2. THE MACROSCOPIC VIEW ON REAL WORLD INNOVATION PIPELINES

As already mentioned in chapter 1, any inno-pipe IP could just be considered in general as an ordered set of N inno-projects IP=$\{Ip(I_1), \ldots, Ip(I_N)\}$ (see (D 3)). This generalization is by no means obvious, cause in reality we are discussing here highly structured and organized R&D systems, whether or not they are privately or state owned and operated. For the inno-gem, it is most important to know how this set of inno-projects IP=$\{Ip(I_1), \ldots, Ip(I_N)\}$ is constructed, structured and operated. Cause there are virtually infinite possibilities to construct such an inno-pipe, we will only discuss the two for practical purposes most important groups of inno-pipes. These are the (not gated) input-planning/selection and the gated/phased inno-pipes. We will deliberately leave the discussion and evaluation of other ones to more mathematically and (socio-) economically gifted authors.

2.1 From inno-projects to inno-pipes – how to construct IP(TtM (t))

A quite common way to operate an inno-pipe is sketched in Fig. 7. There you see how "normal", annual R&D-project planning/selection and control does produce an inno-pipe very much of the kind described or assumed by the inno-gem (see (D 3), (D 4) and (L 3)). The reason behind this is the implicit "ordering" of inno-projects $IP=\{Ip(I_1), \ldots, Ip(I_N)\}$ by annually selecting and launching new "promising" ones. This leads to sets of projects in (almost) the same maturity state, which are more or less jointly migrating/aging down their (individual) maturity stages (milestones and/or quality gates) until they either become an inno-success or they are sorted out as an inno-failure. Thus their joint and inherently exponential success probability statistics (L 2) do, on an TtM-scale naturally, reproduce an equivalent TtM-exponential success probability statistic $Ps(IP(t_i)) \approx \exp(-\lambda * TtM(IP(t_i)))$ for the whole set or the inno-pipe as a whole.

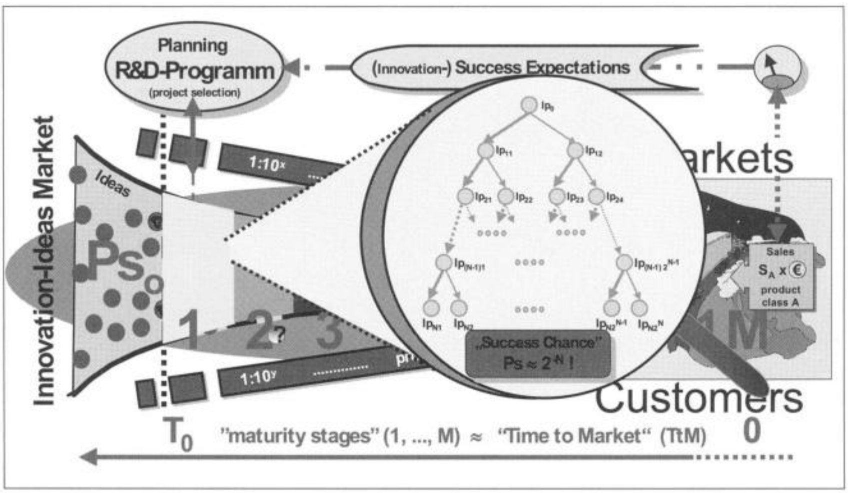

Fig. 7: Sketch of a "R&D-input planning" inno-pipe (⇔ "select the right input strategy")

Thus we can state the following lemma for any inno-pipe or R&D-system operated according to the "selecting the right input" strategy S_c1 (see also chapter 1.2):

Lemma 8 - the exponential TtM-dependency of Ps(IP)

(L 8) ***Any inno-pipe operated according to the "selecting the right input strategy" does reproduce on a statistically determined TtM-scale the exponential time/TtM-dependency***

$$\mathbf{Ps(IP(t_i)) \approx exp\ (-\lambda * TtM(IP(t_i)))}$$

of its underlying set of individual inno-projects $IP=\{Ip_1, \ldots, Ip_N\}$, provided the variances of the individual λ_k-values and the corresponding start-risks $Ps_0(Ip_k)$ of the set or of subsets of IP are not beyond the limits of statistical significance for the whole set IP.

Proof of Lemma 8 – exponential TtM-dependency of Ps(IP) for input-planning inno-pipes:
We will leave this proof to the interested reader. Referring to the above said, (L 8) is nothing but the logical consequence of a **time/TtM-respecting aggregation of the weighted exponential success probabilities of its underlying** and annually renewed **set of N inno-projects Ip_k of the respective inno-pipe IP** under investigation. **Q.E.D.**

Naturally there is an infinite abundance of ways to aggregate different inno-projects Ip_k to form an arbitrary inno-pipe IP. We will thus not go into more detail how such aggregations might be organized nor how the exact aggregation mathematics work in detail. What is really important to inno-management is solely the fact, that the respective inno-pipe does show an exponential success-chance or risk dependency with time better with "Time to Market" (TtM). This is true for an overwhelming majority of most of the practically relevant cases. The ones covered by Lemma 8 are, according to our experience the by far largest group. They are thus for real world inno-management the most important ones too.

There still remains another important group of inno-pipes. It is not quite as large or as important as the first one, but it is of special importance for good inno-management (see also chapter 3.4 inno-phase control). Thus we would like to investigate this group, the gated or phased inno-pipes, a bit more in detail.

2.2 The multiple-entry (gated or phased) inno-pipe

Looking a bit more in detail into gated inno-pipes one immediately sees, that they are nothing but a sequence of shortened (not gated) "input-planning inno-pipes" as already covered by Lemma 8 above. For the whole chain, naturally there could be some most radical changes in the inno-pipe success-function depending on the input-selection behavior or function being applied to the new or continued projects for the respective next phase.

Thus we have to state that for these (gated) inno-pipes in general Lemma 8 does not hold and that they could virtually show almost any time and/or maturity (TtM-) dependency of their respective inno-success probability depending solely on the input-selection algorithm for new/continued projects.

The really important question here is not whether or not one could construct a or any inno-pipe success-function **Ps (IP(t)),** but what are realistic or to at least some extend "reasonable" input-selection algorithms being or to be applied? Once we pose the question that way, we immediately do see too, that in general we will reproduce a sequence of more or less exponentially increasing success-functions for each sub-pipe or element of the chain of inno-subpipes. As we will point out in the subsequent chapter 2.4, the optimal choice for the respective "inno-speeds" (λ-values) of the elements (sub pipes) of the overall inno-pipe is the same constant value for all parts. Thus again Lemma 8 and the exponential time/maturity dependency of the inno-success function **Ps (IP(t))** holds. These thoughts do hold for the overwhelming majority of the in the real business world relevant cases of gated or phased inno-pipes.

2.3 General economic optimization rules for innovation pipelines

Following Schumpeters definition of innovation and own definition of an innovation pipe (D 3) it is must obvious that a necessary condition to run an inno pipe IP (e.g. a R&D-system) is the economical stability condition for its respective profits/losses PF(IP).

Definition 7 - the economic stability condition

$$\text{(D 7)} \quad PF\,(IP(\Delta t)) = \sum_{1}^{N} EVA\,(Ip_i(\Delta t)) \geq 0$$

with respect to some arbitrary time period Δt.

Starting with the economic stability condition (D 7), applying the statistical filter paradigm ((L 1), (L 2), (L 3)) and the cost of information principle (L 6), one can derive the following inequation to describe the fundamental economic optimization threshold condition for any innovation pipeline IP:

Lemma 9 - thefundamental inequationfor the economic success ofan innovation pipeline

$$\text{(L 9)} \quad \overline{Ir}(IP,\Delta t) > \frac{\overline{\cos ts}(Ip_k \in IF(IP,\Delta t))}{\overline{EVA_S}(Ip_k \in IS(IP,\Delta t))} = \frac{\overline{C_F}(IF(IP,\Delta t))}{\overline{EVA_S}(IS(IP,\Delta t))}$$

With $\overline{Ir}(IP,\Delta t) = \dfrac{Number\_of\_elements(IS(IP,\Delta t))}{Number\_of\_elements(IF(IP,\Delta t))}$

average innovation-rate ofthe inno-pipe IP

and $\overline{C_F} = \overline{\cos ts}(IF(IP,\Delta t))$

average cost of an innovationfailure $Ip_k \in IF(IP,\Delta t)$

and $\overline{EVA_S} = \overline{EVA_S}(IS(IP,\Delta t))$

= *average* ***E****conomic* ***V****alue* ***A****dded (****EVA****) of an innovation success* $Ip_j \in IS(IP,\Delta t)$ *with respect to an arbitrary time period* Δt

Proof of Lemma 9 – fundamental inequation for the economic success of an innovation pipeline:

We will leave this proof to the interested reader, cause (L 9) is nothing but a statistical and mathematical transformation of the economic stability condition (D 7) applying the filter-paradigm ((L 1), (L 2) and (L 3)) and the corresponding control model (see proof of Lemma 6). **Q.E.D.**

Any economically stable innovation pipeline must fulfill this fundamental inequation, cause always remember, only the innovation successes $\mathbf{Ip_j}$ from set IS and also only their discounted net profits, with all costs deducted, can/must pay for the whole investment-, R&D- or innovation-pipeline. The rest, all the projects $\mathrm{Ip_k}$ from set IF just burn money.

The maximum output one can get from the results of the projects $\mathrm{Ip_k}$ from the inno-failures set IF is technical orientation, information which helps to answer the question:

"How we can do better next time?"

In almost any real inno-pipe or R&D-system this information is mostly discarded. This is done although this information would be most beneficial, once properly stored, coded and used. Personally we are very much inclined to claim that the proper use of this information represents the biggest ratio-potential in any innovation process at all. It is just not very easy to tap on it. That is the key problem, as we will see in more detail, in the discussion of the microscopic project-view in chapter 4 (see also [5] for additional information). We will not proof Lemma 9, for it is a most simple calculation to demonstrate, that this lemma is just a logical consequence of the stability condition (D 7). Now let us discuss the fundamental inequation (L 9) for an inno-pipe a bit more in detail:

a) The three figures **innovation-rate Ir, failure-costs $\mathbf{C_F}$** and the **net profits** of the **innovation-successes $\mathbf{EVA_S}$** are the **decisive set of performance figures** for any innovation-pipe, R&D- or even an investment-system or -process.

b) **Ir, $\mathbf{C_F}$ and $\mathbf{EVA_S}$ are interdependent.** Trying to increase Ir undoubtedly increases in general C_F and decreases EVA_S, cause you now have to go for the not so thrilling chances too.

c) The **time constants** of these performance figures **(Ir, $\mathbf{C_F}$, $\mathbf{EVA_S}$)** are quite **different**:

- **$\mathbf{C_F}$** has the **shortest one,** you know the costs of the stopped projects immediately.

- **EVA_S** is only known (exactly) at the end of the respective product life cycles, thus it has the **longest time constant.**
- **Ir is in between.** You need not wait until the EVA_S of the respective successes are known exactly, but you must be sure that the respective innovation projects do produce an EVA.

A short inspection of the fundamental inequation (L *9*) of the innovation business tells us that there are only **3 basic strategies to optimize the economic performance of any inno-pipe** or -system:

Rule 2 - the 3 most basic inno-pipe economic optimization strategies S_e1 to S_e3		
S_e1)	**Maximize the innovation rate Ir(IP)**	
S_e2)	**Minimize the failure costs C_F(IP) = C_F(IF)**	(see (L 6))
S_e3)	**Maximize the net profits of the innovation successes EVA_S(IP) = EVA_S(IS)**	

To S_e1) - maximize the innovation rate Ir (IP):
This is a typical economic success strategy for young dynamic markets and (product-) technologies. It closely corresponds to M. Porters "technology leader" strategy, where the profitability stems from temporal monopoly profits due to (technologically) produced USP's.

- If you cannot sustainably differentiate yourself from the competition with your products do not try this strategy.
- If you do not master the necessary key- and, in case, the respective brake-through technologies too, do not try either.

The ability to maintain a sustainable technology and/or product differentiation capability is the decisive precondition to go for such a "Premium-Strategy".

To S_e2) - minimize the failure-costs C_F (IP) of the set of innovation-failures IF:
This is not a classical cost cutting strategy. The essence of this strategy is to stop "hopeless" innovation projects Ip_k as early as possible and to reinvest the saved resources into new, more thrilling ideas. Doing this prevents the resources from being wasted and thus your relative search costs per innovation success C_S(IP) are statistically minimized. This overcomes the most severe cloven hoof of standard cost cutting strategies in the innovation-, in the R&D- and in the investment-business:

- They in general are much more effective in damaging and in preventing an innovation success from taking place, than in reducing the costs of the investments necessary to survive economically.

Used properly (see comments to (L 6)), as we will describe in more detail in the chapters 3 and 4, this strategy is the most powerful approach to reduce the necessary investment (costs) to produce 1Euro of innovation-success net profit (EVA_S). This is due to 2 main reasons:

Se2a) **Minimizing the failure-costs C_F** does **hardly affect** the **innovation rate Ir(IP)** and even if, it rather has the tendency to increase it, due to the reinvested resources.

Se2b) **Minimizing failure-costs C_F does not affect EVA_S**, cause the investments in the thrilling ideas are not affected at all. Additionally there is no reason to believe, that the chances to identify innovation-successes are diminished, once your "show-stopper criteria" are carefully selected and monitored (see chapters 3 and 4).

To S_e3) - maximize the net profits EVA_S (IS) of the set of innovation-successes IS:

This strategy can be executed in 2 most different ways:

S_e3a) **Maximize the (discounted) net life cycles profits (EVA_S)** of your product-innovation successes IS.

S_e3b) **Maximize the "expectancy value" of the EVA_S** of your product-/innovation-successes IS and sell them off as early and as good as you can.

To S_e3a) - maximize the (discounted) net life cycle profits EVA_S(IS):

This is nothing but the normal job of any product management. There are quite some techniques on the market and there is literature on that topic in abundance. Thus there is no reason to reinvent the wheel. We just have to assure that product management is doing its job right. This is really not a topic of nor a question specific to innovation management.

To S_e3b) - maximize the "expectancy values" for the EVA_S(IS) and sell them off:

This is a most typical strategy for the VC-industry. It works quite well, but it has the problem of cyclical market, better cyclical investor expectations or "investment fashions".

This is not a strategy accessible for a large firm or company, which wants to make a sustainable long term business other than investment/financing. Even for investment firms this strategy is a quite risky one, cause supposed you go for the big profits, 10 or even some 100 times your investments, how do you guarantee that the next "big deal" is there in time before you yourself go bankrupt? Your only chance is to have enough "promising horses" in the race and this requires very substantial financial assets again. To summarize our discussion of the fundamental inequation

$$\text{(L 9)} \qquad \overline{Ir}(IP,\Delta t) > \frac{\overline{C_F}(IP,\Delta t)}{\overline{EVA_S}(IP,\Delta t)}$$

we may state the following **"two golden rules"** or strategies **for innovation management:**

> *Rule 3 - two „golden" rules S_I1 and S_I2 for good innovation management*
>
> **S_I1) Keep your innovation rate Ir(IP) as high as you can afford, but cut down on your necessary search costs C_F(IP) as much as you can!**
>
> **S_I2) Keep the money saved by stopping "hopeless" projects in your innovation pipeline and reinvest it such, that you maintain a stable flow of innovation projects in your filter!**

It is a little more difficult to monitor whether or not you are still on track with this strategy than writing it down, cause the performance figures Ir, C_F and EVA_S are nasty to determine. But it is for sure not impossible and the inertia of your R&D- or your inno-pipe does help you quite a bit. This inertia, once you have set up an appropriate monitoring system, does enable you to do good estimates for the future development of these performance figures by analyzing their respective histories:

- For **C_F(IP, Δt)** you get values updates once you stop the respective "hopeless" projects Ip_k. This is the performance figure **almost "à jour".**
- For **Ir(IP, Δt)** this is a bit more difficult, cause before you call some innovation project Ip_j a success ($Ip_j \in IS(IP, \Delta t)$), you should at least wait until product marketing successfully starts. Thus on average the values for Ir(IP, Δt) are always about **50% of** an average development time **TtM_D behind.** You just have to extrapolate for this time to compute the inequation (L 9).
- **EVA_S (IP, Δt)** is only known at the end of the respective product life cycle T_{LP}. Again on average you have to extrapolate the respective values for EVAs for about **50% of** your average **product life cycle time t_{pc}.**

From the three basic strategies (S_c1 to S_c3) you see how statistics does help to run and to optimize an innovation-pipeline. It is good to know your statistics and especially their respective development trends, but e.g. if your statistical basis is too small, a look to your industry and to your competitors will help. Thus benchmarking is definitively not obsolete, it is even more important and beneficial, once you use the fundamental inequation to compare the respective results, figures and performances achieved.

2.4 How to design optimal innovation pipelines?

In Chapter 2.1 we saw how our filter and control model together with the principle of "minimized costs of information" did lead us to the fundamental inequation. This is the global economic success condition to run an innovation pipeline. We still do not know an answer to the especially for R&D-dependent companies most important question:

(Q 3) How is an optimal innovation pipeline structured and organized?

We assume, any careful reader of chapter 1 will almost guess the answer to this question. It is really most simple, once one really accepts the validity of the filter paradigm. Just think of a technical filter process, which is a most useful analogy to an innovation-pipeline. For any technical filter process, there are 2 most crucial optimality conditions to be fulfilled. Exactly these two conditions hold for innovation pipes as well:

Lemma 10 - the matching condition for optimal inno-pipe capacities

$$(L\ 10)\quad \sum_j C^{\,j}_{out}\,(IPstage\ \ (k)) \leq \sum_i C^{\,i}_{in}\,(IPstage\ \ (k+1))$$

The maximum output capacity $\boldsymbol{C_{out}}$ *of an arbitrary stage* **k** *of an optimally designed inno-pipe* ***IP*** *must not exceed the input capacity* $\boldsymbol{C_{in}}$ *of the respective following stage* ***(k+1)!***

Lemma 11 - the matching condition for optimal inno-pipe progress

$$(L\ 11)\quad \boldsymbol{Ps\ (t_k)/Ps(t_k+\Delta t_k)\ =\ C_P\ \approx\ ln\ (N_k/N_{k+\Delta})\ /\ \Delta t_k}$$

with $N_{k+\Delta}$ *= number_of_projects in the inno-pipe* ***IP*** *at* ***TtM*** $= \boldsymbol{t_k + \Delta t_k}$

This progress or speed match is the direct correspondence to the constant flow of material condition through a technical filter. This is especially important, for gases, because they are compressible. The same condition holds for inno-projects too. An optimal flow of ideas (corresponding to a constant pressure gradient in a technical filter) is only guaranteed, if there is a constant speed of "complexity reduction" or of augmentation of your respective chance for an inno-success along the respective TtM-scale of your inno-pipeline.

Proof of Lemma 10 – capacity match:

The proof of Lemma 10 is really most simple, almost self-evident: Suppose C_{out}(stage k) > C_{in}(stage (k+1)). Then you most certainly are not able to pursue some m inno-projects IF = {Ip_{k1}, ... , Ip_{km}} due to capacity reasons. As a consequence you will loose some n inno-successes IS = {Ip_{k1}, ..., Ip_{kn}} and their respective EVA_S (IS). But, quite in contrast to the other "normal" continuing inno-projects Ip_k, you already have paid (invested) for (in) their evaluation until the mismatching stage k. Thus you just maximized C_F(IF) and minimized Ir(IP) without changing the respective EVA_S(IP). This is clearly not economical (see also (L 9)) and thus suboptimal. **Q.E.D.**

Proof of Lemma 11 – speed match:

For this proof, there is a formal, more complicated but more scientific way using $Ps(t) \approx \exp(-\lambda^* t)$ and a phenomenological, more simple way. We will take the latter one and leave the other to the interested reader:

Suppose there is some Δt_k, where you do achieve a much bigger progress in your success function Ps. Now it is an optimal choice just to continue with that speed of "complexity reduction" across all your inno-projects Ip_k towards your goal, the end of your inno-pipe and finally the completion of your innovations IS(IP).

The consequence of this "optimal choice" is nothing but a different value for the speed parameter C_P. After having "optimized" the whole inno-pipe IP according to our new "speed-strategy", we finish with just another constant value for our speed-parameter C_P. This again is nothing but another constant speed C_P for our now newly "optimized" innovation-pipeline IP. **Q.E.D.**

It is most important for an optimal inno-pipe design to respect these 2 optimality conditions for speed (L 11) and for capacity (L 10). There are still quite a few companies around, who think they need not pay respect to them. They do and they will pay real money for it.

In vehicle development Toyota and Honda are very often taken as benchmarks [6]. The capacity distribution for their research, pre- and serial-development departments did and does follow an almost exponential curve. This does nicely correspond at least to some extend to our theoretically derived optimality conditions. Perhaps some theories really do describe, what we would like to call reality?

Now let us continue with our quest for the design rules for optimal inno-pipes. Again our technical analogy, the filter paradigm, shows us just by inspection, that there are only 3 basic strategies (S_o1 – S_o3) to structure and organize an inno-pipe (see Fig. 8):

Rule 4 - the 3 most basic inno-pipe organization principles S_o1 to S_o3		
S_o1)	**Cascading** -	divides a given inno-pipe into some k fractions of itself.
S_o2)	**Buy-in** -	adds at some stage k the input from some outside inno-pipe IP
S_o3)	**Paralleling** -	just operates several inno-pipes in parallel with no interaction of their respective pipes, inputs or outputs.

It is obvious, that our 2 basic optimality conditions ((L 10) capacity- and (L 11) speed-match condition) should be respected once executing each of these 3 basic inno-pipe design rules. This has rather drastic consequences, as shown in Fig. 8, for the design parameters of the respective stages for each basic design. These consequences, together with the respective basic inno-pipe designs, will be discussed in the next paragraphs.

To S_o3) – paralleling an innovation-pipeline IP:

It is most obvious that this is just an aggregation of any combination of S_o1- to S_o2-designs for different products, markets, technologies or firms. So there is no interaction between those pipes and the respective in- or outputs just add up. Conflicting needs for shared resources are neglected here. To resolve them, normal operations research does offer more than elaborate tools, and again, we should not reinvent the wheel! Thus optimizing each inno-pipe separately while respecting the A/B-product optimization rules from classical operations research is the right way to run such an innovation-system or -process.

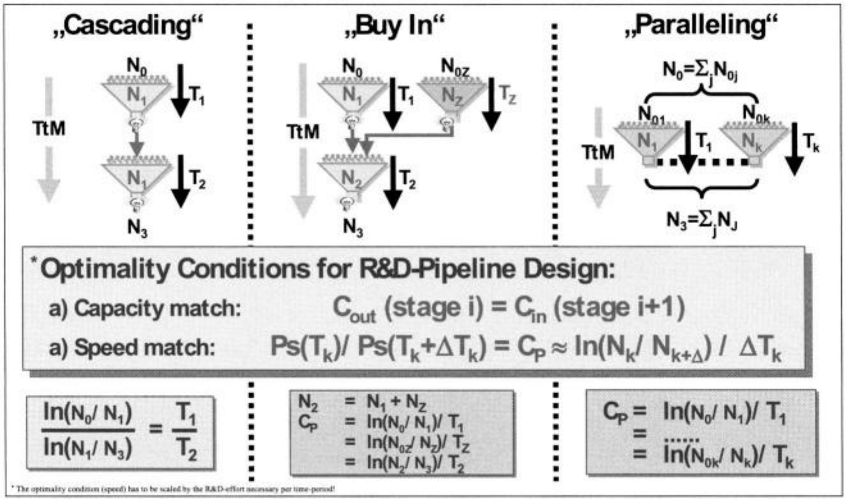

Fig. 8: The 3 basic innovation-pipeline designs and their respective optimality conditions

To S_o2) – buy-in:

This is the predominant inno-pipe design for assembly industries like e.g. the car and the aerospace industry. There you cannot do everything yourself, you just have to integrate the (component-) innovations of other industries into your product innovations. I&C-technologies, electronics and mechatronics are the major buy-in items for these, relatively old industries. Their products instead, are quite young and they are still developing most dynamically. So what are the basic design rules for this case (see Fig. 8):

S_o2a) The capacities at each stage k just add up. So, most important, the input-capacity of stage k must fit to the sum of the internal and the external output-capacities of the respective previous stages (k-1).

S_o2b) The maturity level, especially of the bought-in items (C_{ext}), must match. Once you have a quality gate system in place, the respective requirements must hold for external items too. So you just have to integrate your suppliers into your maturity/quality gate system as closely as your own previous stages of your inno-pipe!
This is a most management intensive task, cause your supplier will remain an outsider. Thus you will have only most limited possibilities to influence his behavior and, even less, his future actions and plans too!

To $S_0$1) – cascading:

Cascading is the basic design rule to get a hand on the controls of an inno-pipe being a statistical filter process. Conceptually this strategy corresponds to the introduction of stages in (technical) filter processes like e.g. refineries, distilleries or even a diamond mine.

The analogy to a technical filter process does really hold quite a bit. Thus, it might be a good idea for MBA's doing innovation management to learn a little more about these processes and their respective design rules and optimality conditions.

Just by looking at technical filter processes we can answer the question – "what are the elementary design rules for cascaded innovation-pipelines?" – much better than by consulting traditional innovation management text-books.

2.5 Design and optimization rules for cascaded innovation-pipelines IP

Rule 5 - the 6 most basic design and optimization strategies S_d1 to S_d6 for cascaded inno-pipes

S_d1) Never ever break the innovation chain:

This is the most obvious and the most violated design rule too. If you break the chain, at least in a technical filter process, you don't get results (products) at all. For inno-pipes, at least their respective performance (the output/input ratio) is usually severely diminished, if you do not respect this design- ,operation- and control-rule for innovation management.

We cannot imagine the reasons, why some R&D-managers still believe that they can cut out parts of their inno-pipe, e.g. the predevelopment department, without severely damaging and/or altering the whole pipe with most doubtful overall performance results, at least in the long run?

S_d2) The weakest part of an innovation pipe limits its overall performance:

This rule is most obvious and accepted for technical filter processes. For an inno-process this is the less dramatic version of "breaking the chain". The consequences are quite similar (see the proofs of (L 10) and (L 11)). Again you do have to pay real money for not respecting this design rule!

S_d3) Once the chaining-conditions are respected one can optimize every part of an innovation-pipe individually:

This is a most useful property of any innovation-processes. The basic idea behind it is a most simple one.

Once you know what the next step in your inno-chain really wants/needs, you exactly know the innovation-market for the stage your in. Once you have knowledge of the output of the previous stages of your inno-pipe, you know your input.

So you know everything you need to optimize any stage of your inno-pipe individually. You now just apply the fundamental inequation (L 9), the capacity- (L 10) and the speed-matching (L 11) criteria. Having done that, you are almost finished with the optimization rules for the individual stage you are designing and managing. By the way, quality gate processes do apply and exploit this intrinsic property of any inno-pipe very much to the benefit of their designers.

S_d4) Organize an innovation pipe according to its respective TtM- or inno-maturity levels:

From the filter-paradigm ((L 1), (L 2) and (L 3)) we know that Time to Market (TtM) or the inno-maturity level achieved (see proof step3 for (L 2) and (L 3)) are the decisive parameters for the respective success-function Ps(t) of every inno-pipe.

Once you want to optimize your inno-pipe, it is thus a good idea to organize it and its respective processes along these parameters. So the information generated inside the pipe will help you to organize and control it accordingly. We will further describe this approach in more detail in the following paragraphs.

S_d5) The capacity distribution along its TtM- or inno-maturity-levels determines the efficiency potentials of the respective inno-pipe:

This design rule is a most important and a most helpful consequence of the principle of "minimal costs of information" (L 6) for any inno-pipe. We will derive and line out some example capacity distributions and their respective costs/benefits using this and the previous rule (S_o1) in the following paragraph.

S_d6) Organize and control the different filter-, technology- or product-stages according to their respective maturity levels and to their respective average throughput times:

Now we finally reached the last optimization possibility/rule for the design of inno-pipes. Applying this design and control rule properly, is top of the notch innovation management. It is the ultimate optimization potential once you exhausted the possibilities of good innovation management, which is nothing but exploiting the respective application potentials of the rules S_d1 to S_d5 properly.

As an example application of the inno-process model (inno-gem) described in chapter 1, we will now apply this model and its respective lemmas to the design and optimization rules S_d4, S_d5 and S_d6.

To S_d4 and S_d5 - optimal capacity designs Ca(IP) for a (cascaded) inno-pipes IP:

Following the filter paradigm (L 1) to (L 3) and the control model (see Fig. 5) it is possible to compute the costs of information according to Lemma 6 for any inno-pipe IP. This is possible, cause the pipe just produces 2 kinds of information, the inno-success info for the members of set IS(IP) and the inno-failure info for the members of set IF(IP). Probability calculus does render us the most helpful relation:

Definition 8 - the error probability

$$(D\ 8)\quad P(IF) = (1 - P(IS)) = (1 - Ps(t))$$

Together with an assumed capacity distribution $Ca_{IP}(t)$ along the TtM- or the inno-maturity scale of the respective inno-pipe, this relation does allow us to compute the costs of information this inno-pipe will produce on average. Here the assumption is made that the costs per inno-projects on average are more or less equivalent to the average capacity deployment inside the respective inno-pipe. According to our personal experiences, this assumption is a most reasonable one for most real inno-pipes. With these assumptions we may calculate the **cost of information Ci(IP)** produced inside an arbitrary inno-pipe IP as follows:

Definition 9 - the costs of information

$$(D\ 9)\qquad Ci(IP) = \int_0^{TtM_{IP}} Ca_{IP}(t) * (1 - Ps(IP))dt$$

$$= \int_0^{TtM_{IP}} Ca_{IP}(t) * (1 - e^{-\lambda t})dt = C_F(IP)$$

With a corresponding set of definitions we may calculate as the respective **investments** we have to make **to generate** a corresponding set of **innovation-successes Cs(IP):**

Definition 10 - the costs of the innovation successes

$$(D\ 10)\qquad Cs(IP) = \int_0^{TtM_{IP}} Ca_{IP}(t) * Ps(IP))dt = \int_0^{TtM_{IP}} Ca_{IP}(t) * e^{-\lambda t} dt$$

With these definitions for the success-investments or -cost Cs(IP) and the failure- or information-costs Ci(IP) we may calculate the **inherent maximum efficiency $E_{IP}(IP)$** of different capacity designs **$Ca_{IP}(t)$** for a given inno-pipe IP:

Definition 11 - the maximum efficiency for a given inno-pipe

$$(D\ 11)\quad E_{IP}(IP) = \frac{Cs(IP)}{Cs(IP) + Ci(IP)} = \frac{Cs(IP, Ca_{IP}(t))}{Cs(IP, Ca_{IP}(t) + Ci(IP, Ca_{IP}(t))}$$

Using the start-risk parameter $\alpha(IP)$, we set the exponential capacity strategy parameter to $\lambda(IP)$, which is by the way an optimal choice. Doing that, we get the following definitions (D 12) to formalize and calculate the effects of different inno-pipe capacity deployment strategies on their respective maximum efficiencies E_{IP}:

Definition 12 - inno-pipe capacity deployment strategies

(D 12)	$\boldsymbol{Ps_0(\alpha) = Ps(TtM_{IP}, IP) = exp(-\alpha)}$	*is the start-riskparameter with*
	$\boldsymbol{\lambda(IP) = \alpha/TtM_{IP} \approx \alpha/t_{pc}}$	*and the capacity strategies*
	$\boldsymbol{Ca_{IP}(t) = k_0}$	*constant R&D-capacity or,*
	$\boldsymbol{Ca_{IP}(t) = k_0{*}(TtM_{IP}-t),}$	*linear R&D-capacity increase or,*
	$\boldsymbol{Ca_{IP}(t) = k_0{*}exp(-a{*}(TtM_{IP}-t))}$	*exponential R&D-capacity increase.*

We can now compute the following table (1) for the respective inherent inno-pipe efficiencies E_{IP} for these 3 most common capacity deployment strategies $Ca_{IP}(t)$. Additionally Fig. 9 shows a plot of the respective (maximum) inno-pipe efficiencies E_{IP} according to the "cost of information principle" (L 6).

Start-chance α:	$\alpha = 2$ (Ps$_0$ = 13,5%)	$\alpha = 3$ (Ps$_0$ = 5%)	$\alpha = 5$ (Ps$_0$ = 0,7%)
$Ca_{IP}(t) = k_0$	$E_{IP} \approx 43{,}2\%$	$E_{IP} \approx 31{,}7\%$	$E_{IP} \approx 19{,}9\%$
$Ca_{IP}(t) = k_0{*}(t_{pc}-t)$	$E_{IP} \approx 56{,}8\%$	$E_{IP} \approx 45{,}6\%)$	$E_{IP} \approx 32{,}1\%$
$Ca_{IP}(t) = k_0{*}e^{(-\lambda{*}(t_{pc}-t))}$	$E_{IP} \approx 56{,}8\%$	$E_{IP} \approx 52{,}5\%$	$E_{IP} \approx 50{,}3\%$

Table 1: Inno-pipe efficiency E_{IP} as a function of the capacity deployment strategy $Ca_{IP}(t)$

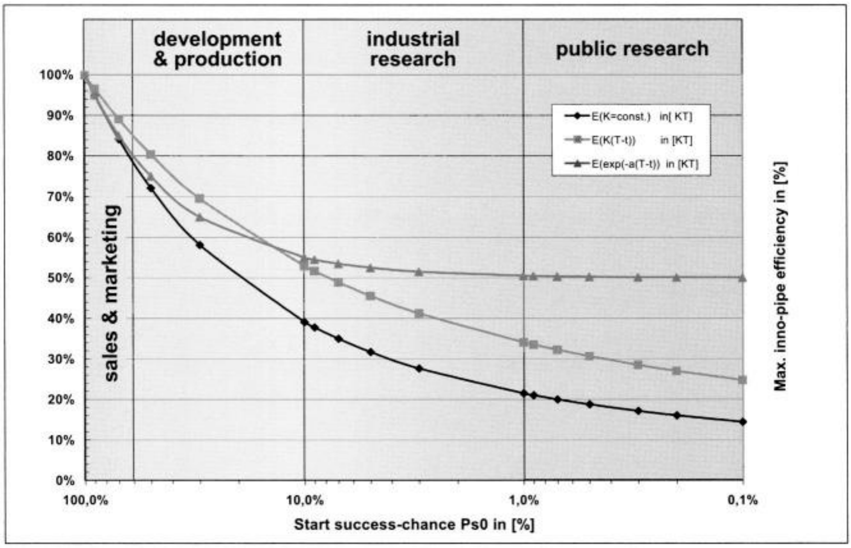

Fig. 9: Plot of the inno-pipe efficiency E_{IP} as function of start-risk Ps_0 and capacity strategy Ca_{IP}

Fig. 9 most impressively demonstrates in numbers the potential efficiency benefits of an exponential R&D-capacity deployment along the innovation chain. This is especially important in the public and in the industrial research sector, where the biggest part of the "complexity reduction" or enhancement of the probability to become an innovation (see success-function Ps(t) in Fig. 3), has to be performed.

The following stages (industrial development, marketing, sales and after-sales) only have to increase the probability in general from some 10-20% to a full 100%, which is a factor of 5-10. Research, in contrast, usually has to deal with factors from 10 to over 100! Again, we cannot overemphasize the enormous efficiency and, as a consequence, the efficacy benefits too, of this R&D-capacity deployment strategy. Having Fig. 9 in mind, it is not astonishing at all, why Toyota and Honda are organizing their inno-pipes the way they do! By the way, we are most certain that a classical chief engineer, like T.A.Edison or G.Daimler, has done and would have done so too.

2.6 Design rules for cascaded inno-pipes - the pharma example

To S_d4 - organize your inno-pipe according to TtM-levels (the pharma example):

Very much in contrast to the automotive or the aerospace industry, you have in the pharma industry an almost one to one relationship between innovation investment (into a drug) and its respective profits or inno-success. So this industry is most suited to test the validity and the applicability of our innovation-process model and the corresponding theory.

The pharma process is a most simple, but a very long one. The **product development** of a new drug usually takes about **15 years** and has about a **1 out of 20 success** chance, which is not too good, compared to other industries. So you have to deal with a considerable risk and also with most remarkable **investments** necessary, about **3,6 Mio $ per drug on average,** before you obtain a new one. This situation is illustrated in Fig. 10 using our control model adapted to the (average) pharma industry drug development process.

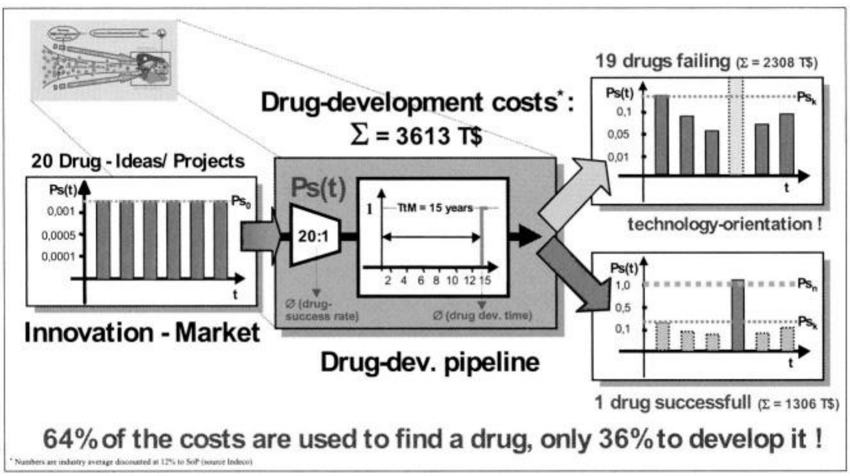

Fig. 10 :Control model of the industry average pharma filter process (inno-pipe)

Compared to our calculated maximum achievable inno-pipe efficiencies, the average **pharma industry development process does not perform too well** at all. It shows quite some room for improvement, cause for an average start-success chance of Ps_0=5%, as in the pharma industry, we would expect some E_{IP}=50% inno-pipe efficiency, not a **rather meager E_{IP}=36%.** Remember these are industry average figures. Thus, there are obviously quite a few companies performing even much worse!

(Q 4) What are the deficiencies of the pharma R&D-process that it performs the way it does?

To answer this question, we have to look a little closer to the drug development process, sketched in Fig. 11, and compare it to our inno-process model to determine, where things are going wrong. Now, what does Fig. 11 tell us about the pharma filter process:

1.) The pharma process is a **phased and gated** development process, with a TtM of about 15 years covering 6 distinct development phases. That is OK according to our theory and our model.

2.) The pharma development **phases are not equidistant.** This is not a problem in itself, but it does make management and control of the whole process (much) more difficult!

3.) The pharma process most obviously does severely **violate our speed-match** criteria and, most probably, the capacity match criteria too! This is by no means a smooth filter process. It rather resembles a **series of notch filters** (see red curve in Fig. 11), just like a comb. This is a **not at all suitable** solution for a statistical filter problem. This is common sense, at least for almost any control engineer. Thus, as already mentioned before (see comments to the proofs of (L 10) and of (L 11)), you have to pay substantial amounts of (real) money for not following these rules!

4.) Starting with year 10 (see blue curve in Fig. 11), corresponding to the **end of** (clinical) **phase 2, drug development is becoming really expensive,** more than 10 times the cost per year than before! Despite that, there is still, on average, a considerable risk, cost and uncertainty left in the process at that stage or phase.

5.) The **pre-clinical phase** is by far the major filter stage and thus the **most costly one,** where (potential) inno-failures are sorted out by the pharma process.

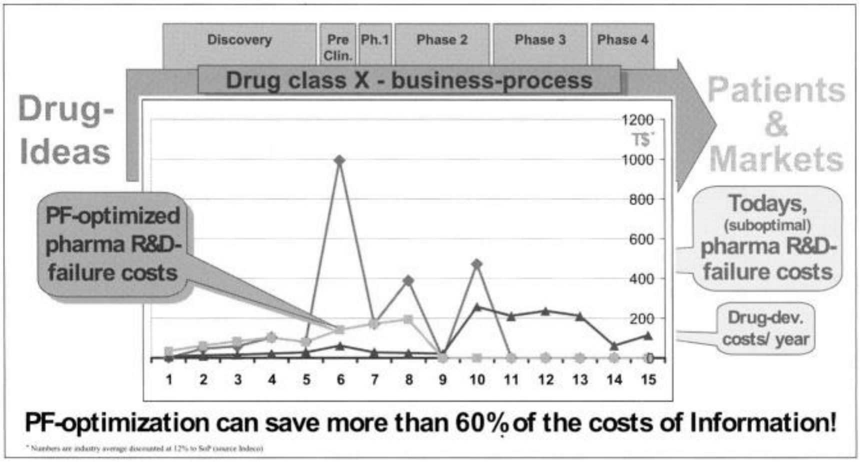

Fig. 11: Plot of the pharma inno-pipe (industry average) and its respective efficiency potentials

These sketched properties (1 to 5) of the drug development process do lead us to following question:

(Q 5) How can we improve the pharma (drug development) filter process?

Again the main answer is a most simple one and it is already outlined in our **inno-gem** (see intermediate summary 1). The theoretically derived speed- and capacity-match criteria do tell us that only smooth, exponential filter designs are optimal. Anything else is nothing but expensive. So, why not replace the main filter stages "pre-clinical" (year 6), start "phase 2" (year 8) and end "phase 2" (year 10) by the most simple (darwinistic) filter approach one can imagine:

- **Until year 10, when pharma projects are still cheap, every year only a fraction (e.g. 70%) of the drug projects do survive their respective (annual) maturity tests!**
- **From year 10 on, when drug projects become real expensive, almost every drug project (e.g. >95%) does/must survive its necessary maturity test!**

Once we recalculate (using the inno-gem) the pharma process under these assumptions we see, that

- **more than 60% of the (necessary) costs of information $Ci(IP_{pharma})$ could be saved!**

- **The overall inno-pipe efficiency E_{IP} could be increased by more than 50%!**

These (potential) savings are not at all taking into account further potential savings due to the application of other aspects (e.g. knowledge management, improved control, etc.) of the inno-gem. Thus there is quite some justification, that we may expect even a lot more room for improvement in the drug development process, than the calculated -60% from the costs to find the "right drug" $Ci(IP_{pharma})$.

Having these numbers in mind, considering the tremendous future market potentials of the "life sciences" in general and knowing the enormous impact of the (drug) development costs on the balance sheets of "big pharma" one might be tempted to promise this industry a rather bright future, once it really makes use of all these still unrevealed efficiency potentials in their innovation-processes!

2.7 Logical paralleling - the ultimate optimization method

To S_d6 - organize and control the filter- (technology-, or product-) stages of an inno-pipe according to the respective maturity levels and to the average throughput times:

Let us now suppose we have organized our inno-pipe according to the inno-gem. Thus we have

a) created a steady and **continuous inno-pipe** without ruptures or weak-links.

b) **organized our inno-pipe along the TtM- or maturity scale** relevant for our product/market and we have selected a start-risk Ps_0 or a corresponding innovation height we are aiming at.

c) implemented a **complete and consistent quality gate scheme** to always be able to compute and to monitor the development of the success-function Ps(t) of our inno-pipe.

d) set up **optimization schemes for each of the stages** of our inno-pipe.

e) always respected and incorporated the **speed- and capacity-match conditions** into the design of our inno-pipe, e.g. using an (optimal) **exponential capacity deployment strategy** (see Fig. 9).

Having done and achieved all that, we may ask ourselves now,

- **are we really done with the inno-pipe optimization possibilities doing steps a) to e)?**

The answer to that question is

- **yes, provided we do have a one product, one technology and/or one market problem only!**

These kinds of inno-problems (one product/market) are more characteristic for the pharma and comparable industries. Especially for assembly industries there is still another, perhaps the last, optimization potential.

This is an effect of the different throughput times and innovation-cycles of the different components and of the different technologies employed in such a system product. Fig. 12 shows a typical situation like that. Thus we will use this picture to outline the basic idea behind this optimization strategy, we would like to call **logical paralleling.** The basic idea of this system optimization scheme is to **profit** as much as you can **from the differences in the respective throughput times** of each component technology in order to maximize the overall system development efficiency. This is achieved by treating each technology different.[vii]

The overall **system** development **throughput time** is in general **determined by its slowest developing component.** In the example motor development project sketched in Fig. 12, this is propulsion technology, e.g. the new combustion technology "space charge ignition". Now, which steps do we have to take to optimally organize such an endeavor?

In order to build on that "most promising" basis a new, clean, fuel efficient and smooth running engine, we have to develop on top of this new base motor a new ignition and a suitable fuel injection system too. This in turn has as a consequence the development of an appropriate control-SW system for this new motor control HW (mechatronics) employing and implementing our new motor control methodology (space charge combustion).

[vii] We will exploit this property of assembly industry innovation pipelines described in the next chapters to restrict our discussions and the "real life" examples to a somewhat virtual company, which we would like to call "XX-Corporation" for simplicity.

XX-Corporation serves as a placeholder for the most difficult and the most general class of inno-problems and/or inno-pipes, the assembly industry product innovation pipeline. Therefor XX-Corporation is assumed to be an international multi-brand, multi-technology and multi system-product company.

It thus shows all the basic and most of the non-basic properties and problems of good and not so good inno-management. Due to this, it will serve us as an example to discuss and demonstrate the very essence of what are the consequences of our novel inno-mamangement theory and approach in real life. This is even more so, because we carefully selected the input data for each of our XX-Corporation examples out of the rich data pool we did have access to.

This data pool has been fed by our own quite substantial professional experience as well as by quite a few international benchmarks we performed or we did have direct access too. These benchmarks covered pharma, chemistry, electronics, IT, communication, aerospace and car industries over a time period from 1995 to 2003.

Thus XX-Corporation never stands for a single company only. It rather should and must be considered to be a typical member of an enterprise or an inno-pipe typical especially for the assembly industries as a whole!

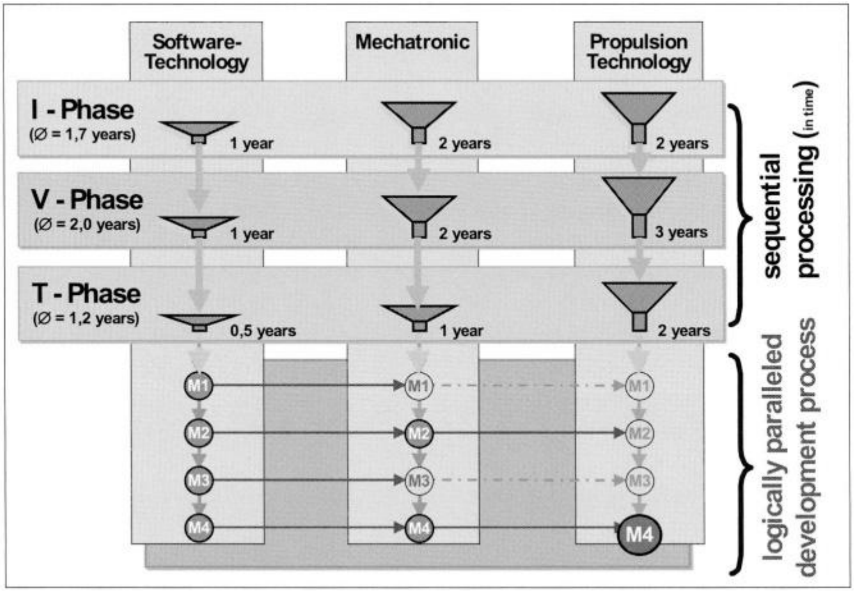

Fig. 12: Logically paralleled system Innovation/development projects and/or inno-pipes

We now do ask you to remember the most widely known fact, that the average **throughput times** of these different technologies **are most different** too. **SW** usually has technology cycles of **some 2-3 years, mechatronics of some 3-5 years** and **combustion technologies** do develop much slower, let's assume a technology cycle time **TtM_{comb} of about 5-7 years.** Whether or not these values are correct or realistic, is not really important for this example. It's their differences which do have an enormous impact on the respective system development efficiency, organization and control too.

From the **inno-gem** we could conclude, that **maintaining a constant speed** (of complexity reduction) in an inno-pipe is a decisive condition for its respective **optimal efficiency and efficacy.** This is only true relative to a assumed technology cycle time TtM_{techj}, cause "mathematically speaking" our model and its respective equations do **scale with their λ- or α-parameters.** As we know from their definitions (e.g. (D 12)) the "Time to Market" TtM_{IP} of the respective inno-pipe IP is a decisive scaling parameter. This is nothing but the mathematical consequence of the fact, that **each technology** and its corresponding inno-pipe has **its own characteristic cycle time TtM_{techj} with which** all the respective **processes and characteristics do scale!**

We can profit from this property of any (system) innovation-process, by exploiting the faster component cycle times to the benefit of a much higher system maturity. This is achieved by **doing more than one development cycle for a component technology for a certain maturity step of the overall system** (see (D 12)). Through this one achieves a **higher maturity with on average the same costs.** This is true, cause a component development team just sitting and waiting until a certain maturity level on the system side is achieved, does cost about the same amount of money than while working on its own targets.

Naturally there is a **price to pay** for these (potential) benefits. The price is a **substantial increase in the necessary persistency and in the maturity of the technical management** involved. It now has to be able to most clearly describe, determine and monitor the respective development and maturity targets of each component and of the system project at the same time. This is really **a challenge even for a** most well educated and **experienced "chief engineer".** This is definitively **not an option for an "administrator",** cause the quality of the technical evaluations and/or judgments of the different steps to take is the success determining part of this strategy.

2.8 Intermediate summary 2 – the inno-gem and innovation-pipeline design

S2a) There is **a fundamental inequation** (L 9) describing the **essential economic optimization properties of any** investment-, development and/or **innovation-process:**

$$(L\ 9) \qquad \overline{Ir}(IP,\Delta t) > \frac{\overline{C_F}(IP,\Delta t)}{\overline{EVA_S}(IP,\Delta t)} = \frac{\overline{C_F}(IF(IP,\Delta t))}{\overline{EVA_S}(IS(IP,\Delta t))}$$

with $\overline{Ir}(IP, \Delta t)$ = average innovation-rate of inno-pipe IP

and $\overline{C_F}(IF(IP,\Delta t))$ = average cost of a failing project from set IF

and $\overline{EVA_S}(IS(IP,\Delta t))$ = average **E**conomic **V**alue **A**dded of an inno-success from set IS

with respect to any arbitrary time-period Δt.

S2b) There are **just 3 basic strategies for the economic optimization** of any innovation-pipeline:

1.) **Maximize the innovation-rate Ir (IP, Δt_k)**

2.) **Minimize the failure costs** (costs of information Ci)
Ci = C_F(IP, Δt_k) of an Inno-pipe IP

3.) **Maximize the** Economic Value Added **EVA_S(IP, Δt_k)** of the respective inno-successes IS(IP, Δt_k)

S2c) There are just **3 basic design options** how **to organize any innovation-pipeline** (see Fig. 8)**:**

1.) **Cascading** - this is the basic design option to optimize and control any inno-pipe IP

2.) **Buy-in** - the predominant basic inno-pipe design option for assembly industries

3.) **Paralleling** - a typical inno-pipe design option for the consumer goods manufacturers

Once the design rules (S2d and S2e) are respected, each of these 3 basic designs can be freely combined with any other option to form a suitable real inno-pipe design for the technology and/or market problem at hand.

S2d) To be at least capable to obtain an optimum inno-pipe efficiency E_{IP} (see Fig. 9), each basic inno-pipe design (see S2c) must respect these 2 basic optimality conditions:

1.) **Capacity-match** (L 10):

$$\sum_j C^j_{out}(IPstage\ (k)) \leq \sum_i C^i_{in}(IPstage\ (k+1))$$

2.) **Speed-match** (L 11):

$$\mathbf{Ps\,(t_k)/Ps(t_k+\Delta t_k) \ = \ C_P \ \approx \ ln\,(N_k/N_{k+1})\,/\,\Delta t_k}$$

with $\mathbf{N_{k+\Delta}}$ = number_of_projects in the inno-pipe IP at TtM = $t_k + \Delta t_k$

S2e) From the inno-gem we can derive 5 basic rules for the design of any inno-pipe IP:

1.) **Never break the inno-chain nor allow to have weak links in between!** - this is the most basic and most cost saving, but, in general, the most violated design rule for any inno-pipe IP!

2.) **Every stage of an inno-pipe can be optimized individually once the chaining conditions are respected** - this allows for quick, effective and easy optimizations!

3.) **Always organize your inno-pipe according to its TtM- or maturity-levels** - this is most important for the development of optimized inno-pipe design and control strategies.

4.) The **capacity strategy Ca(IP,TtM)** pursued **determines** the maximum **efficiency potential** of an inno-pipe IP and **Ca(IP,TtM) ≈ exp(-b*TtM(t_i)) is** the **optimal** one (Fig. 9)

5.) **Logical paralleling** (see Fig. 12) is the **ultimate optimization strategy** once all the other options (S2a to S2e) are exhausted.

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