THE IMPACT ON RECEIPTS OF CONVERSION TO ONE-MAN BUS OPERATION

Some Explanations and Predictions

By M. H. Fairhurst*

During 1972 a large study was performed within the London Transport Executive to assess whether one-man-operated (O.M.O.) buses could or should be operated in Central London. This paper sets out the results of a receipts analysis of a set of suburban conversions, which was one of several contributions to the final evaluation.

In the early months of 1972 it was apparent that on many bus services converted to split-entrance O.M.O. in 1971 receipts had fallen by 10 to 20%. Evidently, if such losses were entirely due to O.M.O. and represented real receipts losses to London Transport, the wisdom of further conversions would be questioned. In the event, the analysis (presented here) of thirty of the 1971 conversions has shown that (excluding diversion to parallel services) receipts losses due to O.M.O. itself have been on average only 3 or 4%. The paper discusses part of the work done to identify and assess the relative importance of the several factors which depressed receipts after past conversions.

THE PROBLEM, THE APPROACH AND ITS LIMITATIONS

An assessment of the financial consequences of O.M.O. based on a simple "before and after" comparison is likely to be misleading, since:

1. conversions are usually accompanied by changes in bus mileage run, either as a matter of policy or—as currently—because the easier staff situation on O.M.O. services leads to a significant reduction in bus miles lost from staff shortage;

2. almost any converted service is likely to be only one of a number of services covering the route of the service converted. If passengers treat this set of services as basically one service, any alteration in the frequency (due to changes in bus miles run) or the waiting and travel times (due to O.M.O.) of any of the services will:

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*Economic Research Section, London Transport Executive. This paper represents the views of the author, which may not be those of the Economic Research Manager or of the London Transport Executive. The author thanks Dr. D. A. Quarntby and Peter Collins, of London Transport, for much help and advice. Any faults remaining are the author's.

1A split-entrance one-man-operated bus has two boarding streams: one of these is served by the driver, the other by a self-service machine. Such buses divide into SMS (single deck, part standee) and DMS (double deck, also partly standee on the lower deck).
(a) produce automatically\textsuperscript{2} transfers of passengers within the set;  
(b) alter the total passenger demand for all the services along the route. 
Thus, because of (b) the total number of people waiting at bus stops will change and because of (a) the share of the passengers going to each service will change.

**Parallel Services**

Parallel services to a service whose waiting and travel times worsen will thus experience two contrary factors: passenger reaction to the decline in ‘service’ along the road will tend to depress their receipts, but this tendency will be more than offset by transfers of traffic from the first service to the parallel services. The net effect of these two factors is commonly called within London Transport ‘diversion to parallels’.

It is shown (below) that the eventual real\textsuperscript{3} loss to a converted service (when all the parallel services covering the route have also been converted to O.M.O.) will be its own real loss when first converted plus the real losses suffered by the parallels under 2(b) above. Thus, it is only possible to evaluate the true receipts implications of O.M.O. by considering all the services that cover the route of the service concerned.

As a simple example, consider a stretch of road covered by two identical services (A and B). Passengers arrive randomly at stops and take whatever bus arrives first. Suppose the ‘service’, however defined, provided by A declines by 10\%\textsuperscript{.} The result will be that some passengers will cease arriving at bus stops, producing a real loss that will affect A and B equally. However, if A’s deterioration results in longer waiting times, B’s loss may well be masked by diversion of passengers from A.

Now suppose service on B also declines by 10\%—again the resulting real loss will split about equally between A and B. The original balance of traffic between the two will be restored. The final real loss to A is thus equal to its own initial loss plus the initial loss to B.

If, originally, A had been taking 75\% of the passenger miles generated along its route and B the remainder, an analogous relationship would hold. On A’s initial deterioration 25\% of the resulting drop in total passenger miles would come from B. On B’s deterioration 75\% of the resulting demand reduction would devolve on A; as B is only $\frac{1}{3}$ the size of A, this means that A’s additional loss is equal to 25\% of the initial total loss (to both services). Thus again the final real loss to A is equal to its own initial real loss plus the initial real loss to B, or its own initial real loss divided by its initial share of the total passenger miles generated along the route. The principle can be extended straightforwardly to a route covered by several services.

To use this framework of a set of services operationally, however, it must be possible to make measurements within it: to estimate, for a service to be converted, the proportion of the passenger miles generated along it that is captured by the service to be converted and the proportion taken by other parallel services.

An index has been developed which does this. The details are discussed in Appendix B. Very broadly, the index estimates the likely split of traffic between

\textsuperscript{2}The longer the headway of a service or the worse its regularity, the smaller is the probability that one of its buses will be the first to arrive at a stop.

\textsuperscript{3}The total receipts loss to a service occasioned by its conversion is called the gross or apparent loss, and is equal to a real or net loss plus diversion to parallel routes.

224
parallel services by considering along sections of a route their relative frequencies, the distances for which they run and the distribution of passenger journey lengths. The index does not provide a perfect measure, but it has proved accurate enough for the present purpose. When, elsewhere in this paper, mention is made of "parallelism of x%", this means that the index estimates that of the total passenger miles generated along the route of a service x% is going to other services that run parallel to it.

**Analysis of Services Converted**

From the behavioural framework and index of measurement discussed above, multiple regression techniques were applied to analyse a set of 30 services converted to split-entrance O.M.O. between November 1970 and November 1971. Statistically significant correlations were established between the change in receipts on the service converted and:

— the intensity of demand for the service;
— the extent of parallel services;
— the change in bus miles run (before and after conversion to O.M.O.).

These correlations explained over 90% of the observed variation in receipts. The relationships implied are summarised below. The details of the analysis can be found in Appendix A.

Some qualifying points must, however, be made at once.

1. No attempt was made to trace lost receipts physically by, for example, analysing in detail receipts on some of the parallels; rather, statistically significant correlations have been accepted as sufficient evidence.

2. The model of passenger demand is, perhaps, not completely accurate in assuming that passengers see the set of services passing "their" stop as a single whole. The assumption made is perhaps rather a pessimistic one: that, if a service with x% parallelism is being analysed, the observed real O.M.O. loss on the service represents only (100—x)% of the total loss.

3. The results obtained represent a post-mortem on one set of suburban conversions carried out in a particular manner. For example:
— peak headways were lengthened.
— at timing points, scheduled arrival and departure times were sometimes placed rather close together.
— a graduated fare system was used.

4. The cause of the O.M.O. losses was presumably that passengers experienced increases in in-vehicle travel times and in waiting times, the former caused by the longer O.M.O. boarding times and the latter by the susceptibility of O.M.O. services to disruption.4

These relationships were not observed directly. Rather, indices have been used (for example, boarders per mile has been taken as a proxy for time at stops). However, the relationships between time at stops and boarders per mile is not immutable, but depends on fares and on fare collection systems. Similarly, the relationship

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4Thus an O.M.O. bus following a gap is unlikely to be able to recover in the way a crew bus might, because, once it is delayed, the presence of additional passengers at later stops will delay the O.M.O. more than it would a crew bus.
between stop time and O.M.O. receipts loss may change: more flexible scheduling, for example, might reduce waiting times and hence O.M.O. losses without affecting stop times (though, unless more buses are provided, frequency will decline).

**THE RESULTS**

To evaluate the true receipts implications of converting a service, four factors need to be disentangled:

(a) the real receipts loss to London Transport caused by the conversion to O.M.O.

(b) the transfer of receipts to parallel services caused by the conversion to O.M.O.

(c) the real receipts loss to London Transport caused by changes in bus miles run made at the same time as conversion to O.M.O.

(d) the transfer of receipts to parallel services caused by the change in bus miles run on the converted service.

By means of an analysis of Monday to Friday data on 30 conversions which took place between November 1970 and November 1971, statistical models of these relationships have been developed.

Diagram 1 sets out the results of using these to predict the effect on receipts of

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**Diagram 1**

*Nine Recent Conversions—Predictions and Actual Outcomes*
nine more recent DMS conversions, and the paragraphs that follow outline the characteristics of the relationships on which the predictions are based.

**Real Loss of Receipts caused by Conversion**

On average, the real O.M.O. loss to a converted service seems to have been about 3-0% of the receipts of that service. For any particular conversion, the loss appears to depend on the "intensity" of demand for the service as measured by boarders per bus mile and headway. High boarders per mile and long headways both seem to produce high losses, though in practice these two effects tend to work against each other: the large loss that might be expected on a service with high boarders per mile tends to be offset to some extent by a rather short headway.

Diagram 2 gives a general impression of this for combinations of boarders per mile and headway. It can be shown that real losses of the order shown are generally consistent with the increases in waiting and on-bus times that may be expected to accompany O.M.O.
However, the relationship found does imply that at under five boarders per mile (b.p.m.) the O.M.O. loss vanishes completely. This is not totally implausible—it may be that on such services better driver motivation is sufficient to overcome the operating difficulties associated with O.M.O. It is probably more realistic to assume that the loss tails off as shown by the dotted line in Diagram 2.

**Real O.M.O. Loss along a Road**

The converted services themselves typically formed 80 to 85% of the L.T. bus services along their routes. Hence, if it can be assumed that passengers treat the set of services covering a route as basically one “service”, it can be argued that after any deterioration in service along its route a service typical of those converted will suffer 80% of the real loss and its parallels the remaining 20%. The basic decision a potential passenger must take is whether or not to go and stand at a bus stop: if some proportion of passengers cease to do this, it will affect all services along the road in proportion to their importance.

Thus, one can estimate the total real loss from a typical conversion as:

\[ 3.0\% + \frac{20\%}{80\%} \times 3.0\% = 3.75\% \]

The extra 0.75% can be regarded in two ways, which can be shown to be equivalent: as either

—the real impact on parallel services of the general deterioration in service associated with the conversion, or

—the additional real loss the converted service will suffer when all the parallels are converted to O.M.O.

Diagram 3 shows the relationship implied between the total receipts generated along a stretch of road and the conversion of differing proportions of the buses operating along it.

**Diversion to Parallel Crew Services**

It can be shown that diversion will occur automatically when a service is converted, without passengers making a conscious choice to avoid an O.M.O. bus, simply because the less regular a service is the lower is the probability that one of its buses will arrive first at a stop. This, alone, does not seem enough to account for the level of diversion found. However, diversion is also possible if a crew bus arrives at a stop at the same time as or just after an O.M.O. The higher overall speeds of crew buses give passengers good reason to divert under such circumstances.

Diagram 4 illustrates the relationships found, the parts of lines that are solid indicating that they lie within the range of the data analysed.

The average transfer on the services analysed was estimated as 3.13% (bpm = 7.3) and the proportion of the total receipts generated along the route going to crew parallels before conversion as about 15%.

**Diversion to and from Services Previously Converted**

Of the services paralleling the 30 split-entrance (SMS and DMS) conversions
RECEIPTS AND CONVERSION TO ONE-MAN BUS OPERATION

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Diagram 3
Real O.M.O. losses along a Road

Diagram 4
Diversion to Crew Parallels
analysed very few were already O.M.O. in November 1970—on a typical route only 2 or 3% of the traffic was going to services previously converted. Of these earlier conversions, none were DMS and only a few SMS, a few being conventional O.M.O. services (generally with very low intensity) and the majority suburban flat-fare operations. This small scale and diversity makes it difficult to generalise regarding diversion rates.

Generally, what might be expected to occur when additional services along a route are converted is that traffic will flow back to the services previously converted. Thus, after the first conversion, the remaining crew services are likely to gain receipts. When they themselves are converted, however, the balance that existed originally (when all were crew services) will be restored and traffic will flow back to the first service. However, the balance will be restored exactly only if all the converted services have the same type of O.M.O. buses.

Thus, after the SMS conversions analysed, the rate at which traffic appears to have transferred to the previously converted services suggests that the earlier conversions now had an advantage—not unreasonable considering the sometimes greater capacity, usually faster boarding times and hence presumably greater speed and regularity of the flat-fare operations.

After the DMS conversions analysed, however, further traffic appears to have been taken from parallel O.M.O. services. This is presumably due to the larger capacity of the DMS vehicle, which, for example, enables a DMS following a gap in service to pick up more of the accumulation of passengers than any other type of bus.

Effects of Changes in Bus Miles Run

It is estimated that the response of total receipts along a route to a 1% increase in bus miles run by all the services that run along the route is about 0.68%. This is a reasonable rate of response, in view of the average headway of 15 minutes on the services converted.

Diagram 5 sets out the sort of relationships that emerge if the same sort of assumptions are made here as were made in estimating the real O.M.O. loss (e.g. that a 10% increase in miles run on services providing 50% of the service along a route results in the same passenger response as a 5% increase in bus miles on all of them).

Changes in mileage on one service on a route can be shown to produce—automatically—transfers between services, as the probability changes that a bus from the service with the enhanced mileage will arrive at a stop at any moment in time.

On a service typical of those analysed, it can be shown that almost ¼ of the total loss due to mileage changes (6.4% of receipts) is attributable to diversion effects of this sort (see Appendix B).

The various factors which appear to have worked together to affect receipts on the 30 conversions have now been reviewed. Putting these relationships together, the receipts change between November 1970 and November 1971 on the average conversion can be broken down as shown in Table 1.

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5A very few parallels were themselves converted between November 1970 and November 1971. It has been assumed that no diversion resulted from this.
Table 1

Average Change in Receipts on Conversion

<table>
<thead>
<tr>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of mileage cut</td>
<td>-6.4</td>
</tr>
<tr>
<td>Real O.M.O. loss</td>
<td>-3.0</td>
</tr>
<tr>
<td>Diversion to parallel services due to O.M.O.</td>
<td>-3.1</td>
</tr>
<tr>
<td>Seasonalities/trend* etc.</td>
<td>-3.5</td>
</tr>
<tr>
<td>Total change in receipts</td>
<td>-16.0</td>
</tr>
</tbody>
</table>

*Receipts on services that were neither converted nor parallel to converted services fell by 2.7% between November 1970 and November 1971 despite an increase in car miles of 0.4%. Hence, using the mileage elasticity of 0.68, a trend of about 3% (-2.7 + 0.4 × 0.68) seems reasonable. A split entrance fares revision of August 1971 is estimated to have produced an additional loss of 0.5%.
CONCLUSION

This paper has shown how the receipts implications of O.M.O. were evaluated by:

(1) formulating hypotheses on passenger reactions to changes in service provided along a particular route;

(2) deriving an index of parallelism which made it possible to measure (approximately) the relative importance of sets of services running along a single route;

(3) performing statistical analysis on 30 services converted to split-entrance O.M.O. between November 1970 and November 1971 to assess the correlation between the total change in receipts and
   —the intensity of demand for the service.
   —the change in miles run after conversion.
   —the extent of parallelism.

It was then possible to establish relationships to break down the total change in receipts after a conversion into the four factors (a, b, c, d) set out above in the first paragraph of the section on results. The relationships based on the statistical analysis proved capable of (1) accounting for over 90% of the observed variation in receipts on the 30 services analysed, and (2) predicting with considerable success the outcome of nine recent DMS conversions (see Diagram 1).

APPENDIX A

REGRESSION MODEL

A number of additive multiple regression models were tested, the input used being Monday–Friday data on 30 services for November 1970 and November 1971. Internal working papers, available on request from the author, contain a description of these. Details of the most satisfactory are set out in Table 2. All independent variables used in the models were significant at 95% confidence. When the SMS and DMS services were tested separately the only significant difference in passenger reactions was the apparent diversion to DMS from parallel O.M.O. services. Accordingly, in the models shown, SMS and DMS services have not been tested separately. However, SMS and DMS specific terms have been included for O.M.O. parallelism.

The extent of correlation between the variables is limited, the highest correlations being between the components of O.M.O. loss. This, of course, is a behavioural fact of life—high intensity services tend to have both high receipts per mile and short headways. However, even here the correlations are not unduly high.

\begin{equation}
\text{Correlation Matrix}
\begin{array}{cccccccc}
\text{VAR 1} & 1.000  \\
\text{VAR 2} & 0.257  & 1.000  \\
\text{VAR 3} & 0.053  & -0.452  & 1.000  \\
\text{VAR 4} & 0.053  & 0.385  & 0.266  & 1.000  \\
\text{VAR 6} & 0.034  & 0.102  & 0.163  & 0.134  & 1.000  \\
\text{VAR 5} & -0.337  & 0.129  & -0.068  & 0.171  & -0.137  & 1.000  \\
\end{array}
\end{equation}

232
### RECEIPTS AND CONVERSION TO ONE-MAN BUS OPERATION

**Table 2**

**Regression Models Tested**

<table>
<thead>
<tr>
<th>Variables Used</th>
<th>Model Coefficients</th>
<th>Variable Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>Receipts Nov. 71 × 100</td>
<td>Dependent variable</td>
</tr>
<tr>
<td></td>
<td>Receipts Nov. 70</td>
<td></td>
</tr>
<tr>
<td>X₁</td>
<td>Miles run Nov. 71 × 100</td>
<td>0-788</td>
</tr>
<tr>
<td></td>
<td>Miles run Nov. 70</td>
<td></td>
</tr>
<tr>
<td>X₂</td>
<td>Average receipts per mile* Nov. 70 (d)</td>
<td>-0-195</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X₃</td>
<td>Headway (minutes)</td>
<td>-0-311</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X₄</td>
<td>(Parallelism by crew services) × X₃</td>
<td>-0-27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X₅</td>
<td>Parallelism by services O.M.O. in Nov. 70 (DMS only)) × X₃</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X₆</td>
<td>Parallelism by services O.M.O. in Nov. 70 (SMS only) × X₃</td>
<td>-0-88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>Constant</td>
<td>34-2</td>
</tr>
<tr>
<td></td>
<td>R² (% of variation explained)</td>
<td>92-88%</td>
</tr>
</tbody>
</table>

*Average boarders per mile = Average receipts per mile / Average fare paid

### APPENDIX B

**CALCULATING LOSSES TO PARALLEL SERVICES**

**Parallelism Index**

The aim of the parallelism index is to estimate for a route (i.e. a stretch of roadway) the likely split of revenue between one service (A) along the route and others (Os) that run parallel to it. The output of the index is the estimated proportion of the total receipts generated along the route that is likely to end up on the parallel services.

Each section of the route is examined in turn. The relative importance of this stretch is evaluated. For section j, this is
where $f_j$ is A's frequency over $j$

$d_j$ is the length of the $j^{th}$ stretch

$n$ is the number of stretches on the route

If the value of this is $\frac{1}{6}$ and it is calculated that over the section traffic will split 2:1 in favour of A, then parallelism for this section is $\frac{1}{6} \times 4$. The eventual value of the parallelism index is formed by summing over all sections.

To calculate the likely split of revenue between A and the Os over stretch $j$, three factors are used: the distribution of passenger journey lengths, the length of stretch $j$ and the frequencies of the various services.

Suppose the length of $j$ is 2 miles, that there is only 1 parallel (frequency 5 buses per hour, the same as A's), that 5% of journeys are for under $\frac{1}{4}$ mile

- 20% for $\frac{1}{4}$–1 mile
- 15% for 1–1$\frac{1}{2}$ miles
- 15% for 1$\frac{1}{2}$–2 miles.

Plainly the remaining 45% of travellers have no choice and must take A. This can be translated into a percentage of revenue that must go to A. Since the frequencies of the two routes are the same, half the remaining revenue is likely to go to A. Indeed A will take more than that: consider those travelling 1$\frac{1}{2}$–2 miles and starting from stretch $j$. Since stretch $j$ itself is only 2 miles long, only about a quarter of the total of such journeys (those starting at the ends of $j$) can possibly be made by O, and, given the relative frequencies, only one-eighth are likely to be. Similar calculations can be done for each journey length to build up a final revenue split over the section.

When there are several parallels, this calculation must be done for each service and the figures cumulated.

Thus (see Diagram B1), suppose A has two parallels $O_1$ and $O_2$ and calculations as set out above give (ignoring the existence of the other parallel) $\frac{1}{3}$ as the proportion of passenger miles likely to end up on each of these. Then for section (1–2) parallelism is taken to be $\frac{1}{3} + \frac{1}{3}$ and for (2–3) $\frac{1}{3}$.

The average of these sectional values (weighted by their length and the frequency of A) then gives the final value of the index: (1). In fact the procedure is not quite accurate, since there is an element of double counting in adding the two items of one-eighth. However, the alternatives are far more complex computationally. Furthermore, an element of over-estimation is justifiable here, since one of the basic assumptions of the index—that passengers are generated uniformly over the length of the route—is evidently incorrect: almost by definition, the larger the number of buses operating on a stretch of road the busier it is likely to be.

All this gives rise to the formula:

$$I = 1 - \frac{1}{\sum f_i} \left[ \sum \frac{d_j f_i^2}{f_i + \sum_j f_j S_j} \right]$$

(1)

6The figures used have been scheduled morning peak frequencies.
where $f_i$ is $A$’s frequency over stretch $i$

d_i$ is the length of $i$

$f_j$ is the frequency of the $j$th parallel over stretch $i$

$S_j$ is the proportion of the total traffic generated along the length of $j$’s parallelism that could feasibly use $j$.

$I$ is the proportion of total receipts along the route going to parallels.

This has been used throughout. It is by no means perfect. A more accurate but also more complicated formula would be

\[
I = 1 - \frac{1}{\sum_{i=1}^{n} d_i f_i} \left[ \sum_{i=1}^{n} d_i f_i (f_i + \sum_{j}^{n} f_j (1-S_j)) \right]
\] (2)

Compared with (2), (1) tends to overestimate parallelism. However, as mentioned above, the assumption that passengers are generated uniformly along a route is incorrect: almost by definition the most paralleled stretches of route are the busiest sections. In addition both formulae tend to under-estimate the relative importance of parallels at the ends of a route. These tendencies to underestimation, inherent in the assumptions behind both (1) and (2), greatly curtail the advantages of (2).

Suppose it is desired to calculate indices for two sets of parallels, $O_1$ and $O_2$ (say $I_1$ and $I_2$ represent the proportion of passenger miles going to each of them).

(1) above gives $I = I_1 + I_2$ for all $O$s.

$I_1$ and $I_2$ can be calculated to give the traffic split between $A$ and $O_1$ (assuming $O_2$ do not exist) and $A$ and $O_2$ (assuming $O_1$ do not exist).
Then \[ I_1 = (1 - I) \frac{R_1}{(1 - R_1)} \]
\[ I_2 = (1 - I) \frac{R_2}{(1 - R_2)} \]
i.e. the proportion of total traffic going to \( A \) multiplied by the relative importance of each set of parallels compared with \( A \)

**Diversion following changes in mileage**

Diversion caused by changes in mileage can be calculated by the formula
\[ D = \frac{(d - 1 + p)}{(1 - p)} \]
where \( p \) = index of parallelism for the service
\[ d = \frac{(1 + M - p \times M - p)}{(1 + M - p \times M)} = \]
the proportion of total receipts going to the service after the change in mileage.
\[ M = \frac{\text{the } \% \text{ change in mileage}}{100} \]

\[ D = \% \text{ change in receipts on the service whose mileage has changed.} \]

This can be demonstrated as follows. Suppose a service on which the proportion of receipts generated along the route going to parallels is \((p \times 100)\%\). Suppose a mileage cut of \((M \times 100)\%\). Assuming all passengers arrive randomly at stops, the proportion of route passenger miles that will devolve on the service after the mileage cut will be:

\[ \frac{\% \text{ of receipts going to the service before the change}}{\% \text{ of total route car miles left after the change}} \times \]
\[ \left( \frac{1 + M}{1 + M \times (1 - p)} \right) = d \text{ above} \]

The percentage change in receipts is then

\[ \frac{\text{the change in the share of the service in total receipts before and after}}{\text{the share of the service in total receipts before}} = \frac{d - (1 - p)}{(1 - p)} = D \]