Technology adoption — Total Cost assessment

The failure of CASE (and other tools) is often ~~be~~ considered due to poor management. There are other possible causes — consider the costs of adopting a new technology :-

C_{TP} — Cost of the technology — products — i.e. S/W, H/W, manuals etc.

C_{TT_S} — Cost of short-term training — courses etc that are required to bring people to an appropriate level of competence — external costs.

C_{TT_L} — Cost of long-term training — this can show up as reduced productivity, or, internal training.

The first two items are readily measurable — the second is hard.

Another way of looking at this is through the lost-productivity resulting from the use of a new technology — this can be considered to be a traditional learning curve model — i.e. exponential.

Let P_o be the productivity in
~~output/time (e.g. LOC/person mon~~
output/person-time (e.g. LOC/person-m

Let P_n be the productivity after adopting the new technology.

We assume P_o is constant. $= P_o$

We assume $P_n(\tau) = A(1 - e^{-k\tau})$ ①

that is — the productivity after adopting the new technology increases with time τ

To obtain a value for A . . . —

From ①, when $\tau \to \infty$, $P_n(\tau)$ is effectively constant since $e^{-k\tau} \to 0$

$\therefore \; P_n(\tau)_{\tau \to \infty} = A = P_n$, the steady-state productivity. ②

$\therefore \; \boxed{P_n(\tau) = P_n(1 - e^{-k\tau})}$ ③

The output O can be calculated as

$$O = \int_0^{\tau} p(\tau)\, d\tau$$ ④

ie. the integral of the ~~p~~ instantaneous product of productivity and an increment in time.

The Increase in output is ~~of~~ simply $O_n - O_o$

O_o ↳ original output

O_n ↳ new ~~pro~~ output

being more formal, after some time τ,

$$\Delta O(\tau) = O_n(\tau) - O_o(\tau) \qquad (5)$$

(Alternatively — the increase in output is the integral over time of the increase in productivity — the result is the same)

equation 4

$$\therefore \Delta O(\tau) = \int_0^{\tau} p_n(\tau)\,d\tau - \int_0^{\tau} p_o(\tau)\,d\tau \qquad (6)$$

$$= \int_0^{\tau} \left(p_n(\tau) - p_o(\tau)\right) d\tau \qquad (7)$$

Substitution of $p_n(\tau)$ and $p_o(\tau)$

equation 3

$$\Delta O(\tau) = \int_0^{\tau} \left[P_n(1 - e^{-k\tau}) - P_o\right] d\tau \qquad (8)$$

$$\therefore \Delta O(\tau) = \Big[P_n\big(\tau + \tfrac{1}{k}e^{-k\tau}\big) - P_0\tau \Big]_0^{\tau} \quad (9)$$

$$\boxed{\Delta O(\tau) = P_0 \Big[\frac{P_n}{P_0}\big(\tau + \tfrac{1}{k}e^{-k\tau}\big) - \tau \Big]_0^{\tau}} \quad (10)$$

Converting the above we obtain

$$\Delta O(\tau) = P_0 \left\{ \Big[\frac{P_n}{P_0}\big(\tau + \tfrac{1}{k}e^{-k\tau}\big) - \tau\Big] - \frac{P_n}{P_0}\cdot\frac{1}{k} \right\} \quad (11)$$

$$= \cancel{P_0\Big[\frac{P_n}{P_0}\big(\tau}$$

$$\boxed{\Delta O(\tau) = P_0 \Big[\tau\Big(\frac{P_n}{P_0} - 1\Big) - \frac{P_n}{P_0 k}\big(1 - e^{-k\tau}\big) \Big]} \quad (12)$$

We can approach (12) as follows to obtain a useful value of k.

Reverting to equation (3)

$$P_n(\tau) = P_n\,(1 - e^{-k\tau})$$

we can obtain a value for k in terms of some useful project parameter ~~e~~ e.g., the value of τ (τ_c) at ~~ch~~ which the productivity is 95% of its maximum. i.e. τ_c is the point in time at which learning is complete.

$$\therefore \; P_n(\tau_c) = .95 P_n \quad (13)$$

$$\therefore \; P_n(1 - e^{-k\tau_c}) = .95 P_n$$

$$\therefore \; e^{-k\tau_c} = .05$$

$$\therefore \; e^{+k\tau_c} = 20$$

$$\therefore \; k = \frac{\ln 20}{\tau_c} \quad (14)$$

$$\ln 20 \simeq 2.9995 \simeq 3$$

$$\therefore \; \boxed{k = \frac{3}{\tau_c}} \quad (15)$$

Substituting in (12) we obtain

$$\Delta O(\tau) = P_0 \left[\tau \left(\frac{P_n}{P_0} - 1 \right) - \frac{\tau_c P_n}{3 P_0} \left(1 - e^{-\frac{3\tau}{\tau_c}} \right) \right]$$

$$= P_0 \left[\tau \left(\frac{P_n}{P_0} - 1 \right) - \frac{\tau_c}{3} \cdot \frac{P_n}{P_0} \left(1 - e^{-\frac{3\tau}{\tau_c}} \right) \right] \quad (16)$$

If we extract τ_c — we have

$$\boxed{\Delta O(\tau) = P_0 \tau_c \left[\frac{\tau}{\tau_c} \left(\frac{P_n}{P_0} - 1 \right) - \frac{P_n}{3P_0} \left(1 - e^{-3 \cdot \frac{\tau}{\tau_c}} \right) \right]} \quad (17)$$

$\frac{P_n}{P_0}$ = is the productivity improvement ratio R_p

$P_0 \tau_c$ = original output ~~at~~ that would have been completed with no improvement – after learning is complete

∴ We can call $P_0 \tau_c = O_{0\tau_c}$

$$\therefore \Delta O(\tau) = O_{0\tau_c}\left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_0}-1\right)-\frac{P_n}{3P_0}\left(1-e^{-3\frac{\tau}{\tau_c}}\right)\right] \quad (18)$$

n.b. $\frac{\tau}{\tau_c}$ is the normalized time in terms of ~~the~~ τ_c the learning completion time.

ii. Behaviour based on best – worst case of "learning".

The best possible result is learning is completed before the adoption occurs — i.e. $\tau_c = 0$

* The worst possible result is that learning is never complete

i.e. ~~$\tau_c \to \infty$~~ $\tau_c > \tau$

From equation (16) $\Delta O(\tau) = P_0\left[\tau\left(\frac{P_n}{P_0}-1\right)-\frac{\tau_c}{3}\frac{P_n}{P_0}\left(1-e^{-3\frac{\tau}{\tau_c}}\right)\right]$

$$\Delta O(\tau)\Big|_{\tau_c=0} = P_0\tau\left(\frac{P_n}{P_0}-1\right) \quad (19)$$

$$\cancel{\Delta O(\tau)\Big|_{\tau_c\to\infty} = P_0\left[\tau\left(\frac{P_n}{P_0}-1\right)-\frac{\tau_c}{3}\frac{P_n}{P_0}\right]} \quad (20)$$

actually, τ_c

In the first case, ($\tau_c = 0$) use equation 16

i.e. $\Delta O(\tau) = P_0\left[\tau\left(\frac{P_n}{P_0} - 1\right) - \frac{\tau_c P_n}{3 P_0}\left(1 - e^{-\frac{3\tau}{\tau_c}}\right)\right]$

$\tau_c \to 0 \quad \Delta O(\tau) \to P_0 \tau \left(\frac{P_n}{P_0} - 1\right)$ (19)

~~Second case ($\tau_c \to \infty$) use equation 17~~

~~i.e.~~ $\cancel{\Delta O(\tau) = P_0 \tau_c \left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_0} - 1\right) - \frac{P_n}{3P_0}\left(1 - e^{-3\frac{\tau}{\tau_c}}\right)\right]}$ (20)

~~when $\tau_c \to \infty$ (i.e. becomes very large)~~

~~$\Delta O(\tau) \to 0$ since~~

~~$1 - e^{-3\frac{\tau}{\tau_c}} \to 1 - e^{-3\frac{1}{\infty}}) \to$~~

~~(in practice – the worst case is simply~~

~~Project completion time $\tau^* \leq \tau_c$, so $\tau_c \to \infty$~~

~~does not have much meaning~~

Looking at equation (16), we find some difficulty in interpreting what happens to the term $\frac{\tau_c}{3}\frac{P_n}{P_0}\left(1 - e^{-\frac{3\tau}{\tau_c}}\right)$ when $\tau_c \to \infty$

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when $\tau_c \rightarrow \infty$, ~~&~~ $\frac{3\tau}{\tau_c} \rightarrow 0$

$\therefore e^{-\frac{3\tau}{\tau_c}} \rightarrow e^{-0} \rightarrow 1$ (20)

$\therefore \left(1-e^{-\frac{3\tau}{\tau_c}}\right) \rightarrow 0$ (21)

but $\frac{\tau_c}{3}\frac{P_n}{P_0} \rightarrow \infty$ ie we have

$\infty \cdot 0$ the meaning of this is not clear —

However we are discussing τ_c v. large really, not $\tau_c \rightarrow \infty$ i.e. $\frac{3\tau}{\tau_c}$ v.small

Hence we should look at

e^{-x}, x v. small ($x \ll 1$)

We can use the power series for e^x

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots + \frac{x^n}{n!} \quad (22)$$

$$\therefore e^{-x} = 1 - x + \frac{x^2}{2!} - \frac{x^3}{3!} \quad (23)$$

If $x = \frac{3\tau}{\tau_c}$ ~~then~~ and $\tau_c \ggg \tau$

then $x \lll 1$ hence

$e^{-x} \simeq 1 - x$ (24)

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if $\frac{3\tau}{\tau_c} = \frac{1}{10}$ $e^{-x} = 1 - \frac{1}{10} + \frac{1}{2.100} + \frac{1}{6.1000}$

if $\frac{3\tau}{\tau_c} = \frac{1}{100}$ $e^{-x} = 1 - \frac{1}{100} + \frac{1}{2.10000} - -$

So we ~~should~~ substitute $e^{-\frac{3\tau}{\tau_c}} = 1 - \frac{3\tau}{\tau_c}$ in (16)

$$\therefore \Delta O(\tau)\Big|_{\tau_c \to \infty} = P_0\left[\tau\left(\frac{P_n}{P_0} - 1\right) - \frac{\tau_c}{3}\frac{P_n}{P_0}\left(1 - \left(1 - \frac{3\tau}{\tau_c}\right)\right)\right] \text{ (2)}$$

$$= P_0\left[\tau\left(\frac{P_n}{P_0} - 1\right) - \tau\frac{P_n}{P_0}\right] \quad (26)$$

$$= -P_0\tau \quad (27)$$

(this is the hard way — consider going back to $P_n(\tau) = P_n(1 - e^{-\frac{3\tau}{\tau_c}})$

$\tau_c \to \infty$ then $P_n(\tau)\Big|_{\tau_c \to \infty} = 0$

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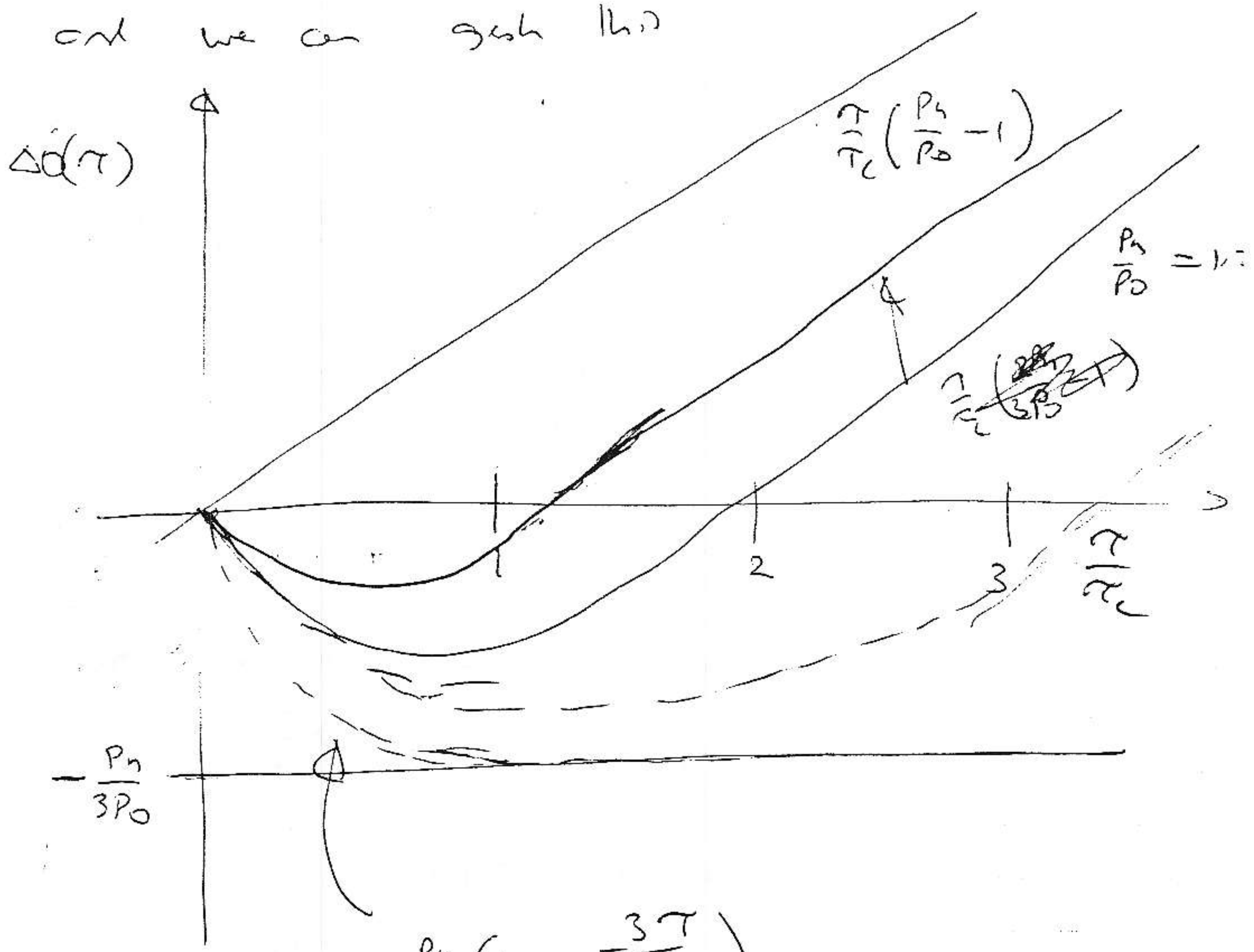
Consider equation (17)

$$\Delta O(\tau) = P_O \tau_c \left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_O} - 1\right) - \frac{P_n}{3P_O}\left(1 - e^{-\frac{3\tau}{\tau_c}}\right) \right]$$

and we can graph this



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Consider equation (17)

$$\Delta O(\tau) = P_0 \tau_c \left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_0} - 1\right) - \frac{P_n}{3P_0}\left(1 - e^{-\frac{3\tau}{\tau_c}}\right)\right]$$

Assume $\frac{\tau}{\tau_c} \geqslant 1$ (i.e. $e^{-3\frac{\tau}{\tau_c}} < 0.05$)

$$\therefore \Delta O(\tau) \simeq P_0 \tau_c \left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_0} - 1\right) - \frac{P_n}{3P_0}\right] \quad (28)$$

To solve for $\Delta O(\tau) = 0$ ...

$$0 = P_0 \tau_c \left[\frac{\tau}{\tau_c}\left(\frac{P_n}{P_0} - 1\right) - \frac{P_n}{3P_0}\right]$$

$$\therefore \frac{\tau}{\tau_c}\left(\frac{P_n}{P_0} - 1\right) = \frac{P_n}{3P_0} \quad (29)$$

$$\therefore \frac{\tau}{\tau_c} = \frac{\frac{P_n}{3P_0}}{\frac{P_n}{P_0} - 1} = \frac{1}{3} \cdot \frac{\frac{P_n}{P_0}}{\frac{P_n}{P_0} - 1} \quad (30)$$

$$= \cancel{\frac{P_n}{3} \frac{1}{P_n - P_0}} = \frac{1}{3} \frac{P_n}{\frac{P_n}{P_0} - 1}$$

First $\frac{P_n}{P_0} > 1$ must hold

Productivity increase $\frac{P_n}{P_0}$	learning curve $\frac{\tau}{\tau_c}$ for $\Delta O = 0$	$e^{-3\frac{\tau_c}{\tau}}$
1.05	7	
1.10	3.33	0.00004
1.15	2.5	0.00055
1.20	2	0.002
1.30	1.5	0.01
1.50	1	0.05