedure, which is not only unsuitable but also not representing the ASEAN children's anthropometric data. This research addresses the need to establish dedicated ASEAN children manikin for utilization of ASEAN NCAP in their future work. In this paper, the development of 3D-printed manikins based on anthropometric data of ASEAN children aged 6- and 10-years old is described. Detailed design was established, and suitable material was selected – i.e., ABS 3D-print as it can provide durability and better resistant performance to crack. The final prototypes will be coated using epoxy resin to prevent stretch, etc. The completed prototypes will be accompanied by their dedicated installation manuals and packaging for ease of storage and transportation. It is expected that these ASEAN children manikins will be used for selected ASEAN NCAP's vehicle safety assessments (for instance, the CRS installation) and other product refinement activities.

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