Reliability and validity of a taekwondo electronic body protector

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Abstract
The Protector and Scoring System was introduced in taekwondo to encourage transparency in scoring during competition. The system, which has been used in the past two Olympics, consists of two main components, the electronic body protector and socks. The few studies that have been conducted on the Protector and Scoring System have not been comprehensive and used questionable testing methods. The main objectives of this study were to methodologically examine the validity and reliability of a Protector and Scoring System body protector. To fulfill these objectives, a customized mechanical pendulum was built to test the Protector and Scoring System. The reliability of the pendulum was first determined by tracking the pendulum’s mean velocity at impact for 50 trials on two separate occasions. Data from both days were compared and showed no significant differences ($p = 0.08$). Mean kinetic energy of the pendulum was then calculated to be 55.52 J. For the experimental trial, the electronic body protector was divided into 12 sections. Each section was tested with the pendulum for 50 trials on two separate days. It was found that only three sections had no significant differences between the two days ($p > 0.01$), while the rest of the sections had significantly different readings between Day 1 and Day 2. Based on the homologous descriptive statistics, only two sections were in the same group, which translated to the Protector and Scoring System being only 16.7% reliable overall for both days. In terms of validity, an independent samples $t$-test was used to determine the differences between the calculated kinetic energy from the pendulum (the criterion) and the displayed kinetic energy on the Protector and Scoring System, and values were found to be significantly different ($p < 0.01$). Overall, the reliability and validity of the Protector and Scoring System was found to be questionable. The system needs to be examined exhaustively before being used in any future tournaments.

Keywords
Martial arts, electronic scoring system, sports technology, kinetic energy, taekwondo

Introduction
Sports technology has a strong potential of improving the sports environment by providing referees with aids to promote fair play. World Taekwondo (WT) recently introduced a major technological change, the Protector and Scoring System (PSS), during the 2012 London Olympic Games and continued its use at the 2016 Rio Olympic Games. The system was implemented to avoid bias scores and encourage transparency of scoring during competition. The PSS uses an instrumented body protector and socks with sensors to help keep score, whereby points will only be awarded objectively whenever kicks landed on the electronic body protector and surpassed the required impact threshold. Two WT-approved PSS brands exist, with the Daedo TK-Strike 2016 selected for this study. According to the equipment user manual, the TK-Strike system is based on Wireless Fidelity (Wi-Fi) technology, which requires an adapter to be plugged into the computer to receive the information from the body protector whenever it senses an impact. Piezoelectric sensors, which are placed in the electronic body protector, are used to detect the impact received from the foot by creating a small quantity of electrical charge, which is sent to the computer using Wi-Fi.

The PSS is meant to assist the judges in scoring, to eliminate judge’s subjective judgement and inconsistency. The possible reasons why bias scores occur are either by visual error or due to subjective scoring by the referees, as there are no proper standard operating...
procedures or judging criteria, such as those used in gymnastic competitions. Advances in sport technology have included devices that help make better judgement calls in many sports. Tennis and cricket, for example, use the now widely accepted Hawk Eye, a system which monitors the trajectory of the ball on the field of play. The Hawk Eye technology provides an accurate visual replay and slow motion capture for referees to review prior to making a final decision.

Presently, limited work has been published on the PSS. One of the first studies that looked at the PSS was a study by Ramazanoglu, who found that the electronic body protector routinely scored points, even with low-impact kicks. The test was conducted using a mannequin foot to deliver a round house taekwondo kick. The mannequin foot was attached to an elastic spring steel rod, which acted like a kick hitting the electronic body protector. However, the consistency of the spring steel’s strength and its flexibility is questionable, whereby only one spring steel was used throughout the whole test. As a result, the impact force may have been inconsistent and unreliable because the spring steel could have degraded over time due to its fatigue loading and spring relaxation. Estimation of the steel rod’s energy at impact was not included in this study. Also, Ramazanoglu only studied the middle section of the body protector wrapped on a mannequin. In the real world, the whole surface of the protector is used and kicked by opponents to obtain points during tournament, not just the middle part of the electronic body protector.

In another early study on the PSS by Tasika, it was found that the electronic body protector showed poor accuracy, reliability and linearity, which are required to act as a scoring tool in official competitions. The study carried out a drop test method with three different drop heights on one particular spot of the body protector and the measurement of impact intensity was presented as kinetic energy. However, the drawback of Tasika’s work was that the weights which were dropped repeatedly on the body protector remained on the body protector after each drop. This long impulse time is not applicable in the real WT kicks, whereby every kick is momentary and retracted after landing on the opponent’s body protector. The average contact time of a kick is typically between 0.023 and 0.029 s.

Taking into consideration the limitation of previous studies and the current gaps in knowledge, the objective of this study was to experimentally examine the reliability and validity of the electronic body protector (PSS) in a more methodological manner. This study consisted of two parts, to conduct a reliability test of a custom made pendulum and to test the pendulum apparatus on the electronic body protector.

**Method**

**Apparatus**

For the first part of this study, a specific measurement tool was needed to test the PSS. Therefore, a customized mechanical pendulum test apparatus was designed and built specifically for this purpose. The pendulum apparatus itself had to be tested for its reliability before it could be utilized as an experimental tool.

The mechanical pendulum shown in Figure 1 was built to mimic a kick hitting the PSS in the most consistent manner possible. The pendulum consisted of metal plates and tubular mild steel sections. Two sealed ball bearings were used to provide low-friction rotational movement for the pendulum arm. The frame was constructed of four tubular sections with a height of 1.4 m, slanted at a 15° angle. The base, which was 0.63 m wide and 0.41 m long, was bolted onto the concrete floor of the lab. The length of the pendulum was 0.94 m. A metal plate was welded in between the front and back frame and had an adjustable clamp to hold the body protector in place.

The placement of the body protector was adjustable, allowing the pendulum to hit different parts of the electronic body protector.

The pendulum was held in place using an electromagnetic lock that was located on an extended tubular arm. The pendulum was released with a flick of a switch. The mechanical pendulum swung at the same distance and velocity, theoretically producing the same amount of kinetic energy for every swing. The pendulum was driven purely by gravity, without other external forces acting on it and negligible wind resistance in the laboratory. More importantly, because of the 15° slant, the pendulum would not ‘stick’ to the body protector, but instead swing back after the impact, very much like a real kick. Once the apparatus was built and tested for functionality, the pendulum section was disassembled to measure its mass and centre of mass location for kinetic energy computation.

**Research design**

To test the apparatus’s reliability, a calibrated Qualisys motion capture system (Qualisys, Sweden) was used to track and record the velocity and contact time at impact (where velocity equals to zero) and the period of the pendulum. Two sets of data, consisting of 50 trials each, were collected on two separate days, using two different testers but using the same hardware settings and procedure. A host computer was linked to the eight Oqus Qualisys cameras with a capture rate of 377 frames per second.

Data were recorded and processed in the Qualisys Track Manager software. The released height of the pendulum magnetic lock was checked after every two trials to ensure that the same height was maintained. A single 14-mm reflective marker was securely fixed at the back of the pendulum. The motion capture system was calibrated prior to testing sessions with a root mean square (RMS) error for three-dimensional (3D) reconstruction of 0.28 and 0.26 mm for Day 1 and Day 2, respectively.
The PSS system consisted of a body protector, socks which acted as a ‘key’ and a transmitter that transferred signal to a Wi-Fi linked computer, which are then analysed by the Daedo TK-Strike software. The mechanical pendulum test apparatus was designed to generate impact on the body protector, while the sock was slipped onto the cylinder at the distal end of the swinging pendulum as a key so that contact was recognized by the Daedo TK-Strike software. The TK-Strike software displayed impact energy values in Joules.

The electronic body protector used in this experiment was a used unit, randomly picked from a batch of six functioning units that were in use by a taekwondo association for competitions. The manufacturer and WT do not specify a use-by-date for the PSS, nor do they require any form of testing or calibration prior to use. The electronic body protector was divided into 12 sections as per Figure 2. Each section was approximately the size of a foot instep (0.15 × 0.15 m²). The 12 sections of the electronic body protector were tested on two different days with 50 trials per day using the same procedures.

A total of 1200 kinetic energy values were recorded throughout the two days. The sequence of each section’s trial was randomized using a draw lots system. Time of testing was specifically set at 12 p.m. for both days to minimize temperature and humidity variation. The temperature and humidity were recorded as 26.0 °C.
and 26.5 °C and 77% and 80% of relative humidity for Day 1 and Day 2, respectively.

**Data analyses**

To test the reliability of the pendulum, a paired \( t \)-test and linear regression analysis followed by Bland–Altman test were used to analyse the differences and agreement between the two data sets from the two days. Box plot method was applied to check the data’s normality distribution.

Meanwhile, to measure the PSS reliability, a paired \( t \)-test method was used to analyse the internal consistency of the PSS. Homologous descriptive statistic was also used to group the sections which displayed the same amount of kinetic energy.

To test the validity of the PSS energy reading, kinetic energy values displayed by the PSS system were compared with the computed kinetic energy values produced by the pendulum (criterion) during impact using the independent samples \( t \)-test. Kinetic energy \( (J) \) of the swinging pendulum was computed using the formula as shown in equation (1)

\[
\frac{1}{2} I \omega^2 = \frac{1}{2} \left( \frac{T^2 M g D}{4 \pi^2} \right) \chi (\mu^2)
\]

(1)

The moment of inertia \( (I) \) was calculated using the formula shown in equation (2)

\[
\frac{T^2 M g D}{4 \pi^2}
\]

(2)

which equated to 5.04 kg m². Weight of the rod \( (m) \) was constant at 8.8 kg. Gravity \( (g) \) remained constant at 9.81 m s⁻². Mean period of the pendulum \( (T) \), as measured by the motion capture system, was 1.84 s. Distance of the pendulum from the centre of mass to pivoting point \( (D) \) was 0.68 m. Meanwhile the angular frequency \( (\omega) \) was calculated using the formula shown in equation (3)

\[
\frac{\nu}{r}
\]

(3)

which was equal to 4.69 rad s⁻¹ and the radius \( (r) \) of the pendulum was 0.94 m. The average velocity \( (\nu) \) at impact of the swinging pendulum recorded by the Qualisys system was 4.41 m s⁻¹. Based on the kinetic energy equation, the pendulum had an average kinetic energy value at impact of 55.52 J. The energy readings from the PSS were compared to this calculated kinetic energy value of 55.52 J. Data were analysed using Statistical Package for the Social Science (SPSS) software version 23.

**Results**

To test the reliability of the mechanical pendulum, a total of 100 trials were recorded, with 50 trials per set, measured on separate days. Table 1 shows the mean velocity of the pendulum, standard deviation, standard error of the apparatus, contact time, mean differences between trials of Day 1 and Day 2, and significance value of mean differences between the sets.

The standard error of the pendulum apparatus was similar for both days at 0.002 m s⁻¹. No significant difference occurred between the two sets of data \( (p = 0.08) \). Points of differences between trials against mean of sets were plotted using the Bland–Altman method (Figure 3). The Bland–Altman plot showed evenly distributed points in the scatterplot graph. The Bland–Altman statistical analysis was chosen because the agreement between two different measurements could be assessed. Based on the Bland–Altman plot, there was an agreement between the two days as noted by the evenly distributed points between the mean differences in the scatterplot graph. A linear regression line was fitted to the Bland–Altman plot, and the gradient was not significantly different to zero, thus

<table>
<thead>
<tr>
<th>Set 1 (S1)</th>
<th>Set 2 (S2)</th>
<th>(S1-S2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean velocity of pendulum (m s⁻¹)</td>
<td>4.41 ± 0.012</td>
<td>4.42 ± 0.012</td>
</tr>
<tr>
<td>Standard error (m s⁻¹)</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Contact time (s)</td>
<td>0.028 ± 0.002</td>
<td>0.029 ± 0.002</td>
</tr>
</tbody>
</table>

Figure 3. The Bland–Altman plot for the mechanical pendulum \( (n = 100) \).
indicating no proportional biasness between the two sets of data (Table 2).

For the experimental trials, a total of 1200 trials were recorded. The test on the 12 sections was conducted on two different days, whereby 50 trials were collected on each section on Day 1, while another 50 trials for each section were collected on Day 2.

Descriptive statistics, mean energy readings and standard deviation of sections for trials on Day 1 and Day 2 are presented in Figure 4 and Table 3. Among the 12 sections tested (S), S2 recorded the highest mean energy reading of 41.9 J on Day 1 and 39.7 J on Day 2. The lowest mean energy readings recorded throughout the 2-day trial were from S3 with values of 20.4 J on Day 1 and 21.4 J on Day 2.

The box plot method was used to evaluate the normality of the data. S7, S10 and S12 were normally distributed, while the rest of the sections were not. Normally distributed data were analysed using paired samples t-test, while non-normally distributed data were analysed using a non-parametric method, the Wilcoxon test.

Among all the sections, only S4, S5 and S12 had no significant differences between Day 1 and Day 2 (Table 3). The ranks of mean starting from the lowest kinetic energy displayed were S3, S4, S10, S6, S9, S7, S12, S11, S1, S8, S5 and, finally, S2 which had the highest mean kinetic energy readout on the PSS. It

Table 2. Coefficient of linear regression of the mechanical pendulum.

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>$\beta$ estimate$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean between trials of sets</td>
<td>0.51</td>
</tr>
<tr>
<td>t value</td>
<td>2.51</td>
</tr>
<tr>
<td>p value</td>
<td>0.80</td>
</tr>
</tbody>
</table>

$^a$Dependent variable: differences between trials.

Figure 4. Bar chart of mean and standard deviation of kinetic energy for each section between Day 1 and Day 2.

Table 3. Descriptive statistics and comparison of mean and standard deviation of each section's kinetic energy on Day 1 and Day 2.

<table>
<thead>
<tr>
<th>Sections</th>
<th>Day 1 (J)</th>
<th>Day 2 (J)</th>
<th>Combined average of Day 1 and Day 2</th>
<th>t/Z value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 $^*$</td>
<td>35.58 ± 0.95 bc</td>
<td>35.00 ± 1.45 d</td>
<td>35.29 ± 1.20</td>
<td>5.30 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S2 $^*$</td>
<td>41.94 ± 2.06 a</td>
<td>39.68 ± 2.18 a</td>
<td>40.81 ± 2.12</td>
<td>5.69 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S3 $^*$</td>
<td>20.44 ± 1.37 i</td>
<td>21.42 ± 2.05 h</td>
<td>20.93 ± 1.71</td>
<td>4.65 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S4 $^*$</td>
<td>21.98 ± 1.49 h</td>
<td>22.62 ± 1.17 h</td>
<td>22.30 ± 1.33</td>
<td>1.76</td>
<td>0.079</td>
</tr>
<tr>
<td>S5 $^*$</td>
<td>36.90 ± 2.01 b</td>
<td>36.22 ± 1.18 c</td>
<td>36.56 ± 2.60</td>
<td>1.16</td>
<td>0.245</td>
</tr>
<tr>
<td>S6 $^*$</td>
<td>27.54 ± 1.97 g</td>
<td>25.38 ± 2.40 g</td>
<td>26.46 ± 2.19</td>
<td>6.13 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S7 $^*$</td>
<td>33.40 ± 3.28 de</td>
<td>32.38 ± 0.50 e</td>
<td>32.89 ± 1.89</td>
<td>3.16 $^+$</td>
<td>0.003</td>
</tr>
<tr>
<td>S8 $^*$</td>
<td>32.88 ± 3.61 ef</td>
<td>38.62 ± 0.49 b</td>
<td>35.75 ± 2.05</td>
<td>6.00 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S9 $^*$</td>
<td>29.90 ± 1.62 f</td>
<td>26.64 ± 0.48 f</td>
<td>28.27 ± 1.05</td>
<td>6.20 $^+$</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>S10</td>
<td>27.28 ± 3.18 g</td>
<td>25.54 ± 3.70 fg</td>
<td>26.41 ± 3.44</td>
<td>3.48 $^+$</td>
<td>0.001</td>
</tr>
<tr>
<td>S11 $^*$</td>
<td>32.78 ± 2.02 e</td>
<td>35.56 ± 4.43 bc</td>
<td>34.17 ± 3.23</td>
<td>3.38 $^+$</td>
<td>0.001</td>
</tr>
<tr>
<td>S12</td>
<td>34.64 ± 2.50 cd</td>
<td>33.50 ± 2.90 d</td>
<td>34.07 ± 2.08</td>
<td>1.66</td>
<td>0.105</td>
</tr>
</tbody>
</table>

$^a$Non-normally distributed.

$^*$Significantly different.

Means with the same letter are not significantly different.
was also interesting to note that the standard deviation of the PSS varied from 1.05 J for S9 up to 3.44 J for S10.

All sections of the electronic body protector were analysed using the homologous descriptive statistics and were tabulated into groups for Day 1 and Day 2 as per Table 3. The sections which were grouped together did not have significant differences between them. For Day 1, S6 and S10 were the only sections that were in the same group – which was group ‘g’ – while on Day 2, S3 and S4 were the only sections that were in the same group – which was group ‘h’. Overall, the electronic body protector can be classified as unreliable, considering that only two out of the 12 sections were in the same group for each day’s trial, and this was translated to having only 16.7% reliability.

When the energy value displayed by the PSS was compared to the computed pendulum energy value criterion of 55.52 J, both the displayed and criterion were significantly different (p < 0.01), as shown in Table 4. The range of the recorded mean kinetic energy was between 20.93 and 40.81 J. The range of the recorded kinetic energy was perpetually lower than the calculated kinetic energy produced by the mechanical pendulum.

### Discussion

It would seem that the pendulum used in this study is a much more convenient and practical method to be used as a test apparatus for the electronic body protector compared to the other two methods developed by Ramazanoglu\(^6\) and Tasika.\(^3\) If needed, extra weights can be added to the pendulum during a test to produce higher kinetic energy during impact. More importantly, with its adjustable clamps, the pendulum can be used to test many different sections of the electronic body protector by moving the desired test section to the middle of the apparatus. The pendulum can also impact each section accurately due to the fixed movement pattern of the pendulum. At the same time, the highly durable solid metal structure allows for minimal dissipation of kinetic energy during impact. In fact, this apparatus design and test procedure can also be used to check every electronic body protector’s reliability before they are used in tournaments.

The pendulum apparatus was shown to be reliable, whereby the p value for t-test and the coefficient of regression were 0.08 and 0.80, respectively. Both analyses found no significant differences in velocity at impact between the two days of testing (p > 0.01). In addition, the Bland–Altman plot was also used to corroborate these findings, with the plot showing evenly distributed points in the scatterplot graph. Basically, the pendulum was highly consistent over both test days.

Once the reliability of the pendulum was established, the PSS was put through experimental testing. Normally, in tournaments, there is only one threshold for the PSS which is set according to the weight category. Since there are no different pre-set settings for different sections of the PSS, the varied readings that were recorded from the PSS for the same given impact energy was perplexing. From the 12 sections tested, only three sections (S4, S5 and S12) had no significant differences (p > 0.01) between the two days of testing. Overall, this particular electronic body protector appeared unreliable considering that out of 12 sections, only two sections could be classified in the same homologous group for each day’s trial, and this was translated to being only 16.7% reliable. If this is representative of all PSS on the market, then there is certainly a need to question the use of the PSS in taekwondo tournaments.

The energy from the pendulum apparatus was found to be consistent based on the Bland–Altman plot which had shown agreement between two sets of data. The pendulum was able to consistently generate a mean of 55.52 J. However, during experimental trials to examine the validity of the PSS, none of the 12 sections displayed an average kinetic energy reading of more than 41.94 J. There were significantly large differences between the displayed energy values and energy from the pendulum. It may be argued that some energy is absorbed by the foam during collision. Laboratory tests have shown that the possible energy absorption of foam is in the range of 0.05–0.15 J/cm\(^3\), depending on the foam density.\(^11\) The body padding is only 2.0 cm thick and the contact point of the pendulum head is 22.0 cm long and 1.0 cm wide, thus creating only 44.0 cm\(^3\) foam directly involved in the collision. Therefore, the possible energy absorbed by the PSS foam during impact in this study would only be in the range 2.2–6.6 J. This makes the discrepancy between the PSS readout and the kinetic energy of the pendulum rather puzzling.

When a kick is landed on the PSS, it senses the impact and registers the energy value. If the energy reading is more than the minimal threshold set for the particular weight category, then it will count as a score. To be able to meet its objective, the energy value
reading has to be valid and consistent for the same amount of impact energy. Based on the energy readout by the PSS system in this study, S2 displayed the highest mean kinetic energy, while S3 had the lowest mean kinetic energy value. Even though the same amount of energy was provided by the pendulum, the readout from PSS was markedly varied. In an actual competition, this would make S2 the easiest section to score on due to the high energy reading. This is because a kick at this section will have the highest likelihood to surpass the pre-set threshold for a point count. Meanwhile, S3 would be the hardest section to score points because it had the lowest reading among all 12 sections. Therefore, for this section, opponents would have to kick harder to register a point. If the findings of this study are consistent with other PSS units, coaches may actually start to plan their training method to emphasize kicking on the higher readout areas as a gameplay strategy. The most effective and efficient way of kicking and scoring is the key to success in any taekwondo tournament.

It is possible that the electronic body protector was manufactured and produced in a flat shape. However, over time, the shape of the electronic body protector had changed from a flat shape to a curved shape because it has to be bent and worn by wrapping around the athlete’s body. Due to the changed shape, the sensors in the electronic body protector may have shifted position. Hence, the sensors which had shifted did not cover the electronic body protector thoroughly and caused some parts of the electronic body protector to be less sensitive. In addition, bending may have caused damage to wiring in the electronic body protector by interrupting the connectivity, as well as the sensitivity, between the sensors and transmitters.

Further studies focusing on the inconsistency between the sections need to be carried out. Specifically, the actual placement of all the sensors within the electronic body protector should be investigated. Inconsistency between sections may be due to the uneven arrangement of the sensors, which have been built-in and placed in between the padding. Placement of sensors can only be seen clearly once the electronic body protector is cut open to expose the interior design and technology of the equipment. Issues could exist with the product materials or the software itself. Using unreliable equipment in a taekwondo tournament would diminish fair play among athletes, while tarnishing the good name of the WT as the world governing body for taekwondo. Moreover, unreliable equipment would jeopardize taekwondo as part of the Olympic event in the future due to the lack of reliability of the scoring system.

The findings support the inconsistency of scoring, which was experienced by athletes, coaches and spectators in taekwondo tournaments that had used the PSS. Previous studies have found that the PSS is unreliable and has poor consistency, in line with Leveaux’s finding. This study reaffirms the earlier findings, concluding that there are inconsistencies in all sections of the body protector. It may be argued that the limitation of this study is the use of only one PSS unit during testing. However, considering that previous studies also used single units and reported issues with the PSS, a clear indication now exists that the reliability of the system is in question. This study highlights the dire need to have a standardized test and calibration method for the PSS prior to it being used in any tournament. With the large financial investments made by teams and countries on preparation for major tournaments, athletes deserve to know whether the judging equipment used are measuring and classifying energy from kicks correctly and reliably. WT needs to set clear ‘use by’ guidelines, either by date of manufacture, degradation in thickness of padding or failure in calibration tests.

The main objective of introducing the PSS to taekwondo was to eliminate bias scores, enabling more objectivity in terms of judging and scoring. PSS was supposed to provide aids to referees by reducing human error and promoting fair play among participants, unlike the manually judged subjective scoring system. However, with the current findings, doubt exists as to whether this system can fulfill its main objective, to remove the unreliable nature of subjective scoring, due to questionable reliability and validity of the equipment.

**Conclusion**

This study found that the PSS unit used in this investigation was unreliable because the kinetic energy readings from different sections of the electronic body protector varied considerably, despite being generated from the same impact energy from the pendulum. In addition, the kinetic energy displayed by the electronic body protector was significantly lower than the criterion energy values of the pendulum. It is recommended that a standardized pre-tournament calibration test for the PSS be introduced. Furthermore, a detailed examination of the overall PSS system should be conducted by relevant authorities with the data made available to the public.

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References