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Item Description: This is a draft manuscript of a lengthy report compiled by the RAF Bomber Command Operational Research Section, probably some time in 1945. The report was authored by Dr. Basil Dickins, a rising star in the field of physics who served as Section head during the war. Using a thematic approach it explores in excellent detail the challenges inherent in strategic bombing, making it a valuable source for both historians of air power and those studying Europe in the Second World War.

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CHAPTER 21

HOLLERITH MACHINERY USED BY BOMBER COMMAND
OPERATIONAL RESEARCH SECTION

Causes of Introduction

1. In November 1943, a new Raid Report pro forma, which gave considerably more detailed information than previously, was introduced. In particular, the pro formae which were completed by the Station Intelligence Officers for each individual sortie, detailed the special equipment carried by each aircraft.
2. Prior to the introduction of the new pro forma, analyses which were conducted to discover the efficacy of each equipment had been carried out on data obtained from specially designed questionnaires - one for each equipment. The new pro forma thus eliminated the necessity for the special returns and also gave additional information about the combinations of equipments carried, enabling, therefore, more precise investigations to be made. Furthermore, a new statistical method of analysing the data was introduced and this required figures broken down into fine divisions.⁽¹⁾
3. To obtain figures in these small divisions, giving all the various combinations of equipments, it was clearly necessary to introduce some form of recording which gave the facts in an easily sorted manner. The Paramount card system involving the use of a small card with holes punched round the perimeter was, therefore, attempted. Each special equipment was given a specific hole as were the aircraft's group, type, mark and result. A card was taken in conjunction with each Raid Report and a portion of the card from the appropriate holes to the edge of the card was clipped out by hand and, for reference purposes, the squadron and letter of the particular aircraft was written onto the card. All figures were then obtained by needling off the cards required and counting them by hand.
4. As this method of recording suffered from two serious defects, namely, lack of speed and inaccuracy due to hand counting, attention turned to mechanical methods. Preliminary conversations with the British Tabulating Machine Company were held and a knowledge of Hollerith machines and their capabilities was obtained. It was decided that, apart from facilitating analyses which were already being undertaken, the introduction of this method of recording in which one card was punched for each

(1) Bomber Command O.R.S. Report No. 113.

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aircraft would save personnel and also enable other investigations, which had been considered impossible previously owing to the time factor involved, to be made.

O.R.C. were, therefore, asked to obtain for the section two punches, a mechanical verifier and a counter sorter.

5. The concurrence of the Treasury was obtained and after several meetings with the British Tabulating Machine Co. (B.T.M. Co.) who were told what information was required on the cards, a specimen card was drawn up. A Treasury official who attended one of these meetings stated that since the card was to contain a large amount of double punching, a mechanical verifier was not particularly apposite and suggested that an electrical verifier should be supplied instead. The original request was therefore altered and the machines demanded were:-

- (a) Counter Sorter (Type 75, 80 Column)
- (b) Two Manual Punches (80 Column)
- (c) One Electric Verifier (80 Column)

Preliminaries (Training of Operators etc.)

6. Although the original cause of the introduction of this form of recording was the analysis of special equipments, it was obvious that assistance might be given in other sides of the sections work. A meeting at which a representative from each sub-section of O.R.S. attended was held and it was agreed that the card should carry most of the information given on the Raid Report as well as that concerning special equipment. (1)

7. Having decided upon the information which it was required to record, it was then necessary to establish in what manner the qualitative information was to be coded. The following broad principles were adopted in drawing up the code sheets:- (2)

- (a) The amount of coding should be reduced to a minimum.
- (b) In order to save time the coding was to be made on the original document.
- (c) To save time in sorting, the number of columns in which double punching occurred was to be a minimum.

8. It was decided to alter the sections establishment and replace two L.A.C. posts by two L.A.C.W.s who were to be trained as punch operators by the British Tabulating Machine Co. Accordingly, two were posted to O.R.S. and then sent on

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- (1) A full note of these questions which were recorded is given in Appendix 5, Form No. 1.
 - (2) The method of coding the original card appears as Appendix 5, Form No. 2 and Appendix 5, Form No. 3 is a specimen coded Raid Report.

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three weeks course to the Company's Head Office in London. At the end of the course, the tutor returned with the trainees and spent a week teaching them to punch from actual Raid Reports.

9. Meanwhile, three clerks who had been engaged in the production of statistics by hand from Raid Reports were set to work on coding Raid Reports for practice purposes. They rapidly became accustomed to the work and, although at first their work was checked, it was found, after some time, only necessary to check their work at intervals. Subsequently, one clerk only was employed, being capable of coding about 600 Raid Reports per day, and it was necessary to check his work only after some major change had been made in the method of coding.

History of Raid Report Cards

10. When the operators had gained some practice in dealing with Raid Reports, work was begun in earnest on cards for the operations occurring on the night of 15/16 March 1944 and cards for most night operations were punched from then until the end of the war with Germany.

11. It was found after just over a month's work that the rate of operations was too great and that the cards were not being produced as expeditiously as required. A critical analysis was made to discover what information on the cards was used infrequently or not at all. These sections were found to be mainly those devoted to recording if special equipments were used or were unserviceable, which could not be analysed owing to inaccuracy of reporting and to the Heading and Indicated Air Speed at bombing. These sections were then deleted from the card and this reduced the length of card from 59 columns to 42 columns.⁽¹⁾ This step together with the omission of cards for operations of the minelaying or light Mosquito type of attack enabled the work to be completed more rapidly.

12. In June 1944, however, the rate of operations increased still further and in order to offset this it became necessary to obtain two more punch operators (L.A.C.W.s obtained on Laboratory Assistant Establishment). Subsequently the cards were generally produced on the average two to three days after the Raid Reports were received or six to eight days after an operation.

13. At the beginning of May 1944 it was found essential owing to operational necessity to investigate the losses of aircraft with Monica equipment⁽²⁾ and as a

(1) A comparison of Appendix 5, Form No. 2 and Appendix 5, Form No. 4 will show the precise differences between the cards used.

(2) Bomber Command File S.28806/2.

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certain amount of doubt existed about the accuracy of the original data, it was decided to make two lists of aircraft by means of a Tabulator. The list detailed over a month the special equipment carried by Date, Target, Squadron and Aircraft letter whilst the other, over the same period, gave the same information by Squadron and Letter. From the latter list it was possible to trace the history of each aircraft throughout the month. By glancing down the equipment detailed for each aircraft it was possible to check the accuracy of reporting on the assumption that the special equipment carried by a particular aircraft normally did not vary much from night to night. If any errors were found then the appropriate corrections could easily be made in the list by date and target. Thus for this list more accurate data on the sorties and missing of aircraft with various combinations of equipments could be obtained.

14. Prior to this date all statistics on special equipment had been obtained by sorting and counting. The use of the tabulator in this particular instance, however, indicated that more results could be obtained from the same data by using more intricate machines. Accordingly, with the help of the British Tabulating Machine Co., an arrangement that O.R.S. should have the loan of their machines for two or three hours per fortnight was made with the Ministry of Food (Potato and Carrot Division) whose Hollerith section contained such machines. In July 1944 it was found that this arrangement was not particularly satisfactory and new arrangements were made so that O.R.S. should use the machines at a British Tabulating Machine Co.'s Service Bureau.

15. The Hollerith Section was committed to the production of data at fortnightly intervals for the analysis of special equipment. For this purpose it was found desirable to obtain a list of aircraft detailing the special equipments carried by, date, target, squadron and aircraft letter and also figures giving sorties and missing of each class of aircraft carrying a particular combination of special equipment. It was found desirable to produce these latter statistics also from the tabulator. Unfortunately, the system of coding special equipment then employed did not easily lend itself to the use of a tabulator as it involved punching more than one hole in the columns for special equipment, and the tabulator could not print this. The method of coding special equipment was, therefore, altered on 14/15 August 1944 to produce only single punching. ⁽¹⁾

(1) See Appendix 5, Form No. 5.

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16. For the analysis of the accuracy of results achieved in bombing it was found necessary to prepare a list giving the plotted position of each aircraft's photograph by bombing times. This was originally done by hand from two sources - the Raid Reports for the times and methods of bombing and from a Photographic interpretation list giving ranges and bearings from the Aiming Point. It was readily obvious that the Hollerith Section could assist by providing a list of aircraft by bombing times indicating the method of bombing. The system of coding the bombing technique was such that double punching occurred and it was therefore deemed advisable to give an extra column to this question on the Raid Report. The coding was therefore altered ⁽¹⁾ and the new card introduced on 1 November 1944.

17. During a visit from a member of VIIIth U.S.A.A.F. it was discovered that at their H.Q. a complete set of American Hollerith machines existed. As this was much nearer than the Service Bureau, permission was obtained at the beginning of 1945 for use to be made of these machines. It was not possible to use their machines for all O.R.S. work owing to the American method of punching alphabetical information - 3 zone instead of 2. ⁽²⁾ Work, however, was greatly facilitated by this concession.

18. Towards the end of the war with Germany so many new equipments had been introduced that it became necessary to alter the method of coding special equipment in order to avoid double punched columns and so still produce a special equipment tabulation. This new card was introduced on 15/16 March 1945 and used until the end of the war. ⁽³⁾

History of Other Cards

19. It had originally been intended to put onto the card punched from the Raid Reports, information from three other sources:-

- (a) Combat reports - giving information concerning attacks by enemy aircraft on our own. ⁽⁴⁾
- (b) Damage reports - showing the extent of damage to our aircraft. ⁽⁵⁾
- (c) Photographic Interpretation - showing the plotted position of an aircraft's photograph which had been taken with bombing. ⁽⁶⁾

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- (1) See Appendix 5, Form No. 6.
 - (2) See Appendix 5, Form No. 2.
 - (3) See Appendix 5, Form No. 7.
 - (4) See Appendix 5, Form No. 8.
 - (5) See Appendix 5, Form No. 9.
 - (6) See Appendix 5, Form No. 10.

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The intention had been to obtain the appropriate Raid Report cards from their file and punch onto the card the fresh information. In order to facilitate the pulling of the Raid Report card, the verifier after having checked the card wrote the squadron and aircraft letter onto the card. It was found, however, that considerable time was lost in this manner and as the same result could be obtained by passing the cards through an 'Interpreter' this procedure was dropped. Furthermore, it was not found practical to punch this new information onto the original cards in the first few months owing to the shortage of available labour. This meant that when enough staff was available a large amount of back work remained and that some other method of putting the fresh information onto the Raid Report cards was required.

20. After some consideration it was decided to punch each of three new sets of information of three new cards. By sorting these into the same sequence as the original file of cards and then passing both files through a 'Collator' it was possible to extract from the larger file of Raid Report cards all the cards corresponding to those in the smaller file of Combat cards, Damage cards and Photo cards. It was not necessary to do this in three stages involving the collation of the large file three times as the three types of cards were easily separated from one another. Thus, in the first collation they would be sorted together and all the cards which required either combat, damage or photographic information would be obtained. Thereafter, it was only necessary to deal with the smaller file of cards and, by means of three collations with the combat, damage and photographic cards separately, it was possible to obtain the cards required. As both master pack and the detail pack were in the same order the cards could immediately be passed through a 'Reproducer' and the new information automatically copied off the new cards onto the old. Owing to the fact that the method of designation involved the use of the aircraft letter whilst the collator was strictly a numerical machine, it was necessary to divide the collation into three parts - one part for each section of the alphabet. Although this method was decided upon and the greater part of the cards for new information were punched it was never possible to put this method into operation owing to the fact that the machine time available at the Service Bureau only allowed the more necessary immediate analyses to be completed.

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21. In the autumn of 1944, the number of escaped and returned aircrew had increased to such proportions that some new method of recording the data was required. It was decided that by using the Hollerith much time would be saved. Full details of the method of coding and the information obtained from these cards is contained in _____ and a Master Code Sheet is attached at Appendix 5, Form No. 11. When the war with Germany ceased and P.O.W.s were returning home it was decided to extend this system to cover the Interrogation reports obtained from each crew member. It was found, however, that the system in use employed a vast amount of double punching and although this was no great hindrance when small numbers of cards were involved it was likely to prove so when handling 10,000 cards as no great use could be made of machines other than the 'Sorter'.

22. The system of coding was therefore altered to meet this requirement but in order to enable all the information required to be recorded it was necessary to use two cards. As a considerable part of each card was duplicate information it was decided to produce three cards - one a General card for the duplicate information and the other two (Casualties and Damage) cards bearing the remaining information. The duplicate information was then to be transferred onto both the Casualties and Damage cards to give the final cards required. (1)

23. To obtain accuracy in coding, each story was coded twice. A 'check coder' then compared the two codings and if a discrepancy was found recoded the information from the original story. Each card was then passed through the sorter counting on every column and, in order to check that the data was consistent, various cross checks made on the figures obtained. This process caused much wear to the cards and therefore, the final cards, were produced on entirely blank cards. A card for aircraft from which there were no survivors was also punched and the sections corresponding to the final cards for survivors being reproduced onto the same type of cards. (2)

(1) Details of the cards and the method of coding are at Appendix 5, Form No. 12.

(2) Full details of this reproducing process are given in Appendix 5, Form No. 13.

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Some Results Obtained from Raid Report Cards

24. Although some of the results obtained have been mentioned in preceding paragraphs full details are given below for these results as well as for other major results obtained from the Raid Report cards.

Special Equipment Analysis

25. For this both a list and a tabulation was required. The list gave special equipment and result of the mission in coded form by date, target, squadron and aircraft letter, and the sorties made by each squadron was simultaneously obtained. The list facilitated reference to the special equipment carried by a particular aircraft. The tabulation gave the number of aircraft despatched and missing for each combination of special equipment by date and target. From this it was therefore easily possible to perform the calculations necessary to complete an analysis along the lines of O.R.S. Report No. 113 and to estimate the efficacy of each special equipment.⁽¹⁾

Timing Distribution

26. Time Distributions were used for two main purposes. A list of aircraft by time giving the method of bombing was required and this in conjunction with information showing the plotted position of photographs was used in analysis conducted into the relative merits of different bombing techniques. Concentration in time was also considered important in reducing fighter losses and information showing the number of aircraft bombing in each minute of an attack was required. In consequence a tabulation giving the number attacking the target in each minute of a raid was made and from the figure obtained it was possible to see if the raid had been carried out as planned.⁽²⁾

Height Distribution

27. From some investigations made to discover the cause of aircraft losses a distribution indicating the number of each aircraft attacking at each height band was found useful. From this it was possible to see whether the planned distribution was maintained and also, by means of this and a timing distribution, the incidence of collisions and the concentration of 'Window' could be estimated.

(1) Specimens of both the list and tabulation can be seen in Appendix 5, Form No. 14.

(2) The figures obtained in this manner form the basis of O.R.S. Reports Nos. B.233 and B.235. (A.H.B./IHH/244/3/814(A) and (B)).

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Losses by Makers of Aircraft etc.

28. When it was discovered that aircraft with the Nitrogen Tank equipment had higher losses than expected a full investigation into the possible causes was made. As this investigation involved splitting the cards on the Aircraft Serial Number, it was decided to discover what other differences existed between two sets of data obtained in this manner. It was found that certain sets of aircraft split in this manner had two other main differences apart from Nitrogen Tanks. One being that the manufacturers were different and the other that a larger proportion of aircraft were equipped with Merlin XXIV engines as well as with the special tanks. By sorting the cards on serial numbers it was possible to split the aircraft by makers, engines and tanks and thus a full investigation could be made. The results indicated the apparent higher losses of the nitrogen tank aircraft could be more accurately described as due to Merlin XXIV engines.

29. It was also possible by sorting on Serial Numbers to investigate the usefulness of glossy paint in avoiding being held in searchlights. An insufficient amount of data was obtained to justify any conclusion.

Distribution of Experience

30. Investigations had been made at various times by O.R.S. into the effect of pilots experience on the missing rate. After the inception of the Hollerith section those figures were provided directly from the Raid Report cards by sorting the cards into experience groups by date, target and group and then counting on the result column to provide sorties and missing. The investigation was completed by using the same statistical methods as were used for analyses of special equipment.

Abortive Sorties

31. The Raid Report cards provided a ready source of information for investigation into the effect of weather and icing on the abortive sortie rates. This information was used to estimate the economic weight of de-icing equipment.

Bomb Load

32. At various times O.R.S. had been asked to discover if the carrying of certain types or loads of bombs was subject to special risks. The data for each operation showing loss rates by types of bomb load were easily obtained from these cards and investigations, showing null results, were made.

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Night Raid Report Tables

33. One O.R.S. commitment was the production of a report on each night's operation. An appendix to this report was a table giving a breakdown by target, group, aircraft type and mark which showed for each subdivision the number of aircraft despatched, attacking the primary or secondary target, abortive and missing as well as the number of those damaged and intercepted. The first half of this table - numbers despatched, attacking etc. - was obviously easily obtained from the cards in the required breakdown.

Results obtained from Interception and Damage Cards

34. As stated in para. 20 above, these cards were punched in order to put information concerning aircraft damaged or intercepted onto the corresponding Raid Report cards. It was hoped in this manner to collate information obtained from special returns for these aircraft with that given on their Raid Reports. For reasons, also given in this paragraph above, it was never found practicable to collate the additional cards with original cards and, up to the time of writing, these cards have not been used in any analysis.

Results obtained from Photographic Cards

35. Although providing mainly for the purpose of putting photographic information onto the main cards, after the end of the war it was found necessary to investigate the trends in bombing accuracy throughout the war. It was proposed to do this by calculating a parameter for each major raid from 1942 to the end of 1944 and, to this end, cards were punched for each aircraft with a plotted photograph on any of the selected operations. As this investigation is probably the most representative example of statistical calculations done by O.R.S. using Hollerith machines, the procedure given is more detailed than that in the previous paragraphs.

36. As in Bomber Command O.R.S. Report No. 127 ⁽¹⁾ the distribution of bomb fall, or in this case photoplots, has been assumed to consist of two parts, being in part a normal distribution and in part a totally different distribution consisting of gross errors which may overlap the normal distribution. The method of eliminating the gross errors and in obtaining a parameter - the standard radial error of the distribution - is given fully in the Report quoted above and the manner in which this method has been adapted for Hollerith purposes is given below.

(1) A.H.B./II/39/1.

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37. As can be seen from Appendix 5, Form No. 10, the only information showing the position of the photograph was given as a range (r) and a bearing (θ) from the detailed Aiming Point.

Calculation of M.P.I. of Photographs

38. It was first necessary to calculate the mean point of the photographs from the data given on the cards. The cards were sorted into order on the θ columns and each group of cards for each value of θ (0° - 360°) was preceded by a master card giving for that angle the value of θ, sin θ and cos θ. The whole file of cards was then passed through a 'Reproducer' and the appropriate signs for sin and cos were master gang punched onto the detail cards. The cards, still in the same order, went next into a 'Multiplier' where the following calculation was done - $r \times \sin \theta = x$ and $r \times \cos \theta = y$ to give the Cartesian Co-ordinates of the plotted position with respect to the Aiming point. After being sorted into date and target sequence the cards were passed through a Tabulator and the totals $\sum x$, $\sum y$, and \sum with appropriate signs was obtained. The calculation $\bar{x} = \frac{\sum x}{\sum}$ and $\bar{y} = \frac{\sum y}{\sum}$ then gave the M.P.I. in cartesian co-ordinates.

Elimination of Gross Errors and the Calculation of σ^2

39. A master card for each operation giving \bar{x} and \bar{y} as well as indicative information was punched. After collating these into the main file with the θ master cards removed, the cards passed through a tabulator where the following calculations were performed on every card:-

$|x - \bar{x}|$ and $|y - \bar{y}|$ and the results summary punched onto new cards. By gangpunching, after sorting into values of $|y - \bar{y}|$, the value $(y - \bar{y})^2$ was obtained. The Multiplier then performed the calculation $(x - \bar{x})^2 + (y - \bar{y})^2 (= R^2)$. Thus, each new card bore the square of the distance of the plotted position from the mean point.

40. A new tabulation was then made by operation in which after each card had been fed into the machine the following was printed:-

$$R^2 \quad \sum R^2 \quad \text{and} \quad \sum$$

The gross errors were eliminated by neglecting the distribution as soon as

$\sum R^2 \geq k \cdot R^2 \sum$ and the value taken for σ^2 was $k^1 \times R^2$ at this point (for the actual value of k and k^1 see the Report quoted).

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P. O. W. Cards

41. The full details of information obtained from these cards are to be found in

Difficulties Encountered

42. Several difficulties in running a Hollerith section for O.R.S. work occurred. The most important of these were the following:-

- (a) The slow punching and verifying speeds obtained.
- (b) Machines other than those actually in O.R.S. were not easily obtainable, and these had to be adapted owing to the complicated nature of O.R.S. work.
- (c) Changing requirements caused major changes in the manner of coding on the cards.
- (d) Inaccuracies in the data.

(a) Slow Punching Speeds

43. This was partly due to the employment of personnel who were not selected but posted in for punching work. This work was of a tedious nature and not everyone was capable of doing such work. Apart from this, none of the documents were received in a form particularly suitable for punching. The form of the documents had been fixed before the Hollerith was introduced and no major changes were possible, as this would not have suited the other users of the reports. Had it been possible, to (a) choose the operators and (b) adapt the form of the documents received to one suitable for punching, the rate of production of the cards would doubtless have been increased.

(b) Lack of Machines

44. There were many occasions when it was required to produce information from the cards in the form of a list, or by a complicated breakdown. A tabulator would have been particularly useful for these purposes, but the amount of Tabulator time required by O.R.S. was insufficient to warrant the introduction of such a machine. Unless the information required was of sufficient magnitude, it was not economical to make a special visit to the Service Bureau and so the work had to be delayed until the normal visit to the Bureau was due, or alternatively had to be completed by hand, assisted wherever possible by the Sorter. Furthermore, although Hollerith machines are very suitable for some types of statistical calculations and recording, nevertheless, since they have been primarily intended for accounting, it will be readily seen that it is sometimes necessary to adapt a machine and use it in a manner other than that originally intended.

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(c) Coding Changes

45. As can be seen from the preceding paragraphs on the History of the Hollerith Section a number of major changes were made in the method of coding. Apart from the first change, which was due to insufficient staff, all the other alterations were occasioned by the necessity of using machines other than those originally intended for the production of statistics from the cards. It is obvious that any changes in the manner of coding information can cause many difficulties. It is advisable, therefore, when drawing up the card for long term analyses, to try and use a method of coding from the outset which allows a certain amount of flexibility in the use of machines and also leaves sufficient space for additional codings which may arise subsequently. To obtain flexibility in the use of machines it is advisable to avoid double punching as much as possible.

(d) Inaccurate Data

46. It was found by comparison with special returns that the Special Equipment given in Section 'A' of the Raid Report was not always accurate and, as mentioned in para. 43 above, it was attempted to correct the information by means of lists obtained on a Tabulator. This course, however, did not give a complete check and the only really accurate method was to compare all the special returns received by other branches in the Headquarters with the Raid Reports. This was done for some equipments in some periods but, owing to the enormity of the task, it was not possible to make a thorough check. Another difficulty was due to the fact that sometimes two and sometimes no Raid Reports were received for an aircraft. Several attempts were made to remedy the situation, but none were completely successful. These cards, therefore, were never 100 per cent accurate and, although, in general this only reduced the significance of the result obtained from them, it made certain investigations involving small samples impossible.

Extension of Hollerith Work

47. As mentioned in para. 44 above, O.R.S. did not have enough commitments to warrant the introduction of machines other than the Sorter/Counter. There were many records being kept in Bomber Command Headquarters which could probably have been kept more economically on a punched card system, controlled by a Central Statistical Section. This Central Section, which would require a full complement

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of Hollerith machines, would keep any statistics required by more than one section in the Headquarters and a large part of the information required for Operational Research would be provided by that source. The introduction of such a Section would eliminate much duplication of effort and would enable various returns to be easily collated to ensure accuracy, as well as making available to all sections, all types of Hollerith machines.

48. A Central Statistical Section would also obviate the necessity of calling for large numbers of over-lapping returns and would also be able to ensure that, whenever the same information was received from two different sources, they were consistent. Inconsistency and the incorrectness of data was a serious difficulty encountered by O.R.S. A few examples of the type of information which could be recorded easily on punched cards are given below:-

- (a) Aircraft states.
- (b) Personnel Postings.
- (c) All statistical cards required for each operation (obtainable from a Raid Report with very few more questions than that used at the end of the war).
- (d) Engineer Records of Failures and Flying Hours.

It is worthy of note that the American VIIIth U.S.A.A.F. did in fact keep a Central Statistical Section employing punched cards and provided data on several of the above.

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