A new method for the computation of target scores in interrupted, limited-over cricket matches

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Since the limited-over games in cricket are result-oriented, an interruption most frequently due to rains (for the team batting second), requires that a revised target is set. After initial experimentation with some ad hoc (and unsatisfactory) methods, the International Cricket Council (ICC) – the governing body of international cricket – has, since 1998, employed the Duckworth–Lewis (D/L) method for revising targets in interrupted matches. Though based on sound mathematical principles and generally satisfactory, on several occasions, the targets set using the D/L method have seemed quite inappropriate.

The method presented in this article is based on mathematical models describing the natural development of the innings. The method employs the concept of normal (PAR) and target scores. Regression equations obtained from a detailed statistical analysis of a data set of closely fought matches, are used to construct easy-to-use tables for employing the method in the field, though a user-friendly, interactive computer program has also been developed. The method is capable of satisfactorily handling any number of interruptions during any stage of the game, as will be demonstrated with a few illustrative examples. More importantly, in the few situations where the D/L method seems to lead to inappropriate targets, those obtained with the present method are seen to be quite satisfactory. A large number of players, umpires, cricket administrators, critics and cricket enthusiasts who have evaluated the method seem to find it consistently superior to the currently followed D/L method.

MAKING use of the advancements in science and technology, many of the important decisions in a cricket match are now made with great precision, with the help of television replays. Decisions on run-outs, stumpings, boundaries (four/six), and even catches are now taken only after thoroughly analysing the situation on television screens. When these items, decided with such great precision are just a few events in the course of the game, it is extremely difficult to believe that there were no scientific methods, till recently, to work out target scores in interrupted matches[1]. The importance of target scores over any of these individual events specified above, need not be emphasized. The Duckworth/Lewis (D/L) system being followed now[2], is perhaps the first scientific approach[3,4] made in this direction. The earlier methods were hardly anywhere near satisfying even the minimum criteria of acceptability. In this article, a method is presented to solve the above problem of fixing target scores in interrupted cricket matches. After briefly describing the events that led to the development of this method, the theoretical background of the underlying mathematical model will be outlined. This will be followed by the details of the various features and parameters of the model. Next, the principles of applying the model to increasingly complex scenarios of interruptions will be briefly indicated along with a set of worked-out examples, illustrating the different steps involved in the application of the method to real as well as hypothetical situations. This will be followed up with a comparison of the present method and the D/L method; another set of real and hypothetical examples will be used to demonstrate the superiority of the present method. The concluding section will describe the responses and reactions of the various cricketing authorities, and the present status of the method.

Background

The maximum-score overs concept tried out during the 1991–92 World Cup is often criticized as the worst of all

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the rain rules tried so far. In fact, this was a wonderful concept but failed terribly due to unscientific execution. In 1992, after many teams, including India tasted the bitter flavour of this method, the author had developed a concept to improve it using the ‘over grouping’ technique. Though it was sent to the then president of the Board of Control for Cricket in India (BCCI), by that time the ICC had decided to change the method as such, and hence there was no further follow-up.

The main problem with the over-grouping technique is that it requires a computer program if, say more than ten overs are to be deducted. When such a program was developed, it was found to give good results when applied to some actual as well as hypothetical cases. Enquiries with appropriate authorities revealed that the official method for resetting targets then in practice was the parabolic method, also known as the ‘Norm method’ (the D/L method was not introduced at the international level then). Even a cursory examination of the norm method was enough to vividly bring out its advantages as well as its drawbacks. This led the author to the idea of clubbing the concepts in the norm method and ‘maximum-score overs method’, to develop a more scientific system. Thus the first version of the method evolved. Though this was sent to both the BCCI and ICC, by then the currently practised D/L system was introduced, and hence no response was received. By 1999 (just prior to the World Cup), however, the drawbacks of the D/L method became apparent[5].

Theory

There are three broad categories of interruptions – between the two innings, within the innings of the team batting second, and within the innings of the team batting first. There may also be instances of multiple interruptions. To be able to handle such situations, one needs a general mathematical model for making a fair comparison between *R1* runs scored by the first team in *O1* overs and losing *W1* wickets, with the *R2* runs scored by the second team in *O2* overs losing *W2* wickets. Further, even when the two teams face the same number of overs, i.e. $O1 = O2 = O$, they may do so under two different situations. For example, the second team is able to play out the full quota of ‘*O*’ overs allotted to them, while the first team, originally allotted a quota of 50 overs, had it cut down to the same number of ‘*O*’ overs midway through its innings. The model should therefore, also be able to take into account the difference between these two situations. As described below, the method presented in this article is able to effectively and logically handle all these (and more complex) situations that may develop in the course of a limited-overs match.

In the present method, this is accomplished on the basis of two equations, derived from a study of the rate of scoring during the development of the innings. The two curves shown in Figure 1 correspond to these two equations, and constitute the body and soul of the method. Curve-*B*, called the normal-score curve, is the statistical curve. This represents the general scoring pattern of a team in a limited-over cricket match. A number of closely fought matches have been analysed to develop this curve. Different stages of the match are designated as different milestones (5, 15, 25, 30, 35, 40, 45 are important milestones in a 50-over match) and the general score percentages at these milestones are found by observing the data. These are shown in Table 1. For getting a better physical feeling of the situation, the scores at each of the milestones in a 250-runs scored match have also been indicated in Table 1.

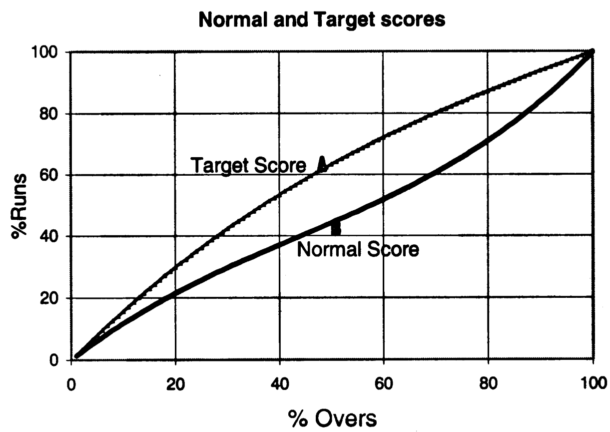

Figure 1. Normal curve and target curve.

Table 1. Data based on which normal score curve is developed

Different stages of the match	Percentage overs	Cumulative percentage	Percentage runs	Cumulative percentage	Percentage runs per percentage overs	Probable scores at different stages in a match of 50 overs in which a team scores 250 runs
Settling down	10	10	08	08	0.80	20 (in 5 overs)
Making use of field restrictions	20	30	24	32	1.20	80 (in 15 overs)
Stabilization of innings-I	20	50	12	44	0.60	110 (in 25 overs)
Stabilization of innings-II	10	60	08	52	0.80	130 (in 30 overs)
Beginnings of acceleration	20	80	18	70	0.90	175 (in 40 overs)
Secondary stage of acceleration	10	90	14	84	1.40	210 (in 45 overs)
Final slog	10	100	16	100	1.60	250 (in 50 overs)

A regression analysis is now carried out using standard spreadsheet software, and an equation relating the cumulative percentage overs and cumulative percentage runs is developed. It is found that a cubical polynomial equation is the most suitable one to represent the scoring pattern of a team. This is because the rate of progress in the score is not uniform in the normal curve. After the first 30% overs there is a decrease in the rate of progress and after 60% overs, the rate of increase becomes sharper. The lowest-order polynomial consistent with this pattern is the cubic one, and hence this is the simplest possible function to describe the normal-score curve. As the cubical polynomial equation itself is found to give a sufficiently smooth curve, it was felt that there is no need to go for a higher degree polynomial. The data used for the regression analysis are furnished in Table 1 and the corresponding regression equation for the normal curve is given by:

$$R = 1.305717007 \times O - 0.013782 \times O^2 + 0.0001069 \times O^3, \tag{1}$$

where R represents percentage of runs and O represents percentage of overs.

Now, the data in Table 1 are rearranged in such a way that the maximum scored overs come first and the minimum scored overs fall last. This is done according to the column in Table 1 which gives the ratio of percentage of runs/percentage of overs. The data thus rearranged are shown in Table 2. Again using the spreadsheet program, the regression analysis is carried out for the rearranged data and the equation for the target curve (Curve-A) is developed. The regression equation for the target curve is thus given by:

$$R = 1.6631192 \times O - 0.009254 \times O^2 + 0.0000261 \times O^3. \tag{2}$$

While these two equations are now capable of handling 90% of the situations that one comes across in the limited-over matches, they are by themselves not adequate for resetting the target when the interruption is within an innings. What one needs to predict from the model in such a situation is the number of runs that could have been scored, had the 'lost' overs been available. It is obvious that this depends not only on the number of overs, but also on the number of wickets that the batting team still has at its disposal. In the present method, the effect of wickets has been incorporated using the same approach described above for runs, namely by examining the pattern of fall of wickets during the normal development of the innings. Table 3 gives the normal fall of wickets corresponding to the normal-score percentages worked out from the data. For getting a better physical feeling of the situation, Table 3 also gives (in brackets) the actual overs and corresponding normal wickets in a fifty-over match. It should be noted that the scores corresponding to the normal-score curve correspond to the normal wickets expected at that stage. It is further assumed that the score corresponding to the target curve corresponds to nine wickets (as the second team can win the match by achieving this score, even by losing nine wickets).

It is observed that there is a certain amount of chance in any limited-overs match, that the batting team loses wickets in quite an abnormal way thus tending to get all-out before the scheduled quota of overs. Under this circumstance, it is necessary to stipulate a minimum percentage of runs to be achieved corresponding to each percentage of fall of wickets. With the assumption that a team normally has seven capable batsmen and four bowlers, Table 4 gives the minimum score percentage to be achieved against each wicket percentage.

These equations and assumptions have formulated the basic ingredients required to analyse any match situation. Now what remains is to devise a systematic procedure to tackle the different problems during the course of a match. The theoretical aspects related to this are explained while dealing with the different categories of interruption in the

Table 2. Data derived for development of target curve

Percentage runs per percentage over	Overs cumulative percentage	Runs cumulative percentage	Remarks
1.60	10	16	Data for normal-score curve are rearranged in such a way that the overs of maximum run rate come first. Regression analysis is again carried out to get the corresponding equation.
1.40	20	30	
1.20	40	54	
0.90	60	72	
0.80	80	88	
0.60	100	100	

Table 3. Percentage of wicket falls corresponding to normal score

Percentage overs	30 (15)*	50 (25)	70 (35)	84 (42)	92 (46)	95 (47, 3)	100 (50)
Percentage wicket fall	20 (2)	30 (3)	40 (4)	50 (5)	60 (6)	70 (7)	100 (10)

*Values in brackets are the number of overs and the corresponding number of normal fall of wickets for a fifty-over match. The last value should be taken as 100% (10 wickets) for theoretical reasons.

'application part'. Generally, in curtailed matches the field restrictions, the number of overs per bowler, etc. are also reduced proportionately. As in this method, the score percentages are taken corresponding to the percentage overs played/available, these changes are also taken care of to an appreciable level.

The target table

It is needless to explain in detail, the practical difficulties one may have in taking values from these curves to solve the problems related to curtailment of overs. Especially when the wickets fallen at the time of interruptions differ from the ones corresponding to the normal curve, and where the minimum score percentage criterion corresponding to the fall of wickets needs to be looked into, the job becomes tedious. A user-friendly table, the target table (Table 5) takes care of these problems.

It can be seen from Table 5 that the column 'target runs percentage' is the one corresponding to the target score percentage curve in Figure 1. In other words, it corresponds to eq. (2) for target score percentage developed through regression analysis of the data in Table 2. The normal curve in the same form as given in Figure 1 or as given by eq. (1) is not directly available in Table 5. The score corresponding to the normal curve is valid only for the normal fall of wickets, i.e. those given in Table 3. These specific entries, which correspond to 1, 2, . . ., 7 wickets, have been shown in boldface in Table 5 (for example, the value of 16.9 corresponding to 15% overs and 10% wickets, i.e. 1 wicket, shown in boldface in Table 5, corresponds to a point on the normal curve). When the fall of wickets differs from these, the normal score gets modified. Since, as described above, the target score is assumed to correspond to 90% of the fall of wickets, the modified normal score for the intermediate values (modified normal scores for the fall of wickets other than what is given in Table 3) is found out by interpolation. Hence there are ten columns (corresponding to 0–9 wickets) corresponding to normal-score percentages for each percentage of overs. These give the modified normal-score percentages corresponding to different percentages of fall of wickets. Again the minimum score percentage criterion is also integrated into this by replacing these modified values by the percentages of minimum requirement according to Table 4, whenever the values go below them. In order to ensure that the curves pass through some of the key points, slight manual adjustments are made in the tabulated values, particularly in the last portion of the target table. On the basis of further rigorous data analysis and changes in playing rules, the table may be subjected to some minor changes, but the principle and the procedure will remain unchanged. An extended version of Table 5, that gives values corresponding to 0.1% of overs, is also available with the author.

Table 4. Minimum value of normal scores assumed for different percentages of fall of wickets

Percentage fall of wickets	0	10	20	30	40	50	60	70	80	90
Percentage runs (minimum)	0	10	20	35	50	60	70	79	87	95

Application of the proposed method for different cases of interruption

With the help of Table 5, it is quite straightforward to compute the target score for several simple situations. It will be helpful to keep the following points in mind while applying the method:

(*i*) *For overs played out before the interruption, always look at the normal-score columns corresponding to the wickets fallen.*
(*ii*) *For the overs remaining after the interruption, always look at the target-score column. This is independent of the wickets fallen.*

Suppose the interruption occurs between the two innings after the first team completes its quota of 50 overs, and the second team can be allotted only 40 overs. Since this is 80% compared to the overs faced by the first team, one looks up Table 5 for the target score corresponding to 80%. This is seen to be equal to 87.6%, and the target for the second team is 87.6% of the runs scored by the first team.

Another situation that clearly brings out the mathematical model underlying the present method is when the interruption is during the innings of the team batting second, and no further play is possible beyond the point of interruption. Suppose the first team has scored 250 runs in 50 overs, and when the second team has scored 165 runs at the loss of 6 wickets at the end of 30 overs, no further play is possible. To decide on the winner, one should look at Table 5 for the value corresponding to 60% overs and 6 wickets, which is seen to be equal to 70%. This means that the second team has completed 70% of its innings. The equivalent value for the first team (PAR score) would be $(70\% * 250 = 175)$, which is greater then 165, so the first team would be declared the winner.

Continuing with the above example, suppose instead of complete stoppage of play, the second team could play only ten more overs after the interruption (instead of the remaining 20). As seen earlier, the team batting second has completed 70% of its innings (as seen from the normal table). That leaves 30%. Of the remaining 20 overs, only ten (i.e. 50%) are going to be possible. However, for this shortened spell, one should look up the entry corresponding to 50% in Table 5 in the target column, and that is 63.4%. So for the remaining innings,

Table 5. The target table

Percentage of overs	Target runs (%)	Normal runs percentages for different percentages of wicket fall									
		0	10	20	30	40	50	60	70	80	90
1	1.7	0.8	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
2	3.3	1.6	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
3	4.9	2.6	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
4	6.5	3.5	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
5	8.1	4.4	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
6	9.7	5.3	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
7	11.2	6.2	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
8	12.7	7.0	10.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
9	14.2	7.9	10.9	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
10	15.7	8.8	12.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
11	17.2	9.6	13.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
12	18.7	10.5	14.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
13	20.1	11.3	15.0	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
14	21.6	12.1	15.9	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
15	23.0	12.9	**16.9**	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
16	24.4	13.7	17.7	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
17	25.7	14.6	18.4	20.0	35.0	50.0	60.0	70.0	79.0	87.0	95.0
18	27.1	15.4	19.3	20.7	35.0	50.0	60.0	70.0	79.0	87.0	95.0
19	28.5	16.2	20.1	21.6	35.0	50.0	60.0	70.0	79.0	87.0	95.0
20	29.8	16.9	20.8	22.5	35.0	50.0	60.0	70.0	79.0	87.0	95.0
21	31.1	17.7	21.4	23.3	35.0	50.0	60.0	70.0	79.0	87.0	95.0
22	32.4	18.5	22.2	24.1	35.0	50.0	60.0	70.0	79.0	87.0	95.0
23	33.7	19.3	22.9	24.9	35.0	50.0	60.0	70.0	79.0	87.0	95.0
24	35.0	20.1	23.6	25.6	35.0	50.0	60.0	70.0	79.0	87.0	95.0
25	36.2	20.8	24.2	26.4	35.0	50.0	60.0	70.0	79.0	87.0	95.0
26	37.5	21.6	24.8	27.1	35.0	50.0	60.0	70.0	79.0	87.0	95.0
27	38.7	22.4	25.4	27.8	35.0	50.0	60.0	70.0	79.0	87.0	95.0
28	39.9	23.1	26.0	28.4	35.0	50.0	60.0	70.0	79.0	87.0	95.0
29	41.1	23.9	26.6	29.1	35.0	50.0	60.0	70.0	79.0	87.0	95.0
30	42.3	24.7	27.2	**29.7**	35.0	50.0	60.0	70.0	79.0	87.0	95.0
31	43.5	25.4	27.9	30.3	35.0	50.0	60.0	70.0	79.0	87.0	95.0
32	44.7	26.2	28.7	31.1	35.0	50.0	60.0	70.0	79.0	87.0	95.0
33	45.8	27.0	29.5	31.8	35.4	50.0	60.0	70.0	79.0	87.0	95.0
34	46.9	27.7	30.2	32.5	36.1	50.0	60.0	70.0	79.0	87.0	95.0
35	48.1	28.5	30.9	33.1	36.8	50.0	60.0	70.0	79.0	87.0	95.0
36	49.2	29.3	31.7	33.9	37.4	50.0	60.0	70.0	79.0	87.0	95.0
37	50.3	30.0	32.4	34.5	38.0	50.0	60.0	70.0	79.0	87.0	95.0
38	51.4	30.8	33.2	35.2	38.6	50.0	60.0	70.0	79.0	87.0	95.0
39	52.4	31.6	34.0	35.9	39.2	50.0	60.0	70.0	79.0	87.0	95.0
40	53.5	32.4	34.7	36.6	39.7	50.0	60.0	70.0	79.0	87.0	95.0
41	54.5	33.2	35.4	37.2	40.3	50.0	60.0	70.0	79.0	87.0	95.0
42	55.6	33.9	36.1	37.8	40.8	50.0	60.0	70.0	79.0	87.0	95.0
43	56.6	34.7	36.8	38.5	41.3	50.0	60.0	70.0	79.0	87.0	95.0
44	57.6	35.5	37.5	39.1	41.8	50.0	60.0	70.0	79.0	87.0	95.0
45	58.6	36.3	38.3	39.8	42.2	50.0	60.0	70.0	79.0	87.0	95.0
46	59.6	37.1	39.0	40.4	42.7	50.0	60.0	70.0	79.0	87.0	95.0
47	60.6	37.9	39.8	41.0	43.1	50.1	60.0	70.0	79.0	87.0	95.0
48	61.5	38.8	40.5	41.6	43.5	50.7	60.0	70.0	79.0	87.0	95.0
49	62.5	39.6	41.2	42.3	43.9	51.4	60.0	70.0	79.0	87.0	95.0
50	63.4	40.4	42.0	43.0	**44.3**	51.9	60.0	70.0	79.0	87.0	95.0
51	64.4	41.3	42.7	43.8	44.9	52.6	60.0	70.0	79.0	87.0	95.0
52	65.3	42.1	43.4	44.5	45.6	53.2	60.0	70.0	79.0	87.0	95.0
53	66.2	43.0	44.2	45.3	46.4	53.7	60.0	70.0	79.0	87.0	95.0
54	67.1	43.8	44.9	46.0	47.1	54.3	60.3	70.0	79.0	87.0	95.0
55	68.0	44.7	45.8	46.9	47.9	54.8	61.0	70.0	79.0	87.0	95.0
56	68.9	45.6	46.6	47.7	48.7	55.3	61.6	70.0	79.0	87.0	95.0
57	69.8	46.5	47.4	48.4	49.4	55.9	62.4	70.0	79.0	87.0	95.0
58	70.6	47.4	48.3	49.3	50.2	56.4	63.0	70.0	79.0	87.0	95.0
59	71.5	48.3	49.2	50.1	50.9	56.9	63.7	70.0	79.0	87.0	95.0
60	72.3	49.2	50.1	50.9	51.7	57.3	64.3	70.0	79.0	87.0	95.0
61	73.2	50.2	51.0	51.7	52.5	57.8	65.0	70.0	79.0	87.0	95.0
62	74.0	51.1	52.0	52.7	53.4	58.1	65.5	70.0	79.0	87.0	95.0
63	74.8	52.1	52.9	53.5	54.2	58.6	66.2	70.5	79.0	87.0	95.0
64	75.6	53.0	53.9	54.4	55.1	58.9	66.7	71.1	79.0	87.0	95.0
65	76.4	54.0	54.8	55.3	55.8	59.3	67.3	71.9	79.0	87.0	95.0
66	77.2	55.0	55.8	56.2	56.7	59.7	67.9	72.5	79.0	87.0	95.0
67	78.0	56.1	56.8	57.2	57.6	60.0	68.4	73.2	79.0	87.0	95.0

Table 5. *Contd..*

Percentage of overs	Target runs (%)	Normal runs percentages for different percentages of wicket fall									
		0	10	20	30	40	50	60	70	80	90
68	78.8	57.1	57.7	58.1	58.5	60.3	68.9	73.9	79.0	87.0	95.0
69	79.6	58.1	58.7	59.1	59.4	60.5	69.4	74.5	79.0	87.0	95.0
70	80.3	59.2	59.7	60.1	60.4	**60.7**	69.8	75.1	79.0	87.0	95.0
71	81.1	60.3	60.8	61.2	61.5	61.6	70.4	75.7	79.0	87.0	95.0
72	81.8	61.4	61.7	62.1	62.4	62.5	71.0	76.4	79.0	87.0	95.0
73	82.6	62.5	62.7	63.1	63.4	63.5	71.5	77.1	79.2	87.0	95.0
74	83.3	63.6	63.8	64.2	64.4	64.5	72.0	77.7	79.8	87.0	95.0
75	84.0	64.7	64.9	65.3	65.5	65.6	72.5	78.2	80.4	87.0	95.0
76	84.8	65.9	65.9	66.3	66.5	66.6	73.0	78.9	81.1	87.0	95.0
77	85.5	67.1	67.1	67.4	67.6	67.7	73.5	79.5	81.8	87.0	95.0
78	86.2	68.3	68.3	68.6	68.8	68.9	73.9	80.1	82.4	87.0	95.0
79	86.9	69.5	69.5	69.7	69.9	70.0	74.4	80.7	83.0	87.0	95.0
80	87.6	70.7	70.7	71.0	71.1	71.2	74.7	81.2	83.6	87.0	95.0
81	88.3	72.0	72.0	72.2	72.3	72.4	75.1	81.7	84.1	87.0	95.0
82	89.0	73.2	73.2	73.4	73.5	73.6	75.4	82.2	84.7	87.3	95.0
83	89.6	74.5	74.5	74.7	74.7	74.8	75.7	82.6	85.2	87.8	95.0
84	90.3	75.8	75.8	75.9	75.9	76.0	**76.0**	83.2	85.9	88.5	95.0
85	91.0	77.2	77.2	77.3	77.3	77.3	77.3	83.7	86.4	89.2	95.0
86	91.6	78.6	78.6	78.6	78.6	78.6	78.6	84.2	87.0	89.7	95.0
87	92.3	79.9	79.9	79.9	79.9	79.9	79.9	84.8	87.6	90.4	95.0
88	93.0	81.3	81.3	81.3	81.3	81.3	81.3	85.3	88.2	91.0	95.0
89	93.6	82.7	82.7	82.7	82.7	82.7	82.7	85.7	88.7	91.6	95.0
90	94.3	84.1	84.1	84.1	84.1	84.1	84.1	86.2	89.2	92.3	95.0
91	94.9	85.5	85.5	85.5	85.5	85.5	85.5	86.6	89.7	92.8	95.0
92	95.5	87.0	87.0	87.0	87.0	87.0	87.0	**87.0**	90.2	93.4	95.5
93	96.2	88.5	88.5	88.5	88.5	88.5	88.5	88.5	90.7	94.0	96.2
94	96.8	90.0	90.0	90.0	90.0	90.0	90.0	90.0	91.2	94.6	96.8
95	97.4	91.6	91.6	91.6	91.6	91.6	91.6	91.6	**91.6**	95.1	97.4
96	98.1	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	95.7	98.1
97	98.7	94.8	94.8	94.8	94.8	94.8	94.8	94.8	94.8	96.1	98.7
98	99.3	96.5	96.5	96.5	96.5	96.5	96.5	96.5	96.5	97.2	99.3
99	99.6	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	99.6
100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

the figure will be (30 * 63.4 = 19.02%). The team thus would complete (70 + 19.02 = 89.02%) of its innings, and the equivalent value for the first team would be 222.55 (the sum of PAR score of 175 and the newly computed score of 47.55 from the additional 10 out of 20 overs). Hence, the target score for the second team to be reached in 40 overs, will be 223 runs.

For more complicated situations involving multiple interruptions etc. the verbal description as given above would become too elaborate to be understood easily. In fact, even for the cases mentioned above, the description of the process of application of the method become much clearer if expressed as a step-by-step procedure, as can be seen in Appendix 1. The five examples described in the Appendix illustrate the systematic application of this method to situations of increasing complexity. It also demonstrates how the method can be applied for cases involving any number of interruptions at any stage of the game.

To compute target scores using the procedure furnished above, a computer is not quite essential. But it is always desirable. Hence, the author has also developed an interactive computer program with the help of which all these computations can be done easily. The source program is written in FORTRAN 77 and it works in the DOS mode.

Comparison with the existing system

The D/L method and the proposed method have been developed based on two different concepts. The former[6] treats the overs to be played and the wickets in hand as 'resources', and uses an exponential type of function to describe how the remaining resources are depleted as the overs get used up and/or the wickets fall during the progress of the innings. The present method[7], on the other hand, uses a regression-based approach to describe the progress of the innings, and is firmly based on data selected from a set of closely fought matches. However, the objectives of the two methods are the same, and hence the theoretical aspects can be compared without much trouble. This is illustrated in Figure 2. Curve-1 in Figure 2 is *similar* to the following: (1) The curve used in the norm method; (2) A specimen curve of the D/L system; (3) The target curve of the proposed system.

If the calculations are done only based on the corresponding curves of the three methods, the results obtained from them also must be quite similar (except for the variations due to the data used for the statistical analysis). Of course, for the 'norm method' there is no second curve, and hence it cannot distinguish between the stages of interruption.

The D/L curves are not actually single curves. Each curve is a family of curves. In other words, each curve has one associated curve with it. In Figure 2, curve-3 symbolizes a sample 'associated curve'. When the first curve represents the resources remaining, the second one (curve-3) stands for the resources utilized. Curve-2 in Figure 2 represents the normal-score curve of the proposed system. This is the counterpart of the associated curve in the D/L system.

It can be seen from Figure 2 that there is a significant change in the behaviour of the curves 2 and 3. This itself is the basic reason for the differences in the results of the two methods in some cases. In the D/L system, the increase in the rate is exponential right from the beginning, whereas in the proposed system such an increase is observed only after 60–70% overs. In the initial part it behaves quite differently. Since the curve is developed based on data at different stages of the match, it so happens that this curve lies closer to the actual match situation than the D/L curve. This is the basic reason why the results obtained from the proposed system become more acceptable.

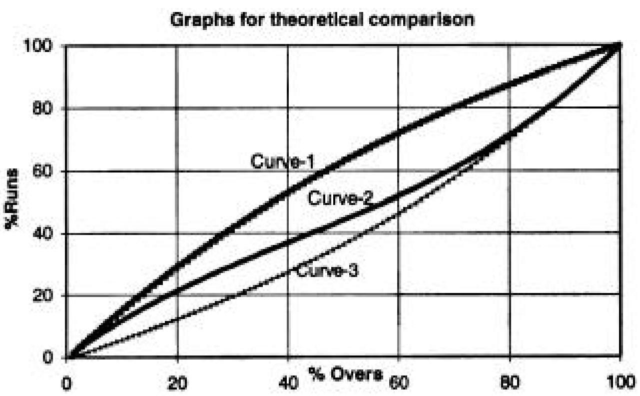

Figure 2. Comparison between the existing method and the proposed method.

Another important difference between the D/L method and the present one is that there is no arbitrary constant in this method like the G50 (the average or typical score of 225 for a completed 50-over innings) of the D/L system. The scaling up is done purely based on the *performance of the first team in more than 25 overs of its innings*. If a model cannot fix a target based on 'the performance of a team in more than 25 overs', it should be treated as a weakness of that model. The history should be used only up to the stage of arriving at a suitable model. It should not again be pulled in (as it is done in the D/L system), while the model is applied to the prevailing situation. To reiterate, a good model should give sensible results from the following facts: team-1 has played '*x1*' overs, has lost '*y1*' wickets and has scored '*z1*' runs; what are the equivalent *x2*, *y2* and *z2* for team-2. The model presented here just does that.

This method was shown to experts in the field of cricket, including players, umpires and statisticians[8–10]. There was unanimous opinion that the method always gives sensible results. On the other hand, the widely talked-about opinion on the D/L system is that it favours the team that is batting when the interruption occurs. Also, when the interruption is between the batting of the two teams, the target set for the second team is quite high.

Table 6. Comparison of certain results of the D/L method with the proposed method (examples for D/L system giving controversial results)

Situation	D/L target	Target in the proposed method	Comments
Team-1: 300 in 50 overs. Interruption occurs when team-2 completes 25 overs by losing two wickets. What is the winning score of team-2 in 25 overs?	115	130	D/L par score appears to be quite low
Team-1: 300 in 50 overs. What is the target for team-2 in 25 overs?	207	191	D/L target quite high
Australia 252 in 50 overs; West Indies (WI), after 29 overs, 138/1. Ten overs are lost. What is the target for WI in 40 overs?	196	208	D/L target quite low
New Zealand after 27.2 were 81/5 when 1 over was lost and then at 114/5 in 32.4 overs their innings terminated. What is the target for South Africa in 32 overs?	153	129	D/L target quite high
India 226/8 in 47.1 overs. What is the target for Pakistan in 33 overs?	201	186	Do
Team-1 after 25 overs 100/0 when their innings terminated. What is the target for team-2 in 25 overs?	185	157	Do
England 176/5 after 36.5 overs when the match was rescheduled to 46 overs. Then after 37.5 overs when England were 181/5 the match was again rescheduled to 40 overs. England makes 193/6 in 40. What is the new target?	223	212	Do
New Zealand 212 in 44.2 over. What is the target for WI in 33 overs?	212	202	Do

A more concrete and quantitative illustration of these impressions is provided in Table 6. The table provides a list of eight situations where the author feels that his results are better than those of the D/L system. The examples presented here suggest that the proposed method is superior to the system presently being followed by the ICC*.

In summary, the method proposed here is capable of solving practically any problem related to fixing targets in an interrupted limited-overs cricket match. It gives results which are likely to satisfy not only both the teams but also the millions of spectators and cricket lovers.

Appendix 1. A step-by-step description of application of the present method

As has been mentioned earlier, the whole problem of fixing target scores is broadly categorized under three cases:

Case-A: The interruption is after team-1 has completed its innings and before team-2 begins its innings.
Case-B: The interruption comes after team-2 has batted through some overs in its innings.
Case-C: The interruption is during the batting of team-1 itself.

Any problem related to fixing target scores can be included in one of the three categories or can be treated as a combination of two or all of these cases.

Step-by-step procedure for case-A

1. Find out the percentage of overs team-2 gets.
2. Find out the corresponding target score percentage from the target table.
3. Multiply the score made by team-1 with the value obtained in #2.

Illustrative example-1: Team-1 scores 264 runs in 50 overs. Before team-2 starts batting, an interruption occurs and the match is reduced to a '42-over' one. Target score for team-2 is found as follows.

Solution

'Percentage overs' to be played by team-2 = 42/50 × 100 = 84.

From target table, corresponding to 84% of overs, target percentage = 90.3.
Hence, the target score = 90.3 × 264 = **239 runs**.

Step-by-step procedure for case-B

1. Find out the percentage of overs played up to the interruption.
2. Find out the normal percentage of runs corresponding to #1 and the wickets fallen.
3. Find out the PAR score (say PAR-1) as, normal score percentage multiplied by the score of team-1.
4. Find out the percentage remaining overs with respect to the *total overs remaining*.
5. Find out the corresponding target percentage.
6. Multiply the target percentage of #5 with 'the total score of team-1 minus PAR-1' to get the target score in the remaining overs.
7. Add PAR-1 with the target obtained in #6 to get the net target.

Illustrative example-2: LOI# 1442: Australia vs West Indies (WI). Australia 252 in 50 overs; WI, after 29 overs, 138/1. Ten overs are lost. What is the target for WI in 40 overs.

Solution

Percentage of overs played by WI at the time of interruption = 58.
Corresponding normal score = 48.3%.
PAR-1 = 48.3 × 252 = 121.7 → (1).
Percentage of the remaining overs wrt the total remaining overs = 11/ 21 × 100 = 52.4.
Corresponding target percentage = 65.6.
Target score for the remaining overs = 0.656 × (252–121.7) = 85.5 → (2).
Net target in 40 overs (1) + (2) = 121.7 + 85.5 = 207.2 = **208 runs**.

In case of a secondary interruption, the procedure will be to find PAR-2 at the secondary interruption and add the target for the remaining overs with it.

8. PAR-2 = PAR-1 plus (*N2*–*N1*)/(100–*N1*) multiplied by 'target in the remaining overs' calculated in #6. Here *N1* is the normal score percentage with respect to the new base at the first interruption and *N2* is the normal score percentage with respect to the new base at the second interruption. (New base means *the over corresponding to the net target calculated in #7 earlier.*)
9. Target percentage in the remaining overs is calculated by multiplying the remaining runs (i.e. net target as per #7 minus PAR-2) with T_c, where T_c is the ratio of the target percentage as shown in Figure 3.
10. Add PAR-2 with the target obtained according to #9 to get the 'net target-2'.

*On 5 July 2000, Sunil Gavaskar extended an e-mail invitation to the author for making a presentation on 11 July 2000 in Pune in a BCCI Technical Committee Conference. Impressed by some of the results of the method, the committee asked the author to make a presentation in the Umpire's Seminar in September 2000 at Jamshedpur. As suggested in that seminar, a computer program was also developed subsequently to effect quick calculations. The BCCI meeting held on 7 April 2001 decided to forward this proposal to the ICC. But for some unknown reasons, the ICC Committee Meeting held in the last week of May 2001 did not take up this proposal and decided to continue with the D/L system.

Illustrative example-3: As a matter of fact, in the match (example-2) there were no further interruptions. But let us now assume that there was another interruption after 35 overs, when WI were at say 172/3. Now two more overs are lost. What is the target?

Now the procedure will be to find our PAR-2 at 35 overs and add the target for the remaining three overs.

PAR-2 = 121.7 + ($N2$–$N1$)/(100–$N1$) × 85.50.

$N1$ is the normal score percentage for 72.5% (29/40 × 100) of overs with 1 wicket lost.
Here it is = 62.2% (*from the target table*).

$N2$ is the normal score percentage for 87.5% (35/40 × 100) of overs with 3 wickets lost.
Here it is = 80.6% (*from the target table*).

Hence PAR-2 = 121.7 + (80.6–62.2)/(100–62.2) × 85.5 = 163.3 → (1).

Target score for the remaining 3 overs = T_c × (207.2–163.3) = T_c × 43.9.

T_c = (Target percentage for 3/15 per cent overs) divided by (target percentage for 5/15 per cent overs) i.e. target for 20% divided by target for 33.3% = 29.8/46.2 = 0.645.

Hence the target for the remaining overs = 0.645 × 43.9 = 28.3 → (2).

Target score for WI in 38 overs would be (1) + (2) = 163.3 + 28.3 = 191.6 = **192 runs**.

Step-by-step procedure case-C

1. Find out the percentage of overs played up to the interruption.
2. Find out the normal percentage of runs corresponding to #1 and the wickets fallen.
3. Find out the percentage of *remaining overs* with respect to the *total overs, which was originally remaining*.
4. Find out the corresponding target percentage.
5. Multiply the target percentage obtained in #4 with the remaining score percentage (i.e. 100 – normal score calculated in #2).

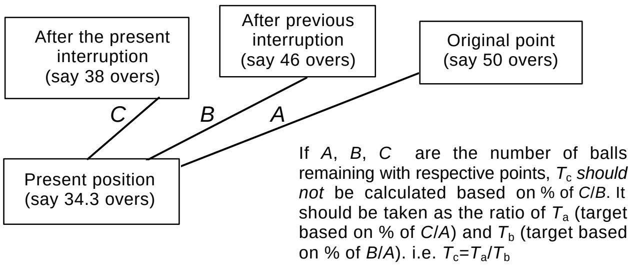

Figure 3. Concept of T_c.

6. Add the percentages obtained in #2 and #5 to get the *effective normal score (ENS) of team-1* in total percentage of overs played.
7. Find out the target percentage for the total percentage of overs played.
8. Target percentage in #7 divided by the ENS percentage in #6 will give the multiplication factor (MF). It is proposed to keep the lower limit of this MF as 1 for game-related reasons.
9. Multiply the score made by team-1 with MF to get the target of team-2.

Illustrative example-4: (Single interruption) LOI #1485 Sri Lanka vs Australia. Australia were 110/3 in 23.1 overs when the interruption took place. Seven overs were lost. Australia make 206 in 43 overs. What is the target for Sri Lanka in 43 overs.

Solution

Percentage of overs played at the interruption = 46.2.
Normal percentage with 3 wickets lost = 42.8.
Remaining over percentage = 19.84/26.84 × 100 = 73.9.
Corresponding target percentage = 83.2.
ENS of Australia in 43 overs = 42.8 + (100–42.8) × 83.2% = 90.39%.
Target score percentage for 43 overs (86%) = 91.6.
MF = 91.6/90.39 = 1.0134.
Target for Sri Lanka in 43 overs = 1.0134 × 206 = 208.76 = **209 runs**.

In the case of a secondary interruption the procedure will be:

10. Find out PAR-2 as PAR-1 + ($N2$–$N1$)/(100–$N1$) × (ENS-PAR-1).
11. Target percentage for the remaining overs as T_c × (ENS-PAR-2), where $T_c = T_b/T_a$.
12. Add the results of #10 and #11 to get the new ENS.
13. Find out the target percentage for the total overs played.
14. MF = Result of #13 divided by result of #12. (The lower limit is kept as 1 for game-related reasons.)

Illustrative example-5: (Multiple interruptions) New Zealand were 81/5 in 27.2 overs when the first interruption took place and 1 over was lost. When they were at 114/5 in 32.4 overs their innings terminated due to another interruption. What is the target for South Africa in 32 overs?

Solution

Percentage of overs played at the first interruption = 27.32/50 × 100 = 54.6.
Normal score corresponding to the above for 5 wickets (PAR-1) = 60.7.
Target score in the remaining 95.6% (21.67/22.67 × 100) overs = 97.8.

ENS in 49 overs = 60.7 + (100–60.7) × 0.978 = 99.1.

For the second interruption

PAR-2 = 60.7 + ($N2$–$N1$)/(100–$N1$) × (99.1–60.7).
$N2$ = Normal score percentage corresponding to 66.7% (32.67/ 49 × 100) overs and 5 wickets = 68.3.
$N1$ = Normal score percentage corresponding to 55.8% (27.32/ 49 × 100) overs and 5 wickets = 61.5.
PAR-2 = 60.7 + (68.3–61.5)/(100–61.5) × (99.1–60.7) = 67.5.

Since New Zealand did not bat after the second interruption, their ENS at the end of the innings = 67.5% + 0% = 67.5%.
The target score in 32.4 overs (32.67/50 × 100% overs) = 76.7%.
MF = 76.7/67.5 = 1.1362.
Target for team-2 in 32.4 overs = 114 × 1.1362 = 129.53.
Target in 32 overs, i.e. 98% (32/32.66 × 100 = 98) overs = 99.3%.
Target score for South Africa in 32 overs = 0.993 × 129.53 = 128.62 = **129 runs**.

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Asian Brown Cloud – fact and fantasy

J. Srinivasan and Sulochana Gadgil*

The wide publicity given to the release of a United Nations Environment Programme (UNEP) report on the so-called Asian Brown Cloud and its multifarious impacts on health, agriculture and climate on both regional and global scales, has led to considerable concern. We find that the UNEP news release (and hence the media reports based on it) is a blend of observations and scientifically sound deductions on the one hand and sensational statements with little scientific basis on the other. The UNEP report is based on the findings of an international programme called the Indian Ocean Experiment (INDOEX). The term Asian Brown Cloud was coined by leaders of INDOEX to describe the brown haze occurring during the period January to March, over the South Asian region and the tropical Indian Ocean, Arabian Sea and Bay of Bengal. It is important to note that, the haze is not a permanent feature of the atmosphere over the Asian region and the surrounding seas. It occurs only during January–March, in the season following the southwest monsoon and northeast monsoon seasons.

It is suggested in the UNEP report that the impact of the haze assessed with the help of an atmospheric general circulation model is a decrease in rainfall in northwest Asia (including Saudi Arabia, Pakistan, Afghanistan). However, we find that the model simulation of the rainfall patterns over this region is particularly poor and hence the reliability of this projection is suspect. Also, the expected magnitude of the impact on crop yields is small and there is no basis for the statement in the UNEP news release that the 'vast blanket of pollution across South Asia is damaging agriculture'.

THE wide publicity given by the electronic and print media to the release of a United Nations Environment Programme (UNEP) report on the so-called Asian Brown Cloud[1] and its multifarious impacts on health, agriculture and climate on both regional and global scales, has led to considerable curiosity as well as concern. This has brought up a number of questions about the nature of the Asian Brown Cloud such as: (i) Is what has been described as a blanket of pollution, really a cloud? (ii) Is it brown, and if so, why? (iii) Is it a special feature of the Asian region? There are also questions about the likely impact on regional and global scales such as: (i) Will it

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