IOSR Journal of Sports and Physical Education (IOSR-JSPE)
e-ISSN: 2347-6737, p-ISSN: 2347-6745, Volume 8, Issue 4, (Jul. – Aug. 2021), PP 10-17
www.iosrjournals.org

A Triple Jump Performance Optimization Model Based on Flight Phase Biomechanical Factors

P. C. Thotawaththa[1], A. W. S. Chandana[1]
[1](Department of Sport Sciences & Physical Education, Sabaragamuwa University of Sri Lanka & P. O. Box 02, Belihuloya 70140, Sri Lanka.)

Abstract:
Background*: The triple jump is an athletic event consisting of three phases which are hop, step, and jump. The optimum proportion of each phase to the total distance jumped is referred as the phase ratio. Sri Lankan male athletes could not be able to reach 17m in the triple jump event. This study was to design a biomechanical model to optimize the performance using the kinematic variables.*
Materials and Methods*: The simulation of this technique was done using the dynamic equation which included kinematic variables for the flight phase of the above three phases. The Matlab17 software was used to optimize the flight phase of two best performers of National standard male triple jumpers. Three cameras (100 Hz) were used to observe the coordinates of the center of mass and kinematics variables on the sagittal plane. The videos were analyzed through the Kinovea (0.9.3 version) software.*
Results*: Their initial performance ratio was 37.3: 26.2: 36.5. The hop-dominated balance technique (35.5: 30.4: 34.1) was used for the optimization. Current hop take-off velocity and angle were optimized by 3 %, 4 %, 5 % and -1 ^{0}, +1 ^{0}, +2 ^{0} respectively. The current performance values of the players were 14.15 m and 15.43 m. The velocity and angle were optimized by 5 % and +2 ^{0} outcomes of the two players were 16.45 m and 17.94 m.*
Conclusion: *Initial current optimization and hop-dominated balance optimization methods were taken to consideration. The 17m marks of male triple jumpers' performance can be achieved by using the hop-dominated balance optimization method and applying this biomechanical model.*
Key Word*: Kinematics, Optimization, Phase ratio, Technique, Triple Jump*

Date of Submission: 10-07-2021 Date of Acceptance: 26-07-2021

I. Introduction

The triple jump is one of the tracks and field events, which requires the jumper to repeat the generation of maximal force in order to maintain the horizontal velocity during all phases of the jump. The triple jump consists of a running approach, 3 take-off phases in which the athlete hops on one foot, lands on the same foot, steps onto the opposite foot, and finally jumps and lands in the sand pit[8]. The 'phase ratio' is the distances of each phase expressed as three percentages of the total distance. Triple jump techniques with respect to phase ratio have been defined as being hop-dominated – where the hop percentage is at least 2 % greater than the next largest phase percentage; jump-dominated – where the jump percentage is at least 2 % greater than the next largest phase percentage; and balanced – where the largest phase percentage is less than 2 % greater than the next largest phase percentage[6].

Triple jump distance is depended on the jumper's ability to apply the basic architectural paths during each of the 3 take-off phases[13]. During each take-off phase a change in the movement structure and rhythm occurs, which affects the timing of each concentric and eccentric contraction[7]. Therefore, each take-off phase has its own dynamic requirements during the braking and propulsive phases.

In the triple jump, it is important that someone maintain the correct posture when jumping. Jumpers need to be conscious to keep their feet flat on the ground, as heel or toe jumping will negatively impact the jump. The triple jump is an athletics event where athletes combine speed, power, and agility to jump as far as possible from a starting point. There have been a number of attempts to determine the effect of phase ratio on triple jump performance using various approaches including observations of elite jumpers[9]; the differences between elite and novice jumpers[11]; statistical relationships between velocity take-offs during the contact phases[12,13]; and even an operations research approach[2].

The most of triple jump players and coaches are trained based on their performance variables. As an example, in the triple jump event we train to improve lower limb muscle strength and other physical finesses. And the technique isn't followed correctly in those training periods. This is due to the lack of knowledge and lack of technical tools. What is being sought here is to determine the performance variables and biomechanical factors of the players related to triple jump, effort the performance of the correct values. By creating a model for every coach and athlete can understand the factors needed for their own fitness, achieve their highest potential, and perform at their highest level.

II. Material And Methods

Data Collection and Parameter Determination

Triple jump players in Sri Lanka were taken as the population in this research study. This is because the triple jumpers in Sri Lanka have not shown international level qualifications. There are three main stages in the triple jump event. Athletes can perform to the best of their ability by applying relevant balance techniques to those situations. This research has considered to create a biomechanical model at the end of the last. It aims to optimize the distance of the players and correct them to improve the skills of the players. In this study, five of the best national triple jumpers in Sri Lanka were selected as the sample. The senior triple jumpers were chosen because it has a higher performance than the junior triple jumpers. Male triple jumpers show higher performance than female triple jumpers when comparing male and female triple jumpers. Therefore, this study focuses on male triple jumpers and this model is applicable to all triple jumpers in Sri Lanka.

This study has selected best national 5 triple jumpers according to national championship in Sri Lanka 2019. Therefore, the selected sample who has specified qualification and it will be more appropriate to become the success of this study. Two best performers were taken from five athletes. Player A (mass: 70 kg; height: 1.78 m; best performance: 15.76 m). Player C (mass: 71.35 kg; height: 1.80 m; best performance: 16.33 m). Before the collection, the video data was done by pilot test in Sabaragamuwa university premises.

Kinematic data was collected at the Sugathadasa Outdoor Stadium, Colombo from two triple jump performance from an approach run of self-selected length. Fourteen reflective markers were placed on the athlete in order that locations of joint centers could be determined. All of cameras were placed 10 m away from the player's performance sagittal plane and Camera height 1.20 m and camera range left 3 m and right 3 m and also focus length 35 mm, and the complete triple jump, captured data at 100 Hz. All cameras were synced using speed light. Before taking the videos calibrated vertical axis using pole in performance on sagittal plane[4]. Approach velocity was defined as the horizontal velocity of the whole-body COM at the touchdown of the hop stance phase. The performance resulted in a take-off velocity of 8.51 ms^{-1} and a triple jump distance of 14.00 m, defined as the angle of the trunk in a global reference frame, and configuration angles were calculated by considering the joint center coordinates on the sagittal plane.

Here the video frames were focused on covering the three phases the triple jump event. That because the reason for this is to find out in which phase the error occurs and to find out whether the athletes are using correct technique. And also, how far it is for the relevant phase as the three take offs of the triple jump event are done in a very short period of time. All analyzes were performed using the Kinovea software and Microsoft Excel 2016 and all kinematics variables were calculated. Two-dimensional coordinates of Center of Mass (COM) were used to find the relevant kinematic variables. Then variables were included in the model. This study is a new experiment that is mainly focused on the biomechanical model. It consists of a mathematical model and the final outcome was to optimized values that occurred when take-offing the athlete. Because knowing this model value would be most important to estimate triple jumper's optimum performances.

Optimization

The take-off velocity of the model was each increased by 3 %, 4 % and 5 %. In contrast, the take-off angle (-1 ^{0},0 ^{0}, +1 ^{0}, +2 ^{0}) from the measured values and all combinations of these two parameters were investigated, leading to 16 optimizations in total. The take-off angle of the model was manipulated by increasing the three phases separately their phase distance. Approach velocities ranged from 8.1 ms^{-1} to 10.5 ms^{-1} (the maximum approach velocity recorded at the 2009 IAAF World Championships in Berlin [German Athletics Federation, 2009]). Optimization was used to maximize the distance of the whole triple jump in each condition.

Hop and Step Flight Phase Optimization

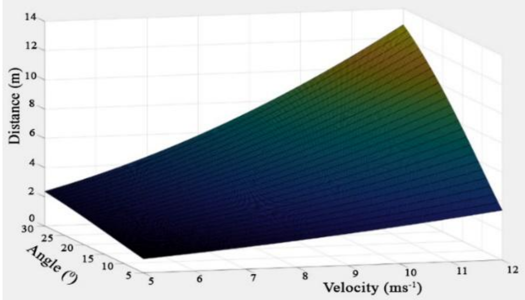

Figure No 1: Hop and Step flight Phase distances optimization graph

The Below equation was used for distance during the flight phase. The optimize values were obtained as follows using Matlab software for this equation (01). In the below equation, h was taken as a constant value and given as a mean value (h = 0.1m) and the following optimization graph was obtained (figure no 1). Data were obtained to optimize the hop and step instances.

$$d_{flight} = v^2 \sin 2\theta / 2g \{1 + (1 + 2gh / v^2 \sin^2\theta)^{1/2}\}^5. \quad (01)$$

Jump Flight Phase Optimization

The following graph was used for the flight phase in the jump phase as h = 0.75 m (01). Data related to the jump phase were taken from it. The data obtained in this way made it possible to obtain a large amount of data for velocity and angle (figure no 2).

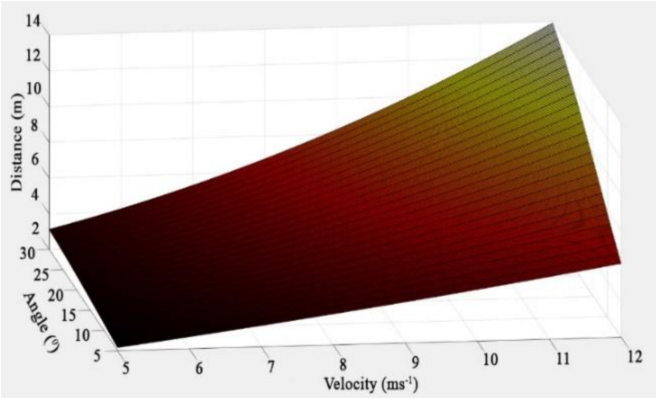

Figure No 2: Jump flight Phase distances optimization graph

Performance Distance Optimization

Current Ratio Optimization

The optimization was done according to the data obtained above. First of all, two of the best players were selected from the above talented players. The performance of player A was 14.21 m. And the performance of player C was 15.49 m. But in video analysis, their performance value was taken as 14.15 m and 15.43 m. Their phase ration values are 37.3 %, 26.2 %, 36.5 %, and 36.3 %, 27.2 %, 36.4 %. 37.2 % efficiency as player A hop phase is 5.28 m. The 5.28 m capacity includes take-off distance and landing distance. The two distances were found using data from Kinovea software. The sum of the two is 1.16 m. Then the flight distance was obtained as 4.12 m. The velocities and angles for that distance are 8.86 ms^{-1} and 14 ^{0}, respectively. (Data charts obtained from Matlab were used for velocity) Take off velocity of the athlete here was increased as 3 %, 4 % and 5 %. In contrast, the angle (-1 ^{0}, +2 ^{0}) is optimized in the range. The values in the table below were taken into the hop flight phase.

Hop Dominated Balance Ratio Optimization

For this purpose, it is used as mentioned above. But the balance technique was used here. That is, its values are 35.5 %, 30.4 % and 34.1 % [3]. There 14.15 m performance was divided according to the above ratio and values were obtained for hop, step, jump. It is shown in the table below. This was done by using Matlab graphs as mentioned above to increase the velocity to 3 %, 4 %, 5 % and keep it at an angle (-1 ^{0} to +2 ^{0}). Then the total distance was obtained as follows.

III. Results

Kinematics Variables

Table No 1: Hop Phase Kinematics results

Hop Phase			
Parameters	**Mean**	**SE Mean**	**SD**
TO Angle (θ)	15.612	± 0.49	1.55
VV (ms^{-1})	2.2233	± 0.0718	0.227
HV (ms^{-1})	7.959	± 0.105	0.331
RV (ms^{-1})	8.266	± 0.105	0.333
TO Height (m)	1.188	± 0.0178	0.0563
Landing Height (m)	1.052	± 0.0178	0.0563
TO Distance (m)	0.4571	± 0.0235	0.0742
F Distance (m)	4.044	± 0.122	0.385
L Distance (m)	0.5947	± 0.0101	0.0318

Hop Distance(m)	5.096	± 0.116	0.367

Table No 2: Step Phase Kinematics results

Step Phase			
Parameters	**Mean**	**SE Mean**	**SD**
TO Angle (θ)	11.875	± 0.727	2.298
VV (ms^{-1})	1.5085	± 0.0911	0.2882
HV (ms^{-1})	7.187	± 0.12	0.38
RV (ms^{-1})	7.349	± 0.118	0.374
TO Height (m)	1.141	± 0.0172	0.0545
Landing Height (m)	1.039	± 0.0097	0.0307
TO Distance (m)	0.5877	± 0.0185	0.0586
F Distance (m)	2.627	± 0.0842	0.2661
L Distance (m)	0.6634	± 0.0224	0.071
Step Distance (m)	3.878	± 0.0625	0.1975

Table No 3: Jump Phase Kinematics results

Jump Phase			
Parameters	**Mean**	**SE Mean**	**SD**
TO Angle (θ)	20.6	± 1.17	3.71
VV (ms^{-1})	2.262	± 0.122	0.386
HV (ms^{-1})	6.026	± 0.109	0.345
RV (ms^{-1})	6.4488	± 0.0963	0.3047
TO Height (m)	1.248	± 0.0142	0.0449
Landing Height (m)	0.528	± 0.0231	0.073
TO Distance (m)	0.449	± 0.0196	0.062
F Distance (m)	4.039	± 0.114	0.36
L Distance (m)	0.444	± 0.0382	0.1207
Jump Distance (m)	4.932	± 0.122	0.387
Full Distance (m)	13.906	± 0.228	0.72

The triple jump (without approach phase) of each athlete was captured by using 3 high-speed cameras (100 Hz), both on the sagittal planes. Through it, there were observed the coordination of all athletes. The collected data (mainly video clips, etc.) were analyzed by using Kinovea software and there were found kinematic variables (Take off Velocity, etc.) There has drawn and measured every frame COM using Kinovea software[4]. Then Find Below Variables in each player.

Looking at these results, the technology of these Sri Lankan players is at a very low level. There is also a 0.448306586 % difference between the data obtained from the video analyzer and the actual distance. This study mainly provides an understanding of velocity and angle. In step and jump, the velocity drop is as low as 11 % and 21.9 %. Athletes also use the maximum take-off height and maximum take-off angle relative to the hop and step for the maximum distance to avoid that velocity drop during the jump phase. The angle is maintained at $19^{0} – 25^{0}$. It also maintains a very low take off angle during the step phase. It is a value between $8^{0} – 15^{0}$. The triple jump event has three supportive phases.

Table No 4: Foot plat time

Foot Plant Time (s)			
Phase	**Mean**	**SE Mean**	**SD**
Hop	0.132	± 0.00327	0.01033
Step	0.16	± 0.00394	0.01247
Jump	0.176	± 0.00562	0.01776

The triple jump event has three supportive phases. Spending more time on those three phases has a direct effect on the horizontal velocity. It can be seen by looking at the times of these players. The hop take-off takes less time and more than two other supportive phases. According to the above data, it is obvious. There is also a big technical difference in the Sri Lankan players. There is a big difference in the phase ratio of these players. The accepted phase ratio can be seen in the ratio shown by Jonathan Edward[3] 35.3: 30.4: 34.3, and[10] 35.7: 30.8: 33.6. But the phase ratios of these players are 36.6 %, 27.9 % and 35.5 % (figure No 3). A big difference can be seen in the step phase of these players. This shows that Sri Lankan players do not use balance technique.

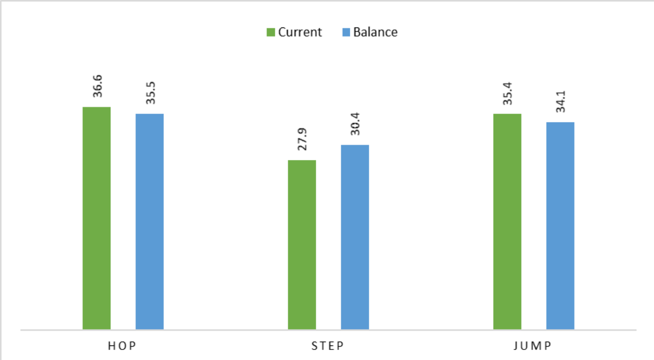

Figure No 3: Current and optimum phase ratios

Performance Distance Optimization

Player A phase ration values are 37.3: 26.2: 36.5. Then 37.3 % efficiency as player A hop phase is 5.28 m. The 5.28 m capacity includes take-off distance and landing distance. The two distances were found using data from the Kinovea software. The sum of the two is 1.16 m. Then the flight distance was obtained as 4.12 m. The velocities and angles for that distance are 8.86 ms^{-1} and 14 ^{0}, respectively. (Data charts obtained from the Matlab were used for velocity) Take off velocity of the athlete here was increased as 3 %, 4 % and 5 %. In contrast, the angle (-1 ^{0},0 ^{0}, +1 ^{0}, +2 ^{0}) is optimized in the range. The values in the table below were taken into the hop flight phase. The step was 26.2 % and the jump phase was 36.5 % optimized according to the data in the hop phase below. The following values give the relevant velocity and angle of the phases. Finally, the total distance is given by the data in the table no 5 below.

Table No 5: Current simulation overall distance player A

Current Simulation					
		Hop TO Angle (^{0})			
		13	14	15	16
Hop TO Velocity Simulation	100%	13.548	14.165	14.755	15.345
	103%	14.138	14.755	15.399	16.016
	104%	14.326	14.97	15.613	16.284
	105%	14.513	15.184	15.855	16.499

Player C phase ration values are 36.3: 27.2: 36.4. Then 36.3 % efficiency as player A hop phase is 5.6 m. The 5.6 m capacity includes take-off distance and landing distance. The two distances were found using data from the Kinovea software. The sum of the two is 1.08 m. Then the flight distance was obtained as 4.52 m. The velocities and angles for that distance are 9.06 ms^{-1} and 15 ^{0}, respectively. (Data charts obtained from the Matlab were used for velocity) Take off velocity of the athlete here was increased as 3 %, 4 % and 5 %. In contrast, the angle (-1 ^{0},0 ^{0}, +1 ^{0}, +2 ^{0}) is optimized in the range.

Table No 6: Current simulation overall distance player C

Current Simulation					
		Hop TO Angle (^{0})			
		14	15	16	17
Hop TO Velocity Simulation	100%	14.778	15.411	16.044	16.677
	103%	15.439	16.127	16.787	17.448
	104%	15.659	16.347	17.035	17.723
	105%	15.879	16.594	17.310	17.998

The values in the table below were taken into the hop flight phase. The step was 27.2 % and the jump phase was 36.4 % optimized according to the data in the hop phase below. The following values give the relevant velocity and angle of the phases. Finally, the total distance is given by the data in the table above (table no 6).

The Balance technique was used here. That is, its values are 35.5 %, 30.4 % and 34.1 % [3]. Player A 14.15 m performance was divided according to the above ratio and values were obtained for hop, step, jump. It is shown in the table below. This was done by using the Matlab graphs as mentioned above to increase the velocity to 3 %, 4 %, 5 % and keep it at an angle (-1 ^{0},0 ^{0}, +1 ^{0}, +2 ^{0}). Then the total distance was obtained as follows.

Table No 6: Optimized Simulation overall distance player A

Optimized Simulation (Hop-Dominated Balance Technique)					
		Hop TO Angle (^{0})			
		13	14	15	16
Hop TO Velocity Simulation	100%	13.549	14.140	14.704	15.295
	103%	14.112	14.760	15.352	15.971
	104%	14.309	14.929	15.577	16.197
	105%	14.507	15.154	15.802	16.450

After the optimization (velocity was increase 5 % and angle was increased +2 ^{0}), player A's total distance was 16.45 m. And also, optimizations of velocity and angle of that hop phases were 8.97 ms^{-1} and 16 ^{0}. The values of the velocity and angle of the step phase were (8.13 ms^{-1} - 8.9 ms^{-1}) and (12 ^{0} - 15 ^{0}). And values of the velocity and angle of the jump phase were (7.5 ms^{-1} - 7.1 ms^{-1}) and (17 ^{0} - 21 ^{0}). Also, the balance technique was used here. That is, its values are 35.5 %, 30.4 % and 34.1 %. Player C 15.43 m performance was divided according to the above ratio and values were obtained for hop, step, jump. It is shown in the table below. This was done by using the Matlab graphs as mentioned above to increase the velocity to 3 %, 4 %, 5 % and keep it at an angle (-1 ^{0}, 0 ^{0}, +1 ^{0}, +2 ^{0}). Then the total distance was obtained as follows.

Table No 8: Optimized Simulation overall distance player C

Optimized Simulation (Hop-Dominated Balance Technique)					
		Hop TO Angle (^{0})			
		14	15	16	17
Hop TO Velocity Simulation	100%	14.760	15.408	16.028	16.647
	103%	15.408	16.084	16.732	17.408
	104%	15.633	16.309	16.985	17.661
	105%	15.859	16.563	17.239	17.943

After the optimization (velocity was increase 4 % and angle was increased +1 ^{0}), player C's total distance was 16.98 m. And also, optimizations of velocity and angle of that hop phases were 9.26 ms^{-1} and 15 ^{0}. The values of the velocity and angle of the step phase were (8.17 ms^{-1} - 9.19 ms^{-1}) and (12 ^{0} - 15 ^{0}). And values of the velocity and angle of the jump phase were (7.28 ms^{-1} - 7.7 ms^{-1}) and (17 ^{0} - 21 ^{0}). The total distance in the position of the player C's was 17.94 m. This can be achieved by maintaining the hop velocity 9.35 ms^{-1} and the hop angle 17 ^{0}.

IV. Discussion

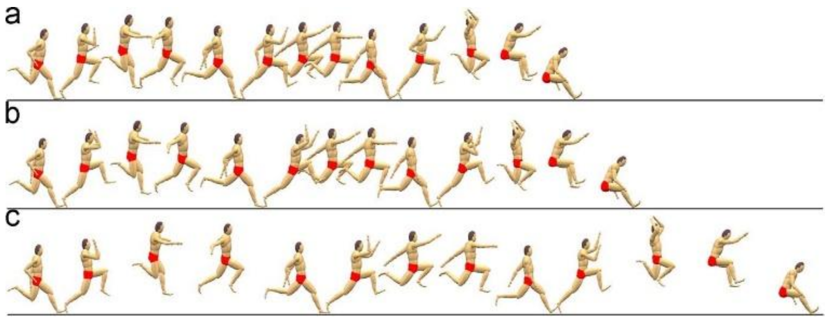

Figure No 4: (a) Techniques employed in Player A; Current simulation 14.15m, (b) Techniques employed in; Player C Current simulation 15.43m, (c) Techniques employed in; 17m mark optimization simulation increased takeoff angles and takeoff velocities

The resulting optimized total distance data cell was selected, and the corresponding velocity and angle were found. Here a value close to 17 m was selected. This is because Sri Lankan athletes have to be close to the 17 m mark to reach the international level. The data obtained above can be represented by graphs as follows. The COM path of the above data can be shown as follows. There is a clear difference between optimization performance and current performance. Also, the behavior of the players in the vertical and horizontal velocities can be seen with a difference. Optimization of jump distance with measured takeoff angle and take-off velocity resulted in a total distance of 14.15 m and 15.43 m (figure no 5) a current technique. Increases in hop take-off velocity resulted in increases in jump distances in every condition, whereas increases in take-off angle led to increases in jump distances in all cases except one (Table no 7 and Table no 8). Figure no 4 gives a visual representation of the techniques employed in selected optimizations.

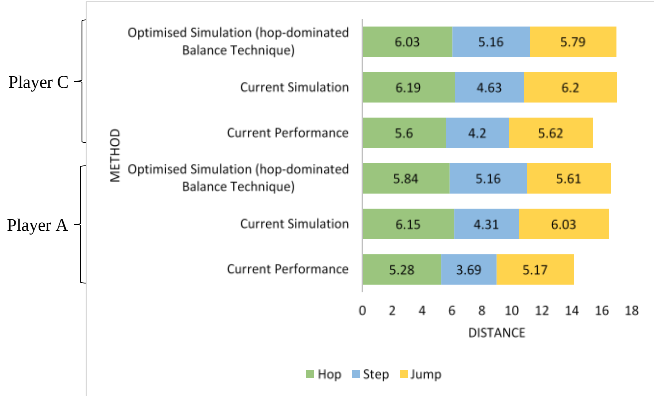

Figure No 5: Current simulation and optimized simulation phase values

To validate the designed biomechanical model all analyzed data were applied to the model of selected sample. Then the results of horizontal, vertical velocity and take off angle were calculated. Through it, optimization distance was calculated. That value of selected and phase ratio player A 37.3 %, 26.2 %, 36.5 %. and player C 36.3 %, 27.3 %, 36.4 %. According to Jonathan Edward, the Phase ratio 35.5 %, 30.4 %, 34.1 %. for balance technique [3]. The model shows the results increase velocity 3 %,4 %,5 % and simulation above hop dominated current performance and balance technique used hop dominated optimization increase the overall performance. But Balance technique is the best results showed. Player A current performance 14.15 m after optimized 16.45 m (figure no 5). Player C Current performance 15.43 m after optimized 16.98 m (figure no 5). That was help to how to do correct technique and body balance and manage the kinematics variables without injury. Current performance is very poor special step phase more force comes, after the hop phase that force, and velocity cannot balance next phase that's why step phase very poor. And also, COM rotation was not forward. Current player places the COM backward while supportive phase landing part. However, this model can be further developed to a 3D optimization model and performance variables optimization and also kinematics and kinetic variable both add to this model can get a better result in applied biomechanics and sport practice which helps to optimize performance of triple jumpers.

Finally, with the optimization here, the following values can be given for each phase to maintain the performance of the players in the 17 m range. Below values were validated for the hop dominated balance technique[1,6].

Table No 7: Outcome of the around 17m velocity and angle range

	Hop	Step	Jump
Velocity (ms^{-1})	8.9-9.4	8.13-9.19	7.11-7.82
Angle (^{0})	16-18	12-15	16-21

The values for the phases were obtained as follow from the above optimization. This shows that distance can be improved by balance technique optimization. Initial current optimization and hop dominated balance optimization method were taken to the consideration. Generally, two athletes' step phase was considerably less than other two phases. After applying current optimization, optimized hop and jump phase values were overreached. Therefore, from those two methods, the hop dominated balance optimization is the best method. From balancing the technique and improving the performance variables can obtain optimum phase ratio.

V. Conclusion

Successful completion of this study, the model's all equations can be input to the software and after entering relevant data of any athlete, optimize velocity, take-off angles and distance can be gain for each athletes / jumpers each phase. Through this research all coaches and athletes can identify their shortcoming phase and values of the optimization variables and performance level. If not, coaching techniques and tactics can be modified. Apart from that, this biomechanical model can be used to improve the talent and to minimize the errors of postures when performing triple jump event. And also, this can be used to identify the relationship between the performance variables and the performance of the players. This provides the differences between potential performances and existing performance of the jumpers. So, this theoretical model can be converted to the practical model. Further, the methodology that uses to create this model can be also used to create this type of models to other sports and other jumping events such as other vertical and horizontal jumping events.

References

[1] Allen, S. (2016). Ooptimization of phase ratio in the triple jump using computer simulation. Human Movement Science, 46, 167-176.

[2] Brimberg, J., Hurley, B., & Ladany, S. P. (2006). An operations research approach to the triple jump. International Journal of Sport Management and Marketing, 1, 208–214.

[3] British, A. (2007, April 17). *British Athletics*. Retrieved from UK Athletics: http://www.britishathletics.org.uk/e-inspire/hall-of-fame-athletes/jonathan-edwards/

[4] Chandana, Arangala W.S. The model of shoulder joint of gymnast interacts with the long swing gymnastic element on parallel bars," ISBS Proceedings Archive: Vol. 38: Iss. 1, Article 86. 2020. https://commons.nmu.edu/isbs/vol38/iss1/86

[5] Hay, J.G. (1985). Issues in sports biomechanics. In Biomechanics: Current Interdisciplinary Research (edited by S.M. Perren and E. Schneider), pp. 49-60.

[6] Hay, J. (1992). The biomechanics of the triple jump: a review. *J. Sports Sci.*, 343–378 .

[7] Koh, T., & Hay, J. (1990). Landing leg motion and performance in the horizontal jumps II. *Journal of Sport Biomechanics*, 361-373 .

[8] Miladinov O, B. P. (2004). Individual approach in improving the technique of triple jump for women. *New Studies in Athletics*, 27-36.

[9] Miller, J.A. and Hay, J.G. (1986). Kinematics of a world record and other world-class performances in the triple jump. International Journal of Sport Biomechanics, 2, 272-88

[10] Rossi, S., Buford, T., McMillan, J., Kovacs, M., & Marshall , A. (2010). Nutritional strategies and immune funtion. *Strength and Conditioning, 70*, 65-70.

[11] Simpson, S.E., Wilson, C., Kerwin, D.G. (2007). The changes in effort distribution from novice to experienced performers in the triple jump. XXV ISBS Symposium, Ouro Preto – Brazil.

[12] Yu, B., & Hay, J. (1996). Optimum phase ratio in the triple jump. *J. Biomech.*, 1283–1289 .

[13] Yu, B. (1999). Biomechanical studies on triple jump techniques: theoretical considerations and applications. *Proceedings of the 17th International Symposium on Biomechanics in Sports*, 17–26

P. C. Thotawaththa, et. al. "A Triple Jump Performance Optimization Model Based on Flight Phase Biomechanical Factors." *IOSR Journal of Sports and Physical Education (IOSR-JSPE,)* *8*(4) (2021): 10-17.