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Technology Transfer and Learning

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ABSTRACT *Despite the fact that international technology transfer has been widely studied its management still encounters many difficulties. To fully understand the issues that are relevant to the process of transferring production technology, it is necessary to determine the important factors that influence this process. Learning curves are often used as a means of determining the time required to become familiar with a transferred technology. The cases discussed in this paper have all employed learning curves, which were established at the outset of the transfer process and which turned out to be incorrect. As a consequence the envisaged efficiencies were not obtained. This phenomenon is partly due to the fact that when technology is transferred to a relatively inexperienced 'destination company', the curve is established based on the circumstances of the 'source company'. The case study findings lead to the conclusion that to establish a realistic curve a more comprehensive method is required than simply basing anticipated performance on that achieved at the source company.*

Introduction

International technology transfer is currently a driving force of international business. Despite the number of publications[1] on this topic that address a range of issues, managing the international transfer of technology still encounters enormous difficulties.

Frequent failures, varying from disappointing efficiencies to outright termination of transfer testify to this.[2] A relatively new approach has been to consider technology transfer as a process[3] and this approach has been adopted in the research reported here. In a practical study of the process it was observed that the learning curve is a core concept in respect of the efficiency of the technology transfer.

Technology Transfer

Several types of process studies can be identified.[4] Here, technology transfer is considered to be a teleological process; there is a movement towards a final goal or state. The final goal of technology transfer is production at the 'Destination Company' with comparable productivity to that achieved at the 'Source Company'.[5]

To judge the success of the technology transfer process it is necessary to distinguish various criteria. First, a distinction needs to be made between installing the technology and utilizing the technology. Second, a distinction has to be made between efficiency and effectiveness. Efficiency is defined as norm sacrifice compared to real sacrifice.

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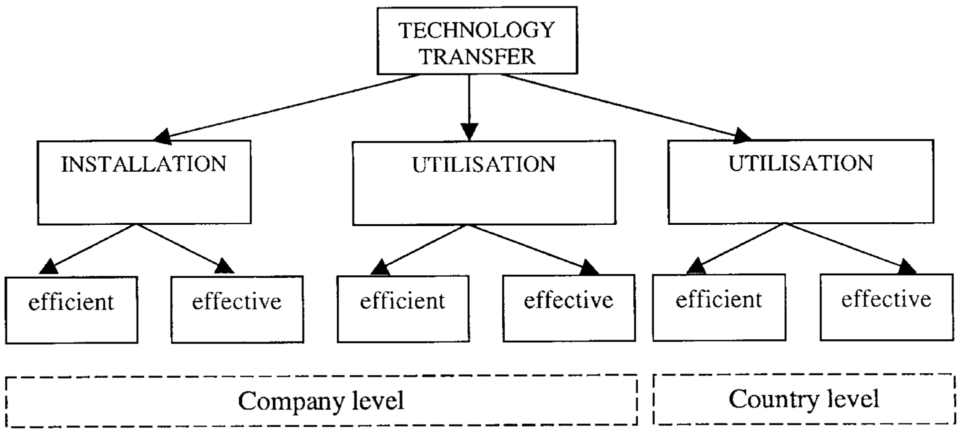

Figure 1. Criteria for technology transfer.

Effectiveness is defined as real results compared to norm results. Third, a distinction is made between the micro (company) level and the macro (country) level. An overview of the criteria is presented in Figure 1.

This study has focussed on the efficiency of technology installation in order to determine which activities and factors are important in the technology transfer process. After evaluating the theoretical and practical issues involved an inductive approach was selected along the lines proposed by Eisenhardt.[6] An in-depth understanding of the technology was considered essential in obtaining meaningful results. Therefore, the field study was limited to one type of technology; namely aircraft production.

Four case studies were selected, based on the concept of theoretical sampling,[7] and executed. In addition, results of previous case studies were used to identify later potential cases to elaborate on certain issues (snowball sampling).[8] The detailed research was undertaken within the destination companies, during the technology transfer process, since this is where installation activities take place. A combination of several data collection techniques such as observation, interviewing and document analysis was used. At the destination companies, a total of 315 interviews were held with 45 different employees representing both the source companies and the destination companies. To overcome a major objection to case study research, namely that the number of variables is larger than the number of units,[9] strategies were followed that increased the degrees of freedom of the data. These included measuring at multiple moments, using the triangulation principle, performing a member check and collecting additional data from other companies for comparison purposes.

Learning Curves

In aircraft production, scheduling is based on the concept of learning curves. The learning curve concept is generally considered to have been applied first in the aircraft industry. Wright observed that the number of hours of labour needed to produce a certain aircraft declined the more aircraft that were produced.[10] Later, it was shown that the resource input necessary to complete a unit of production decreased by a constant percentage each time the production quantity was doubled.[11]

The general formula for a learning curve is $Y = aX^b$, where Y is number of production hours for the Xth unit, a is the number of hours for the first unit, and b the learning rate. In practice, engineers use the learning curve rate rather than the learning rate (b). The relationship between the learning rate (b) and the learning curve rate is as follows:

$$b = \frac{\log \textit{learning curve rate}}{\log 2}$$

Although in practice it is common to speak of the learning curve rate as a percentage (e.g. 85% curve), in the formula above it has a numerical value between zero and one (e.g. 0.85).

In the aircraft industry, the learning curve is used to predict the increased time required to produce the early aircraft based on an estimate of the number of production hours required once production is stabilized, typically after 100 (Y_{100}) or 200 (Y_{200}) units are produced. In other words the value for (a) is determined by assuming $X = 100$ (or 200), estimating a value for Y_{100} (or Y_{200}) and applying a certain learning curve rate. Thus, in the aircraft industry, the three variables used to define the learning curve are; the learning curve rate, the learning curve duration until production stabilizes and the number of hours in the stabilized production stage.

The focus in this study is on the learning curve rate and the learning curve duration because these reflect the installation of the technology. The number of hours required once stabilized production is achieved is a measure that more reflects the utilization of the technology and this aspect is discussed elsewhere.[12]

The learning curve is widely used in the aircraft industry[13] because labour is a major cost factor in aircraft production and the number of aircraft produced in total is unlikely to be sufficiently large that initial 'inefficiencies' become insignificant. The application of a learning curve is instrumental in calculating the average price of the aircraft produced.[14] Using the learning curve concept aircraft manufacturing companies are willing to initially sell aircraft below actual production cost and this can enable them to launch a programme.

Case Study Characteristics

The relevant characteristics of the four case studies that were carried out in the aircraft industry[15] are given in Table 1.

Table 1. Case study characteristics

	Case 1	Case 2	Case 3	Case 4
Technology transfer	Transfer of the production of an entire aircraft	Transfer of the production of an aircraft cockpit	Transfer of the production of an aircraft empennage	Transfer of the production of an aircraft skin panel
Transfer from: to	UK to Romania	Canada to Romania	UK to Romania	Germany to the Netherlands
Learning curve determined by	Source company	Source company	Source company	Destination company
Planned learning curve	85% detail parts (for first 25 units) 78% sub-assembly (for first 25 units) 75% assembly (for first 50 units) + 100% inefficiency	80% assembly for 13 units	85% assembly for 16 units +10% inefficiency	90% detail parts (unit 1–3) 95% detail parts (unit 3–20) 80% assembly (#1–3) 85% assembly (#3–30) 90% assembly (#30–100) 95% assembly (#100–200)

Table 2. Scheduled and actual aircraft deliveries

Aircraft	1	2	3	4	5	6	7	8	9
Actual delivery (month/year)	12/82	04/83	04/84	02/86	03/86	09/86	10/88	12/91	12/91
Planned delivery (week/year)	25/82	52/82	20/83	38/83	52/83	12/84	22/84	32/84	42/84
Approximate delay in weeks	25	15	47	125	115	129	227	382	372

Case one

The technology transfer concerned was from the UK to Romania. The transfer involved a complete aircraft manufacturing line. The transfer process started in 1978 and was terminated in 1990. The manufacturing line was transferred in eight phases; within each one additional manufacturing activities were transferred. The first seven phases each covered the production of three aircraft, the last one contained the production of one complete aircraft.

For scheduling technology transfer it is essential to have some knowledge of the efficiency of the destination company. In this instance the transfer was scheduled using the learning curve concept to develop a production schedule.

Several learning curves, determined by the source company, were used. For the manufacture of detail parts a learning curve rate of 0.85 (commonly referred to as an 85% curve) was used with final production speeds anticipated after 25 units. For sub-assemblies a learning curve rate of 0.78 was used, also for 25 units. For assembly activities a learning curve rate of 0.75 was used but extended to 50 units. Apart from these estimated learning processes, the eventual production times were assumed to be double that achieved in the UK, since it was foreseen that production in Romania would be slower due to different circumstances. In the original production schedule the first nine aircraft should have been delivered before week 42 of 1984, and 50 aircraft should have been completed before the end of 1990. However, when the project was abandoned in 1990 only nine aircraft had been produced. It is apparent that the planned learning curves were not achieved, as can be seen from Table 2.

Case two

This study concerned a technology transfer from Canada to Romania. The transfer involved activities related to cockpit assembly. In 1996, the technology was transferred to Romania and as of the current time (2001) production is ongoing. The assembly line was transferred in a single phase.

A learning curve rate of 0.80 was scheduled for the first 13 units. The required time for production in Romania was based on the stabilized production time in Canada. The destination company received payment for assembly work based on production man-hours calculated according to this curve.

The first two cockpits were delivered according to the original schedule by the Romanian company. Delivery of the following cockpits was delayed to meet demand changes from the Canadian side, see Table 3. However it seems clear that the performance of the Romanian company did not meet the learning curves. In various instances overtime or re-working was required suggesting that the scheduled number of hours were insufficient. Unfortunately it was not possible during this study to determine the actual production hours since records were inadequate for this purpose.

Table 3. Scheduled and actual cockpit deliveries as of 2 May 1998

Cockpit	Planned date in Canada	Actual date in Canada	Delay in weeks
1	27 February 1997	27 February 1997	0
2	14 April 1997	27 May 1997	0
3	20 May 1997	4 August 1997	1
4	25 June 1997	8 October 1997	5
5	21 August 1997	11 November 1997	7
6	26 September 1997	22 December 1997	6
7	3 November 1997	24 February 1998	7
8	12 December 1997	not yet delivered	10
9	3 February 1998	not yet delivered	13+
10	16 March 1998	not yet delivered	7+
11	27 April 1998	not yet delivered	1+
12	8 June 1998	not yet delivered	–
13	11 August 1998	not yet delivered	–

Case three

The third study dealt with technology transfer, involving the assembly of aircraft tail components, from the UK to Romania. After these tail components were assembled in Romania they were shipped to the UK where the entire tail was then assembled. The transfer started in 1997 and production is ongoing in Romania. The tail assembly activities were transferred in a single phase. For scheduling production, a learning curve rate of 0.85 was used over 16 units. In addition to this learning curve rate, because it was expected that due to local circumstances Romanian efficiency would be lower than in the UK, the number of hours allowed for each activity was increased by 10%. The expected production time was thus estimated by using production figures from the UK assembly line, increasing these by 10% and imposing the learning curve on the calculated times. As in the second case study, the scheduled production hours served as a basis for price calculations.

Only one rudder was delivered on time by the Romanian company. All other deliveries were delayed, see Table 4. Since it took longer to complete the components than was scheduled it can be concluded that the imposed learning curves were not met by the Romanian company.

Table 4. Scheduled and actual tail assembly deliveries as of 2 May 1998

Assembly	Unit	Planned	Actual	Delay (in weeks)
Rudder (planned lead time from start of project 27 weeks)	1	10 December 1997	10 December 1997	0
	2	10 December 1997	2 February 1998	7.5
	3	10 December 1997	13 March 1998	13
	4	10 December 1997	on-going	20+
	5	10 December 1997	not yet started	20+
Horizontal stabilizer (planned lead time 28 weeks)	1	15 December 1997	18 March 1998	13
	2	15 December 1997	on-going	19.5+
	5	15 December 1997	not yet started	19.5+
Vertical stabilizer (planned lead time 44 weeks)	1	8 April 1998	on-going	3+
	5	8 April 1998	not yet started	3+
Elevators (planned lead time 43.5 weeks)	1,2	3 April 1998	not yet started	4+
	9,10	3 April 1998	not yet started	4+

Table 5. Scheduled versus actual skin deliveries as of 2 July 1999

Shipping sets	Planned delivery date	Actual delivery date
1–4	20 November 1998	20 November 1998 (1–3)
5–8	11 December 1998	11 December 1998 (4–8)
9–12	15 January 1999	15 January 1999
13–16	12 February 1999	12 February 1999
17–20	26 February 1999	26 February 1999
21–24	12 March 1999	1 April 1999
25–28	1 April 1999	23 April 1999
29–32	23 April 1999	14 May 1999
33–36	14 May 1999	11 June 1999
37–40	11 June 1999	production finished: to be delivered
41–44	9 July 1999	production finished: to be delivered
45–48	6 August 1999	production finished: to be delivered

Case four

In this case study the subject was the transfer of aircraft skin panel manufacturing from Germany to The Netherlands. The transfer commenced in 1998 and production is ongoing. The manufacturing line was transferred in a single phase, covering the production of one aircraft skin panel. In this transfer, for scheduling purposes, the receiving Dutch company used the learning curve concept to estimate the time it would need to do the work. For detail parts manufacturing a learning curve rate of 0.90 was used for the first three units and a learning curve rate of 0.95 for units 3–20 (i.e. the number of hours for unit 3 served as the new (a) in the learning curve formula for units 3–20). For assembly activities learning curve rates of; 0.80 for units 1–3, 0.85 for units 3–30, 0.90 for units 30–100, and 0.95 for units 100–200, were used. The agreed price for the aircraft skin panels was to an extent related to the production hours estimated by the Dutch company.

During the period covered by the research, the Dutch company delivered all the parts as scheduled. It can be observed from Table 5 that one group of components (a/c 21–24) was not delivered on time but this reflects a change in demand from the source company. To finish the first set of parts on time, limited overtime was required. However, all the following parts required slightly less production time than scheduled and were consequently finished ahead of schedule, again see Table 5. The predicted learning curves were therefore in this instance also at variance with reality, although the differences were very small and this time performance exceeded that predicted.

Discussion

The learning curve was identified in the case studies as a key factor in the technology transfer process. In all the cases studied, learning curves were used to schedule the transfer and the companies' evaluations of the progress of the transfer were based on this scheduling.

In all of the studies it was found that the actual learning curve differed to the predicted learning curve. In the first three cases studied, the differences were considerable and much more time was needed than scheduled. From discussions about this observation it has been concluded that the probable cause of the discrepancy is that the learning curves were established by the source companies and based too heavily on their own experiences.

Because the source companies of the second and third case studies are related it is interesting to examine these learning curves in more detail. Although the planned learning curves are different, the amount of learning anticipated is in fact very similar. This can be seen from the calculations of 'relative learning'. 'Relative learning' is defined here as the extra time relative to normal production hours that a company is given to learn to produce at the eventual production rate.

$$\text{Relative learning} = \frac{\sum_{X=1}^{n} (aX^b - Y_n)}{Y_n}$$

where production is stabilized on reaching the *n*th unit.

In the second case study, with a learning curve rate of 0.80, the relative learning has been calculated as 4.261.[16] Due to confidentiality reasons, the detailed calculation of this value based on man-hours etc. cannot be shown.

In the third case the learning curve rate had a value of 0.85. Relative learning, based on the man-hours given in the contract, is 3.870. However, in this transfer, relative inefficiency was taken into account with 10% added to times. In other words, the final production time used is not the number of man-hours used in the UK but 110% of these. If the additional 10% is subtracted from the final production time then the relative learning becomes 4.257.

This value is essentially equal to the relative learning found for the second case. This observation is remarkable and it adds further evidence when questioning whether the applied learning curves were valid.

Assuming that, in the third case study, the source company had experienced a similar learning curve rate to that set for the destination company (0.85) with a stabilized production line after 100 units (this type of curve is commonly used in the aircraft industry), then one can show that the relative learning for the source company over units 48–100 is equal to the relative learning of the destination company over units 1–16, or:

$$\frac{\sum_{X=1,destination}^{X=16,destination} (aX^b - Y_{16,destination})}{Y_{16,destination}} \approx \frac{\sum_{X=48,source}^{X=100,source} (aX^b - Y_{100,source})}{Y_{100,source}} \quad \text{where } Y_{16,destination} = Y_{100,source}$$

In other words it would suggest that the destination company is expected to start from an equivalent position to the source company reached after 47 production units. Obviously one can expect the source company to pass on some of its learning (through improved tooling, etc.) but it is arguably unrealistic to argue that all the acquired 'learning' to date can be effectively transferred. Further in this case study, since it involved a new aircraft, it is very questionable whether the source company had produced 47 units when the planning for the technology transfer was made. Based on this argument it would seem plausible to argue that the source company had imposed an 'unfair' learning curve on the destination company to its own advantage.

The observation of the application of apparently inappropriate learning curves in the case studies leads to the interesting question what learning curve *should* have been planned for the destination company. There are significant differences in learning rates for different industries, different firms, different products, and different types of work.[17] Important adaptations have been made to the original model, for example by De Jong and by the Stanford Research Institute.[18] De Jong showed that not all types of production activities improve as production increases. The Stanford Research Institute in its approach included a learning benefit carried over from the production of earlier products.

Although a range of factors have been identified that influence the actual shape of the learning curve, and despite continuous research efforts,[19] the process of learning is still not fully understood. This means that for the moment it is not possible to determine the precise learning rate of a randomly selected organization.

Despite a lack of understanding of the underlying principles, a particular company is able to gain a fairly good indication of the type of curve that is feasible for certain processes in that company. A company can achieve this by examining its earlier learning curves. During the transfer of technology the situation can be more complicated than with in-house development because in many instances the destination company lacks experience with the technology. In these instances, a destination company does not know what type of learning curve to apply and often the more experienced source company dictates the production schedule. This is seen as inappropriate because the source company's circumstances influence its own learning curves and therefore there is no reason to assume that another company, with different circumstances, should demonstrate the same propensity for learning. As the case studies showed and which is supported by other literature, the actual learning curves for a source company and a destination company are likely to be different.

It is concluded that scheduling a technology transfer is especially complicated in situations where the destination company has little or no experience with a particular technology. The destination company cannot be certain what parameters are appropriate for use with the learning curve based on previous work. At the same time it will be inappropriate for the source company to impose its learning curves because of the differences between the destination company and the source company. Thus it is also inappropriate to evaluate the performance of the destination company based on learning curves that were imposed by the source company.

One proposed approach is to use source company's learning curves in a 'looser' way. The involved companies should track progress from the start in order to develop a more appropriate schedule for the technology transfer process as it progresses. Additional research to determine the underlying factors for learning would also be of benefit. Special attention should be given to learning curves appropriate for organizations in industrially developing countries. The circumstances in these organizations may deviate significantly from organizations in developed nations and therefore radically different learning curves may be needed in each instance.

Conclusion

This research has identified the learning curve as a key factor in the process of technology transfer. The learning curve concept has previously not been discussed in technology transfer literature. In the aircraft industry case studies learning curves were used for scheduling purposes. In three of the cases the source company determined the curve applied and these learning curves were not met. One explanation for this could be that the destination companies were performing below their capabilities, but detailed analysis using the concept of 'relative learning' suggested that inappropriate and unrealistic curves were applied to the destination companies. Although much research has been carried out on learning curves, additional research is needed to determine what learning rate is applicable for companies in industrially developing countries. A sound method for determining the parameters needs to be developed to ensure the correct planning of the technology transfer process.

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16. This value, as well as that in the third case, were determined from the contract. These differ slightly from the theoretical ones due to rounding errors in the number of hours assigned for producing each unit. A theoretical learning curve rate of 0.80 over 13 units leads to a relative learning value of 4.503. A theoretical learning curve rate of 0.85 for 16 units leads to a relative learning value of 3.891. With 10% inefficiency taken into account this becomes 4.280.
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