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Human Effort Dynamics and Schedule Risk Analysis

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Abstract

Human work duration and related risks are the results of human actions. Therefore quantitative analysis of human action dynamics is becoming a problem of paramount importance for the new challenges of project planning and schedule risk analysis. In most cases contemporary schedule risk analysis is not adequate because we do not know the form of the risk function. Hypothesizing the normal distribution for that purpose is not adequate because it leads to undesirable results.

This paper presents a new view on the problems of schedule risk analysis. Instead of hypothesizing the mathematical form of the distribution of work closure time, this paper suggests a qualitative explanation of the need for Heavy (Fat) tail distributions for schedule risk analysis and an analytical derivation of the closure time distribution function.

Key words: Human action dynamics, schedule risk analysis, Heavy (Fat) tail distributions, linear and non-linear work, deterministic and stochastic work, bursts of human actions, effort and duration, State equation of human actions.

Introduction

The main thesis of contemporary schedule risk analysis is the belief that the development process can be represented as a sequence of work portions. Each one of these work portions has its random duration with some distribution function. According to the Central Limit theorem the whole duration of work which is the sum of the durations of the work portions must have an asymptotic normal distribution.

This approach to the problems of schedule risk analysis always results in inaccuracy. Practical schedule risk analysis indicates that the risk function is not a symmetric one and it almost always has a long slippage tail.

Therefore during the last several years there have been attempts to develop a new schedule risk analysis methodology that is based on Heavy (Fat) tail distribution theory.

This new direction of research has not yet achieved satisfactory results because of the strategy to hypothesize Heavy (Fat) tail distributions. The point here is that there are many Heavy tail distributions and it is not clear which one of those can cover successfully the needs of a particular problem.

This paper suggests a new approach to the problems of schedule risk analysis. It is based on the state or balance equation of human actions that incorporates effort, time duration, human productivity, size of action, and difficulty of the task. According to this equation the time duration of human action is a function of others. By measuring or hypothesizing the distributions for independent parameters and using the theory of the functions of random variables, it is possible to find the mathematical form of the Heavy (Fat) tail distribution. Then the final Heavy (Fat) tail distribution for the total project duration can be seen as the distribution of the sum of separate actions. In this case the central limit theorem produces an asymptotic Heavy tail distribution because sequential action durations have Heavy tail distributions too.

The key issue here is the form of the functional relationship between time duration and other parameters. It allows deriving analytically the functional form of the final Heavy tail distribution. We do not need to hypothesize it, instead we can derive it.

1. Balance Equation for Human Action's Quantitative Analysis

Consider a person who is performing some work with sequential steps. Each step represents itself an action intended to complete the corresponding portion of work.

Quantitatively each human action can be characterized with a set of parameters. Namely – the time to complete the action "T" (which is equal to the effort "E", consumed by the person), human productivity "P", size of the portion of task which is being solved "S," and the difficulty of the portion of the task "D".

The work portion "W" done by the person can be represented as

$$W = EP = TP. \qquad (1)$$

The same work portion can be represented as the product of the portion size "S" and difficulty "D".

$$W = SD \qquad (2)$$

Equalizing expressions (1) and (2) we can have a balance equation that incorporates all the quantitative measures of the human's single action.

$$TP = SD \qquad (3)$$

From here we can have an expression for human action's duration

$$T = \frac{SD}{P} \qquad (4)$$

The seeming simplicity of this expression is delusive because all parameters in it are interrelated. Firstly there is a very complicated functional relationship between difficulty of task D and human productivity P. Secondly there is another relationship between the size of task and its difficulty. This simply means that any separate change of size, difficulty or human productivity will lead to a change not only for the human action's duration but also for the changes of two remaining parameters. For instance ΔS change of the task's size will lead not only to the change of action's duration, but also to the changes ΔD of task difficulty and ΔP of human productivity. So the resulting ΔT change of task duration will be a complicated function of ΔS, ΔD and ΔP, although we had changed only the size of the task.
This phenomenon is well known from the other fields of science and technology. The typical example of that is the classical static thermodynamics.
Expression (4) can be used for several purposes including geometrical modeling of the space of human actions, schedule risk analysis, change analysis, etc.

2. Qualitative Analysis of the Feasibility of Human Actions at Work

Depending on the difficulty of human actions, they can have different levels of feasibility. Besides, for each action there is a limit of difficulty in the vicinity and beyond which the action is infeasible. Rising difficulty of an action leads to a higher effort consumption for its accomplishment. Taking into account that for one person the effort consumed and the duration of an action are the same, we can use action's time durations only. In the vicinity of the difficulty wall D_w action's duration is rising very rapidly because of the large number of iterations for the action accomplishment (Fig.1.)

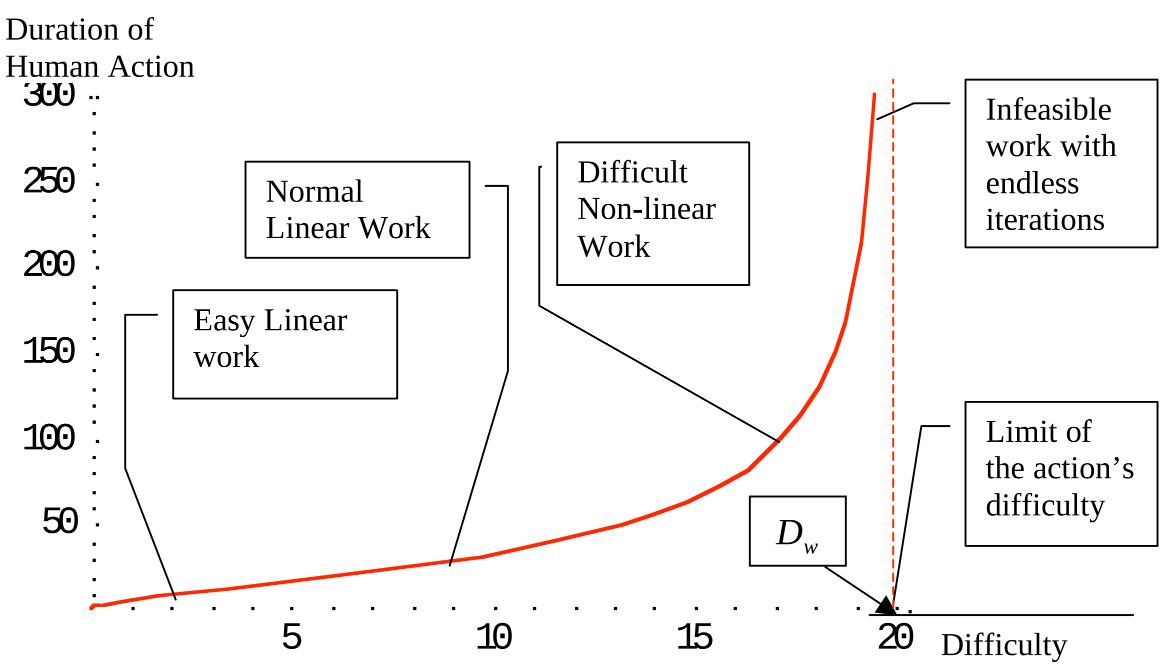

Fig.1. Non-linear relationship between the duration of human action and action's difficulty

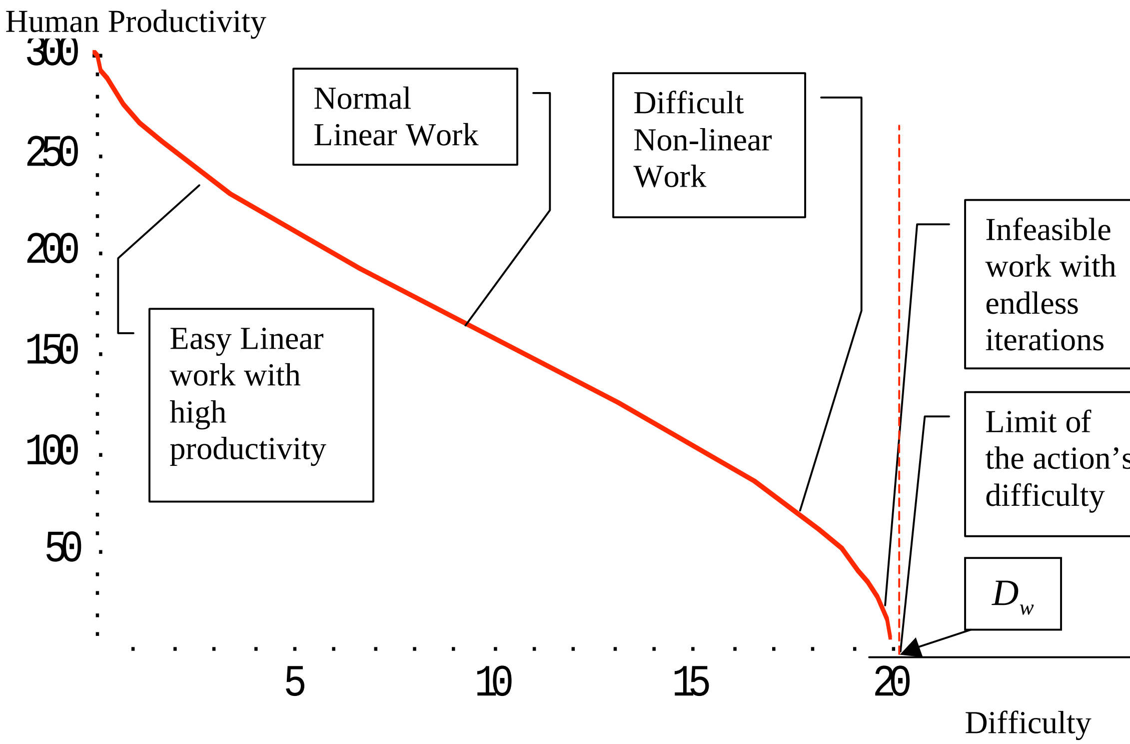

Fig.2. Non-linear relationship between productivity of human action and action's difficulty

In this picture the vertical axes represents the duration that consumes a person to accomplish the action. Numerically this effort for one person coincides with the duration of action. This is not the case for two or more people because of interaction between them that decreases the aggregate group productivity of work.

The relationship which is presented in Fig.1. has several characteristic regions that cover the whole range of human actions starting from an easy and simple work to infeasible non-linear work. The region of non-linear work in this curve requires special attention because it is a region of the trade-off between cost of work and advanced solutions in it. This is the region where the most high-end human activities take place, including project works, creative actions, research works, etc. Also this region is the main source of action iterations and work delays and therefore it is extremely important from the point of view of schedule risk analysis. In other words this is the region where the progress occurs.

Feasibility of human actions can be reflected by the relationship between human productivity and the action's difficulty too. This is represented in the Fig.2.

Analysis of this curve indicates that individual productivity cannot be considered as something constant and inherent to some person. In reality human productivity is a direct function of the difficulty of tasks being solved. Moreover, human productivity is highly variable and highly controllable. It depends on task assignment, planned time for work, meeting time, learning and training plans, and many other things.

It is worthy to notice that fundamental research in this direction has discovered many unexpected ways for improving human work productivity.

Let's try to understand what is the task assignment from the point of view of schedule risk analysis.

3. People have different effort and productivity characteristics in the same fields of work and levels of difficulty

Let's analyze the situation of the joint work of two people with different timing and productivity characteristics (Fig.3. and Fig.4.).

Assume people are doing some job with an average difficulty D_{w1}.

As we can see from the pictures this is an ordinary work for person 2 with the red performance characteristics and this is an almost impossible work for person 1 with the blue performance characteristics. To do the job with D_{w1} difficulty the first person will consume in average T_1 time, and the second person - T_2 time. Also people will have quite different productivities, correspondingly P_1 and P_2.

We can see that this kind of task assignment is not good because it will be impossible to synchronize the work of these two people. Besides it is very risky for the first person to work very close to the limits of his capacity.

The solution in this situation is to change the task assignment, reconciling it with the real capacities of people and the real difficulty of tasks.

From the simultaneous task completion point of view the obvious solution is to divide the action into two parts with different difficulties or different task sizes. Let's utilize expression (4) for analyzing this situation with the right task assignment. From this expression we can see that for the same action size S there must be a correspondence between the people capacity and task difficulty. Namely, to finish the job in a synchronized way people and tasks have to have the same $\frac{D}{P}$ ratio which means that

$$\frac{D_1}{P_1} = \frac{D_2}{P_2} = Constant \qquad (5)$$

This means that for solving the problem we need to find out the family of curves (5) in the Productivity/Difficulty field. This is a system of straight lines passing through the origin of coordinates. In this particular case we will have

$$P = \frac{D_1}{P_1} D = \frac{D_2}{P_2} D. \tag{6}$$

This line is presented in Fig.4.

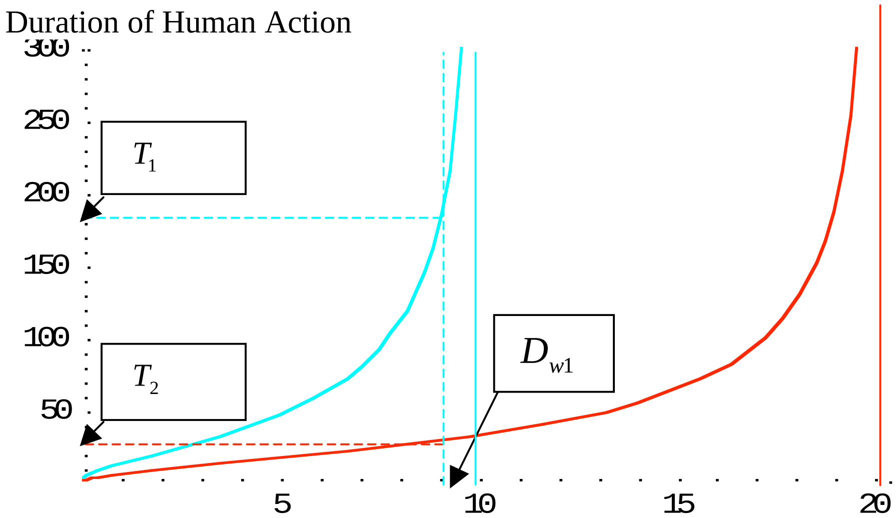

Fig.3. People with different knowledge, experience and skills have different effort-time duration characteristics

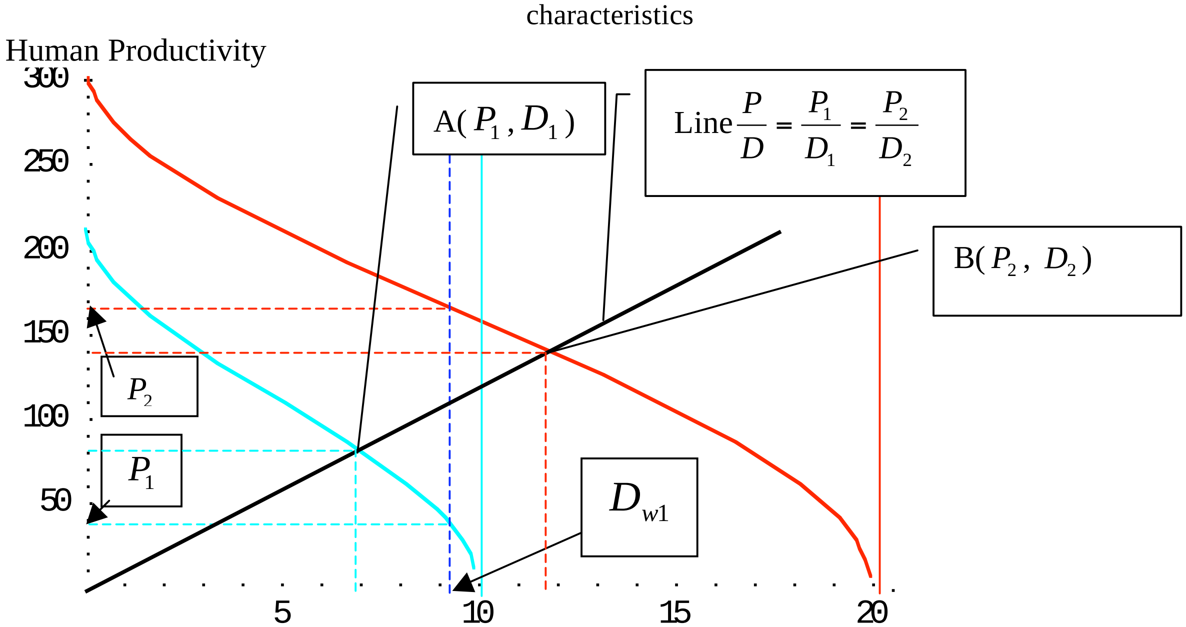

Fig.4. People with different knowledge, experience and skills have different performance characteristics

Besides the ratio $\frac{P_1}{D_1} = \frac{P_2}{D_2}$ is equal to the ratio $\frac{T}{S}$, where T is the required time to do the job and S is the size of task. Therefore to solve the task assignment in this case we need to find the intersection of the line P/D=Constant with two performance characteristics in Fig.4. The solutions are the points A(P_1, D_1) and B(P_2, D_2) in this figure.

5. Timing and Bursty behavior of Human Actions

Investigation and understanding of the timing of human actions and their bursty behavior is the key for the explanation of project delays, overruns and failures. The complicated process of project failure always starts with minor and invisible delays in human actions. Part of these delays has an objective character, meaning unexpected difficulties of tasks, market change and many others. But many of them have a subjective character due to the lack of responsibility, conflict of interests and even laziness.
All these factors can become components of a negative accumulation process over time and eventually to failure of a whole project.

Besides the majority of successful projects exceeds the planned budget and time. All these facts need to be understood and this understanding used to control project situations.

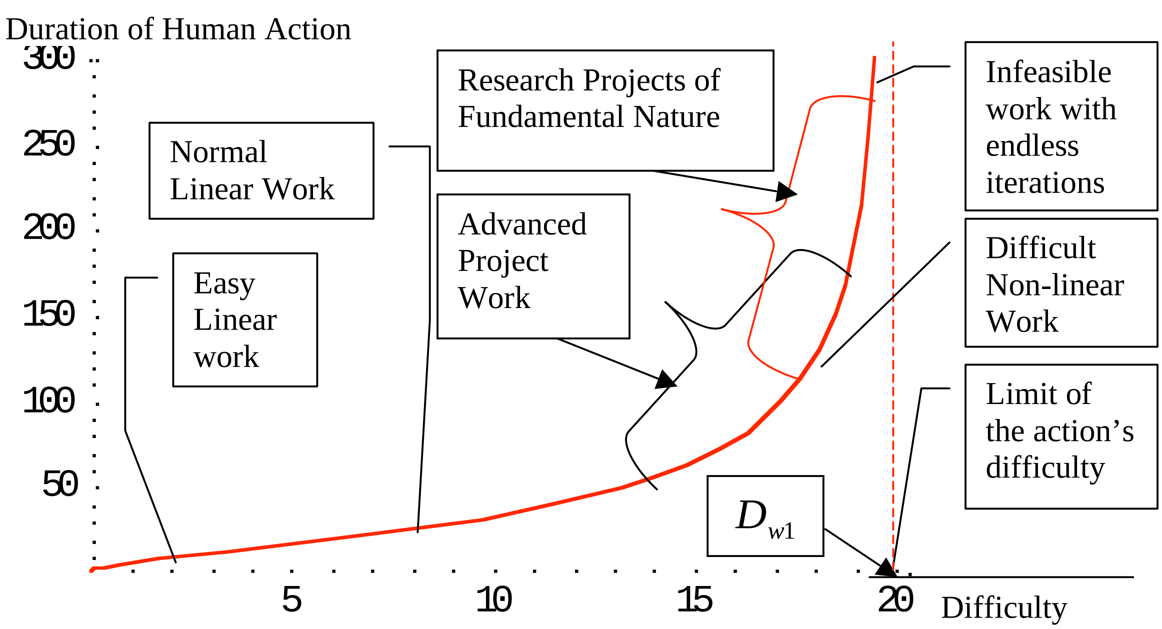

Fig.5. Non-linear relationship between the effort of human action and action's difficulty

All these delays and failures are related with the bursty timing behavior of the single human actions. In reality the sequence of human actions has a random behavior. As we saw before,

the duration of the single human action depends on the size and difficulty of tasks and human productivity. In their turn all these three parameters of human action have random characteristics too. Besides the very nature of project work is closely connected with the solving of difficult problems, the solutions of which may require many iterations until satisfactory results can be reached. This simply means that advanced project work always occurs in the non-linear region of human performance characteristics. Moreover, many research projects of a fundamental nature take place between the non-linear and infeasible regions of human performance characteristics (Fig.5).
The combination of the randomness of human action parameters and non-linear relationships between them are the causes of the bursty timing behavior of human actions. In their turn these bursts of human action durations are the main reason for the arising of Heavy tail distributions of the whole project duration. This is why we need a totally renewed approach to project schedule risk analysis.

6. Stochastic behavior of human actions

Everyday human activities indicate that sequential actions have random difficulties. This fact has an important role in schedule risk analysis.

Let's consider two random difficulties for the same person with different average values (Fig.6.). Each one of these random difficulty processes has an average value D_{w1}, D_{w2} and distribution function $f_1(D)$, $f_2(D)$.

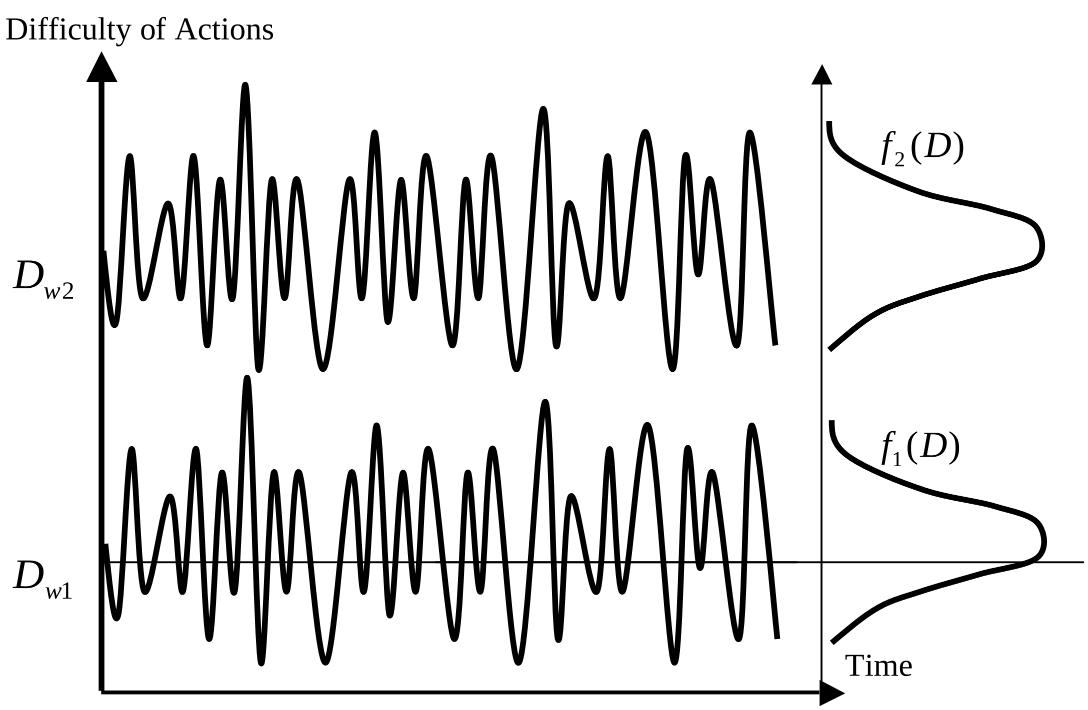

Fig.6. Two random processes that reflect the difficulty of human work

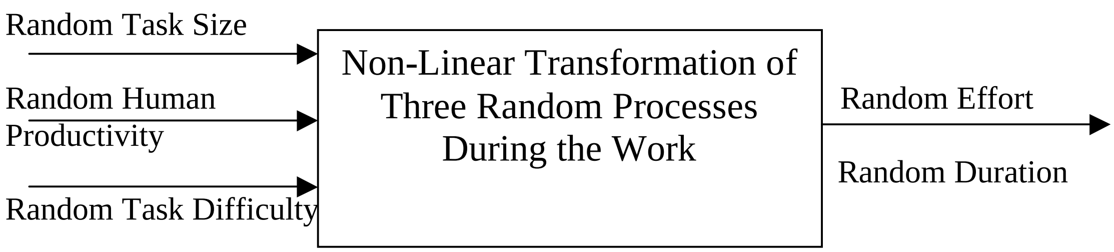

Fig.7. Presentation of work as a random process

In fact the work process converts a random difficulty process into a random timing process of human actions. Likewise the same work process converts another random process of the human productivity. Along with the obvious functional relationship between human productivity and task difficulty, both have independent stochastic components.

Similarly the size of tasks can be a random variable too. So according to expression (4) the duration of the human action must be a random variable too.

In the limit case when the variances of task size, human productivity and task difficulty are small numbers, the work process can be considered as a deterministic one. The line production is a classical example of this kind of work organization with predefined task sizes, human productivities, and work difficulties.

7. Conversion of the difficulty random process into the action's timing random process

Let's analyze how the different difficulties of human actions can be converted into different timings for them.

In Fig.8. is shown an example of the non-linear transformation of the input random difficulty process into the output random process of action's duration. In this combined picture are presented the difficulty process as a random input with an average D_w difficulty, and the relationship between the duration of human action and its difficulty.

This relationship serves as a converter that transforms the random input difficulty into the output random process of an action's duration.

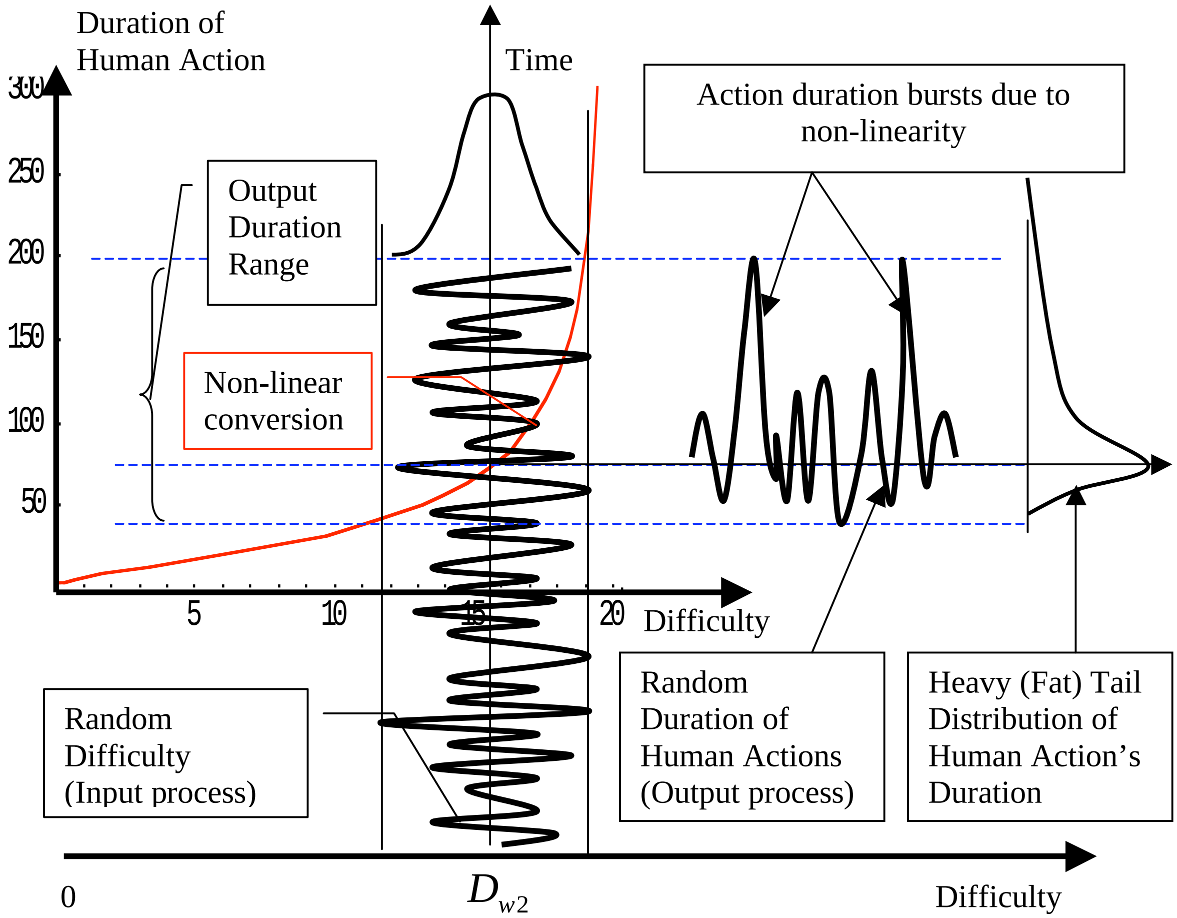

Fig.8. Non-linear transformation of the action's difficulty into the action's timing

This picture shows that an ordinary and symmetric difficulty process can produce timing bursts of human actions due to the nonlinearity of the human performance characteristics.

If an individual works in the linear region of human performance characteristics then the output timing process will be the linear reflection of the input difficulty process (Fig.9.).

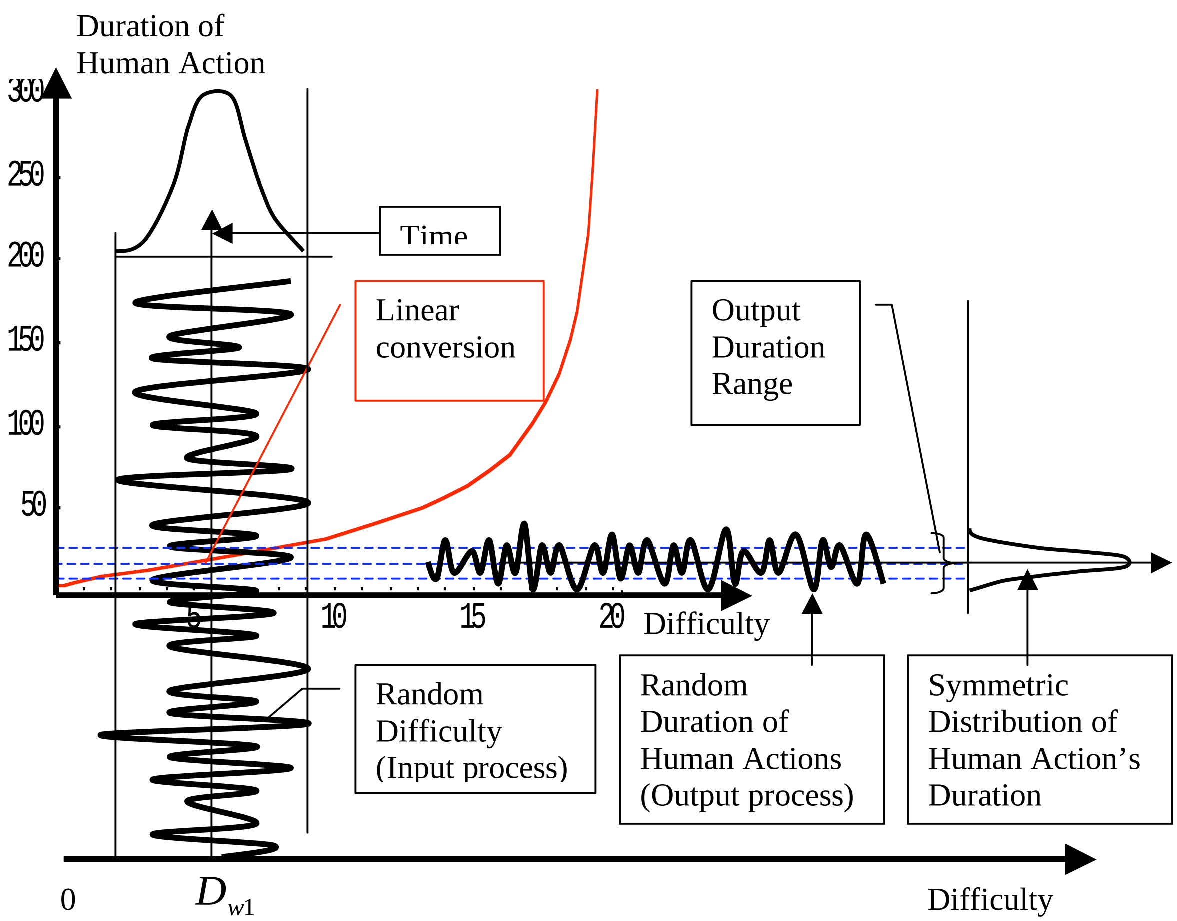

Fig.9. Linear transformation of the action's difficulty into the action's timing

8. Quantitative analysis of the distributions of human action's durations

During the last several years the problem of human action dynamics has been studied experimentally and theoretically [1, 2]. Using web-based statistics about some human activities, these works show that Poisson distribution based estimates of human action dynamics are not adequate in many cases. Instead these works suggest using for quantitative analysis of human actions Power Laws.

The most important problem in quantitative analysis of project schedule risk is the form of the risk function. In fact, a Gaussian approach to this problem encounters many difficulties. Sometimes the risk modeling and simulation show that the Gaussian approach can be used successfully, but in most cases, especially in the realm of advanced project and research work, it fails. In this case Heavy or Fat tail distribution functions are more appropriate. But the notion of Heavy tail distribution is uncertain for this analysis because there are many kinds of these distributions and the problem remains open. Which one of the distributions is appropriate for the given conditions of work? What are the differences between ordinary work and advanced work? Why the Gaussian analysis is not applicable for advanced work? How can the stochastic behavior of human performance and task difficulties influence the final risk function? Is this analysis applicable for all kinds of human activities or this is applicable for project works only? What is the role of tools and design flows for human performance analysis? There are many other questions and unsolved problems here because practically this is a virgin land of research.

Let's analyze and show that there are no standard answers to the above questions. Everything depends on the specific circumstances and work conditions.

Expression (4) indicates that the duration of human actions is a function of task size, task difficulty and human productivity. Each one of them can have a predefined deterministic behavior or stochastic behavior. Simpler works tend to have more predefined character. But it doesn't mean that simple works will always have a Gaussian risk function. Everything can be changed if the worker is lazy. This laziness can produce an asymmetric risk function. Similarly a wrong work breakdown can be a cause for non-Gaussian risk function. So the form of the risk function is not a dogma and depends on many circumstances.

Let's illustrate the new approach to the problem by analyzing some specific cases that are common in project management. In general each one of the three input parameters can have a deterministic behavior or stochastic behavior. In its turn the stochastic behavior can be characterized by distributions with finite or infinite standard deviations. The real situations of work are the combinations of the above possibilities. For instance an individual can have a stable constant productivity and deal with task portions of constant size and difficulty. This is deterministic work and many people do this kind of job. There are many other combinations of input parameters and their different behaviors.

Besides there are many ordinary situations in the process of work that lead to unexpected delays. Let's analyze one of them.

Assume we are doing some work in the linear range of difficulty. Besides we deal with task portions of constant size but with random difficulty, with a normal density function. The third variable is the productivity of human actions which can have a constant value or can be a random variable with some distribution function. For simplicity, let us assume a normal density function for productivity too.

In the first case when we have: constant size, constant productivity and a random difficulty with a normal density function, we will have a normal distribution for the action's duration and a normal risk function without extraordinary delays.

The situation could be dramatically changed if the developer's productivity is not stable and has some distribution.

From the expression (4) we can see that in this case we deal with the ratio of two random variables D and P.

$$T = S\frac{D}{P} \qquad (4)$$

Having the density functions for D and P we can analytically derive the distribution function for their ratio meaning the action's duration T (S = constant). Probability theory says that the ratio of two normal distributions has a Cauchy distribution which is a Heavy tail distribution. This example indicates that even in ordinary project situations, delays are quite possible.

Conclusions

1. Schedule Risk analysis is in crisis because the old Gaussian approach is not adequate, especially for advanced projects.
2. A new risk analysis paradigm that is based on the usage of Heavy (Fat) tail distributions needs to be studied comprehensively.
3. The problem here is that there are many Heavy tail distributions and there are no selection criteria for choosing one of them which is appropriate for the solution of a specific risk problem.
4. One of the ways to do that is to derive analytically the form of the risk function instead of hypothesizing it.
5. For that there is a need to go into details of feasibility and failure mechanisms of single human actions.
6. It can be done by the investigation of timing characteristics of the single human actions.
7. The duration of a single human action is a non-linear function of task size, task difficulty and human productivity.
8. In addition each one of these parameters can have a random behavior and their combination can produce Heavy tail risk functions.

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