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LINEARISED SYSTEMIC ROLES OF PARTICIPANTS IN COMPLEX ORGANIZATIONS

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Abstract

In construction management as well as in real estate development an appropriate stakeholder analysis is essential to determine the roles a particular participant plays within the complex system of a project. This is, since though a major part of the projects' organization is available for being constructed sensibly, stakeholders typically reside outside the reach of being subjected to organizing but have to be taken as they are. So, at least they need to be understood regarding their ability to mirror the systems' behaviour and stability or possibly impact, control and steer the development of the organization. Only then, the respective players can be treated accordingly and efforts to make an organization travel safely toward the expected goal can be expected to be successful. Approaches based on systems theory are well-known, indicating the participants' roles as being active, reactive, buffering or critical to some measurable degree. However, these values suffer from non-linearity and fail to reflect on dominating causal cycles within the organization. This paper proposes some progress on elaborating these values towards more meaningfulness. Linearizing these characteristics offers to remove some criticized faults and helps to introduce the more appropriate parameters leverage, criticality and recursiveness for better reflecting the systems' dependency on the singular players and, hence, allows for their improved handling. Therewith, more stable systems, i.e., organizations are to be expected and, hence, quite more safely approaching the projects' target.

Keywords: Construction Management, Real Estate Management, Systems Theory, Organization, Stakeholder Analysis.

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1. Introduction

According to the definitions of the IPMA and many other references [1, 2, 3, 4], a specific organization is a central characteristic of projects. This is due to the fact that projects refer to unique products, which are determined by the contracts, while the service of getting them produced, which is the organization, is subject to the market of offering participants.

On this background, most of the organization is created and constructed in a way that it meets the needs of coordination and motivation, generally through respective contracts [3]. However, the issue of stakeholder analysis [5, 6, 7, 8, 1] points out, that there are numerous players present in the context of a project, which are not linked via contracts but nevertheless have substantial interest in the proceedings of the projects as well as impact on the forthcoming. Hence, these cannot be integrated in the complex network of organization but though need to be understood and addressed in order to have them contribute to the projects' success. Over the last years, the original idea of a stakeholder analysis has been developed further into higher-order cross-impact analysis [9, 10, 11], revealing at least the systemic role a player takes and therewith allows understanding the possible impact, threats, help, criticality or operability of the stakeholder [12]. The parameters determining the role as critical, buffering, active or reactive, derived on the basis of systems' theory, turn out to be extremely helpful, though are criticized as being partly not very descriptive, in particular non-linear. This paper proposes a slightly different set of more meaningful parameters aiming at the same functionality and meaning, but derived through a simple linear operation.

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2. Higher Order Cross-Impact Analysis

The adjacency matrix *A* of the system [13, 14, 15, 16] is formed by the impacts $a_{i,j}$, a node *j* is having on another node *i*, i.e., the weight of the unidirectional tie from *j* to *i*. Then, according to the original approach [17, 9, 10, 11], the degree to which a node is actively impacting the rest of the system is given by the "Active Sum" (according to [17] here named *activity*), which is formed by cumulating the weight of all outgoing ties. In the same manner, the "Passive Sum" (according to [17] here *reactivity*) is composed by cumulating the weights of all ingoing ties. Hence, the vectors of *activity*, resp. *reactivity* are given by

$$\underline{h}^{(a)} = A^T \cdot \underline{1} \text{ (Activity)} \qquad h_i^{(r)} = A \cdot \underline{1} \text{ (Reactivity)} \tag{1,2}$$

This original approach only refers to the nearest neighbors and is therefore incomplete [18]. Since the weights of a tie can easily be understood as the number of paths with lengths 1 from node *j* to node *i* with weight $a_{i,j}$, the k-th power of A reflects the paths with lengths *k* from node *j* to *i*. The weights within a longer path are therewith multiplied while the elements of A^k contain the cumulated weights of all such paths. Then, the sum of all paths with lengths from 1 to *k* with their individual weight is represented by the elements of the higher-order adjacency matrix

$$A^{(m)} = \sum_{k=1}^{m} A^k \tag{3}$$

The components of $A^{(m)}$ represent, in fact, the total strength of impact a particular node *i* is subjected to or is handing out. The number of iterations *m* actually needs to be chosen infinitely large in order to include all possible paths. However, if the impact is dying down with longer paths (which is required for stability) a limited number of iterations will be sufficient.

Then, higher-order *activity* and *reactivity* are computed from the higher-order adjacency matrix in the same way as with the first order approach (while redefining from here on $A := A^{(m)}$).

$$\underline{h}^{(a)} = A^T \cdot \underline{1} \qquad \underline{h}^{(r)} = A \cdot \underline{1} \tag{4}$$

Furthermore, the cumulated weighted paths leading back to any particular node are held in the diagonal of $A := A^{(m)}$. Hence, the recursiveness of the nodes is determined by

$$\underline{h}^{(s)} = \operatorname{diag} A \tag{5}$$

3. Parameterization of Systemic Roles

Mimicking stakeholder analysis plots, *activity* and *reactivity* are denoted on a graph depicting the roles of the nodes (stakeholders/participants/elements/aspects) as being active, reactive, critical or buffering.

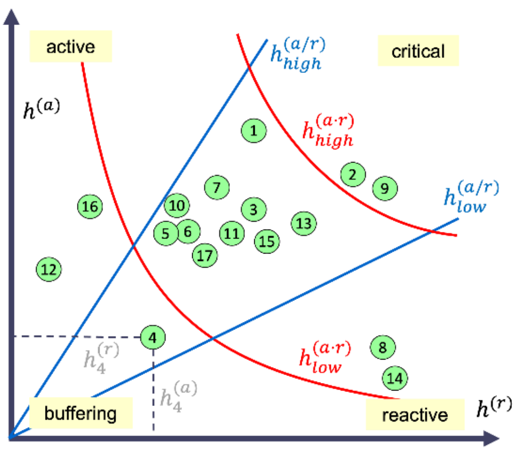

Fig. 1. Plot Roles.

Active nodes would steer the system behaviour while reactive nodes are useful as indicators of the state. Critical nodes are both active as well as reactive and therefore tend to destabilize the system as a consequence of small modifications which again lead to more modifications. Buffering elements are decidedly noncritical and serve as inertia of a system.

According to Vester [17] the parameter $Q_i = AS_i / PS_i = h_i^{(a)} / h_i^{(r)}$ distinguishes between activity and reactivity while the parameter $P_i = AS_i \cdot PS_i = h_i^{(a)} h_i^{(r)}$ serves as a measure of criticality. In particular, Q reflecting the tangent of the angle pointing to the node is criticized as approaching infinite values for highly active nodes. Criticality again does not deal with possibly existing loops within the system.

4. Linearization of Characteristics

The parameters *activity* and *reactivity* turn out to be easily derivable from the cumulated adjacency matrix. However, their quotient and product are strongly non-linear and, hence, can only be obtained by computing the characteristics component-wise. Since they are only of qualitative value and more or less arbitrarily defined, more suitable definitions may be found.

Graphically, normalised *activity* and *reactivity* vectors in the n-dimensional space of node-components point into the most active, respectively most reactive direction. The components indicate the degree to which the respective node contributes to the character of *activity* or *reactivity*. If these two vectors were added, the result (*criticality*) would point into the direction where most critical nodes lie, while the difference of vectors (*leverage*) is expected to represent the tendency to lean on the active side or the reactive side.

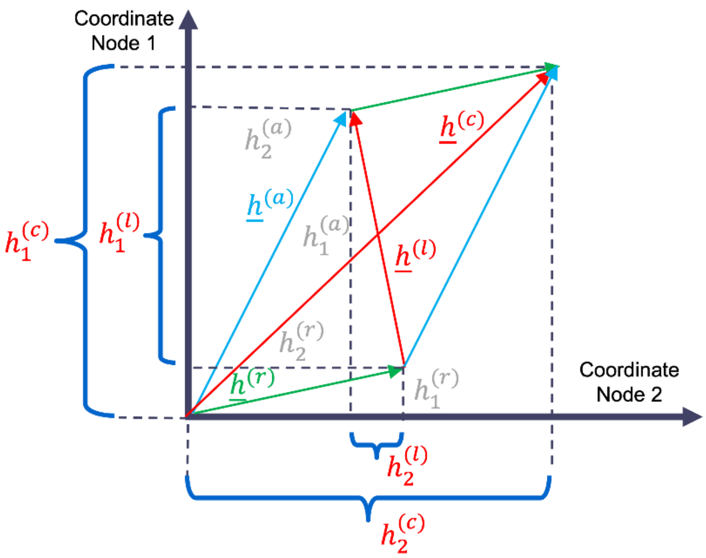

Fig. 2. Space spanned by the nodes with activity and reactivity vectors and linear leverage and criticality vectors.

This understanding is supported by developing the quotient and the product into Taylor series in close proximity of the fix-point $h_i^{(a)} = 1$ and $h_i^{(r)} = 1$. For this consideration the abbreviations $h_i^{(a)} = a$ and $h_i^{(r)} = r$ are used.

4.1. Linearized leverage

The quotient $h_i^{(a/r)}$ is supposed to indicate the degree of activeness versus reactiveness. The formal definition as a quotient $h_i^{(a/r)} = a / r$ bears the mentioned problems of infinity and might helpfully be replaced by the therewith determined angle, additionally turned by -45 degrees to the horizontal axis.

$$h_i^{(a/r)'} = \arctan \frac{a}{r} - \frac{\pi}{4} \tag{6}$$

Developed to the first order around $(a, r) = (1,1)$ we obtain the linear *leverage*:

$$h_i^{(l)} = \left[\arctan \frac{a}{r} \right]_{a=1,r=1} - \frac{\pi}{4} + (a-1) \left[\frac{\partial \arctan(a/r)}{\partial(a/r)} \frac{\partial(a/r)}{\partial a} \right]_{a=1,r=1} + (r-1) \left[\frac{\partial \arctan(a/r)}{\partial(a/r)} \frac{\partial(a/r)}{\partial r} \right]_{a=1,r=1} \quad (7)$$

The first two constant terms are equal with different sign and, hence, cancel for each other:

$$\left[\arctan \frac{a}{r} \right]_{a=1,r=1} = \pi / 4 \quad (8)$$

The $(a-1)$ term at $(a,r)=(1,1)$ is:

$$(a-1) \left[\frac{\partial \arctan(a/r)}{\partial(a/r)} \frac{\partial(a/r)}{\partial a} \right]_{a=1,r=1} = (a-1) \left[\frac{1}{1+(a/r)^2} \frac{1}{r} \right]_{a=1,r=1} = \frac{a-1}{2} \quad (9)$$

Equally, the $(r-1)$ term at $(a,r)=(1,1)$ is:

$$(r-1) \left[\frac{\partial \arctan(a/r)}{\partial(a/r)} \frac{\partial(a/r)}{\partial r} \right]_{a=1,r=1} = (r-1) \left[\frac{1}{1+(a/r)^2} \frac{-a}{r^2} \right]_{a=1,r=1} = -\frac{r-1}{2} \quad (10)$$

In total, we obtain the linear approach for *leverage*

$$h_i^{(l)} = \frac{a-1}{2} - \frac{r-1}{2} = \frac{1}{2}(a-1-r+1) = \frac{1}{2}(a-r) = \frac{1}{2}(h_i^{(a)} - h_i^{(r)}) \quad \underline{h}^{(l)} = \frac{1}{2}(\underline{h}^{(a)} - \underline{h}^{(r)}) \quad (11)$$

4.2. Linearized criticality

The product $h_i^{(a \cdot r)}$ is also arbitrarily given by the area of the rectangle spanned by a and r. In the end, the value is expected to rise with high active and high reactive values which might be roughly given by the sum of the vectors. Instead of just the product $a \cdot r$ we sensibly use the geometrical mean $\sqrt{a \cdot r}$, alternatively, the length of the diagonal $\sqrt{a^2 + r^2}$.

The *geometrical mean approach* runs like this:

$$h_i^{(a \cdot r)'} = \sqrt{a \cdot r} \quad (12)$$

The Taylor development around $(a, r) = (1,1)$ to the first order leads to the linear *criticality*:

$$h_i^{(c)} = \left[\sqrt{a \cdot r} \right]_{a=1,r=1} + (a-1) \left[\frac{\partial \sqrt{a \cdot r}}{\partial(a \cdot r)} \frac{\partial(a \cdot r)}{\partial a} \right]_{a=1,r=1} + (r-1) \left[\frac{\partial \sqrt{a \cdot r}}{\partial(a \cdot r)} \frac{\partial(a \cdot r)}{\partial r} \right]_{a=1,r=1} \quad (13)$$

The first term obviously equals 1, the $(a-1)$ term is

$$(a-1) \left[\frac{1}{2\sqrt{a \cdot r}} \frac{r}{1} \right]_{a=1,r=1} = \frac{a-1}{2} \quad (14)$$

while the $(r-1)$ term is, respectively

$$(r-1) \left[\frac{1}{2\sqrt{a \cdot r}} \frac{a}{1} \right]_{a=1,r=1} = \frac{r-1}{2} \quad (15)$$

In total, we obtain, as expected, a sensible linearized definition of *criticality*

$$h_i^{(c)} = 1 + \frac{a-1}{2} + \frac{r-1}{2} = \frac{1}{2}(2 + a - 1 + r - 1) = \frac{1}{2}(a+r) \quad \underline{h}^{(c)} = \frac{1}{2}(\underline{h}^{(a)} + \underline{h}^{(r)}) \tag{16}$$

The *diagonal approach* develops accordingly:

$$h_i^{(a \cdot r)'} = \sqrt{a^2 + r^2} \tag{17}$$

Again, the Taylor development to the first order around the fix-point $(\mathrm{a}, \mathrm{r}) = (1,1)$ yields

$$h_i^{(c)} = \left[\sqrt{a^2 + r^2} \right]_{a=1,r=1} + (a-1)\left[\frac{\partial \sqrt{a^2 + r^2}}{\partial (a^2 + r^2)} \frac{\partial (a^2 + r^2)}{\partial a} \right]_{a=1,r=1} + (r-1)\left[\frac{\partial \sqrt{a^2 + r^2}}{\partial (a^2 + r^2)} \frac{\partial (a^2 + r^2)}{\partial r} \right]_{a=1,r=1} \tag{18}$$

Then, the constant term is $\sqrt{2}$, while the $(a-1)$ term comes to be

$$(a-1)\left[\frac{1}{2\sqrt{a^2 + r^2}} 2a \right]_{a=1,r=1} = \frac{a-1}{\sqrt{2}} \tag{19}$$

and the $(r-1)$ term is

$$(r-1)\left[\frac{1}{2\sqrt{a^2 + r^2}} 2a \right]_{a=1,r=1} = \frac{r-1}{\sqrt{2}} \tag{20}$$

In total, we obtain the same result, scaled in a slightly different way (which has no meaning):

$$\begin{gathered} h_i^{(c)} = \sqrt{2} + \frac{a-1}{\sqrt{2}} + \frac{r-1}{\sqrt{2}} = \frac{1}{\sqrt{2}}(2 + a - 1 + r - 1) = \frac{1}{\sqrt{2}}(a+r) \\ \underline{h}^{(c)} = \frac{1}{\sqrt{2}}(\underline{h}^{(a)} + \underline{h}^{(r)}) \end{gathered} \tag{21}$$

On this background, we redefine the essential characteristics of nodes from the symmetric and the antisymmetric parts of the adjacency matrix (of order m) as follows:

$$\underline{h}^{(a)} = A^T \cdot \underline{1} \text{ (Activity)} \tag{22}$$

$$\underline{h}^{(r)} = A \cdot \underline{1} \text{ (Reactivity)} \tag{23}$$

$$\underline{h}^{(s)} = \operatorname{diag} A \text{ (Recursiveness)} \tag{24}$$

$$\underline{h}^{(l)} = \frac{1}{2}\left(\underline{h}^{(a)} - \underline{h}^{(r)}\right) = \frac{A^T - A}{2} \cdot \underline{1} \text{ (Leverage)} \tag{25}$$

$$\underline{h}^{(c)} = \frac{1}{2}\left(\underline{h}^{(a)} + \underline{h}^{(r)}\right) = \frac{A^T + A}{2} \cdot \underline{1} \text{ (Criticality)} \tag{26}$$

Obviously, these parameters offer themselves for a much easier approach to analyse the characteristic roles of the nodes:

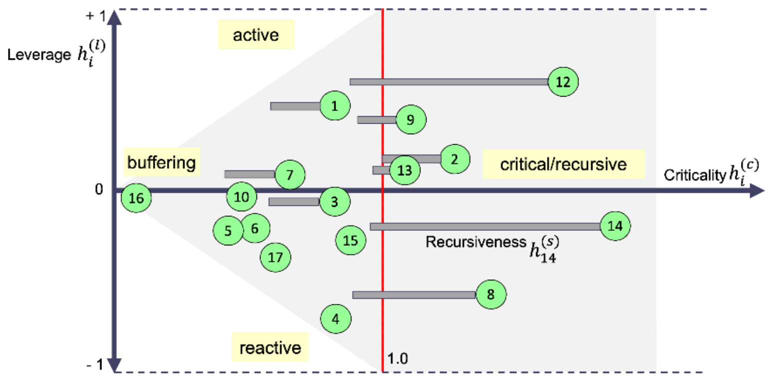

Fig. 3. Roles based on linearized *criticality* and *leverage*.

Due to the linear character of the parameters (based on unscaled linear impact values), the interpretation requires normalisation which extends equally into all dimensions. *Criticality* offers itself best for normalisation since the lower end is well-defined as zero while the most critical situation may be set to 1. However, this needs sensibly to be limited to loop-less structures. Loops are capable to increase *criticality* to unlimited heights. Since the diagonal $\underline{h}^{(s)}$ is an additive part of $\underline{h}^{(a)}$ and $\underline{h}^{(r)}$ thus shows up as a term in *criticality*, but not in *leverage*, maximum *criticality* reduced by *recursiveness* is normalised $(\underline{h}^{(c)} - \underline{h}^{(s)})_{(max)} =: 1$. Then, maximum *activity* as well as *reactivity* come to be 1 as well.

For a sensible and interpretable graph, *criticality* is plotted on the abscissa running in $[0..1]$ without *recursiveness* and further to higher values including *recursiveness*. *Leverage* is indicated on the ordinate in the range $[-1...1]$. Nodes are limited to the grey area of the graph. The particular *recursiveness* of a node as a share of its *criticality* is plotted as an additional bar at the position of each node pointing to the left. Since the graph is based directly on the characteristic parameters, limits to the domains are not sensibly indicated.

5. Representation of Fundamental Structures

Clearly, any such analysis of systems is mainly intended for the part of the organization, which cannot be constructed in an appropriate way but needs to be takes as it is. The constructable part should *per se* follow sensible rules and, therefore, lead to well-understood structures. Though, a proper cross-impact analysis might reveal and point out respective weak spots which have been overseen up to then or deliberately disregarded.

An abstract interpretation of the cross-impact analysis then allows detecting sensible criteria of manageable structures.

5.1. General interpretation

First of all, *recursiveness* indicates the degree and strength of loops. With orders rising from linear to higher values, very small loops which were implemented for reasons of control can be identified and removed from the system by merging the controlled node and the controlling node into one independent node. Then, further and higher-order loops obviously indicate feed-back problems, weighted with their strength. Such are strictly to be avoided, at least if they are of significant strength. With the given analysis a quantitative measure is available and allows judging these situations.

The absence of loops indicates sensible structures, i.e., graph-theoretical tree-structures and precedence networks. These are purely causal structures, where the reason for a value is only given by predecessors and all successors are following to some degree. Then, *activity* and *reactivity* are taken from the position where a node is sitting within the causal chains. More *active* nodes are found at the beginning while more *reactive* nodes are positioned further down the causal sequences. *Critical* nodes (since not due to loops) are in the middle of causal chains. They have a lot of information to follow and at the same time are causing modifications to numerous successors. Hence, the further up a node sits, the higher the positive *leverage* in the chain, the further down, the more negative *leverage* is expected.

On this background some fundamental causal networks can be elaborated:

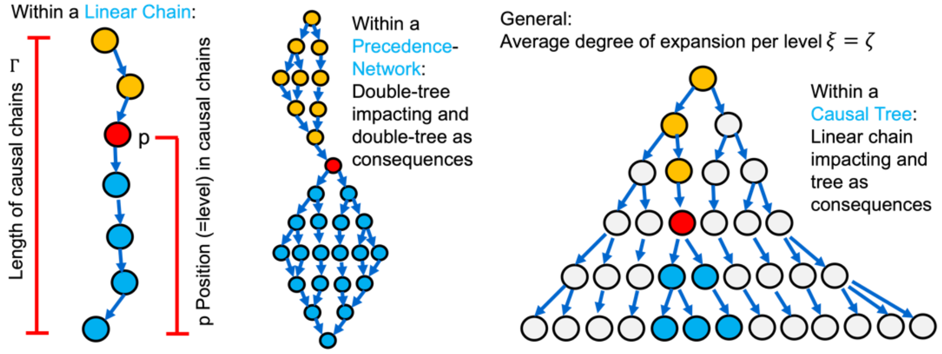

Fig. 4. Fundamental causal structures.

5.2. Linear causal chains

Let all nodes sit on a singular causal chain with length Γ. Each node at position $p=[1..\Gamma]$ where $p=\Gamma$ is the top reason of the chain and $p=0$ the bottom consequence computes $\underline{h}_p^{(a)}=p$ and $\underline{h}_p^{(r)}=\Gamma-p$. Therewith we obtain:

$$\underline{h}_p^{(c)}=(p+\Gamma-p)/2=\Gamma/2=const \quad (27)$$

$$\underline{h}_p^{(l)}=(p-\Gamma+p)/2=p-\Gamma/2=[-\Gamma/2...\Gamma/2] \quad (28)$$

indicating roles of constant *criticality* and linear *leverage*. Hence, these roles show up in a vertical line from the top of the scale to the bottom. In particular, no critical nodes are standing out. Normalised, the longest causal chain occupies the $\underline{h}^{(c)}=1$ line, shorter chains make smaller copies to the less critical side.

5.3. Causal double tree

Within graph-theoretical precedence networks, given by a single starting node, a single ending node and just loop-less structures in between, causal substructures would be double trees expanding and then reducing themselves from the top to the node and the same from the node to the bottom. Let there be a structure of causal length Γ, where at the top of activity a single node extends its impact causally to a next level of ξ nodes which again are impacting ξ nodes and so on for the first half of Γ. For the second half of Γ this is reversed, and the impact of the higher layers is brought together by $\zeta=\xi$ until all consequences are collected by the singular resulting node. Again, let p be the considered level of the graph, $p=\Gamma$ as the top and $p=0$ the bottom. Then, the number of impacted nodes of a position p is all the underlying nodes which can be accessed by ξ via the respective sub-net, the impacting nodes taken from the respective subnet above p, i.e., $\Gamma-p$ Hence, we have using geometrical series:

$$\begin{aligned}\underline{h}_p^{(a)}&=2\cdot(1+\xi+\xi^2+...\xi^{p/2})=\frac{1-\xi^{p/2+1}}{1-\xi}\\ \underline{h}_p^{(r)}&=2\cdot(1+\xi+\xi^2+...\xi^{\Gamma/2-p/2})=\frac{1-\xi^{\Gamma/2-p/2+1}}{1-\xi}\end{aligned} \quad (29)$$

5.4. Causal tree

The classical causal tree makes use of the parameters $\xi=\zeta$ and Γ as before, though maintaining a single causal path to the root of the tree for each node. Then, all nodes above p sum up to a single chain of length $\underline{h}_p^{(a)}=\Gamma-p$, while the reactive nodes below are formed by the sub-tree:

$$\underline{h}_p^{(r)}=(1+\xi+\xi^2+...\xi^p)=(1-\xi^{p+1})/(1-\xi) \quad (30)$$

These strictly causal structures are limited to a criticality of 1 and occupy the roles as indicated in the graph

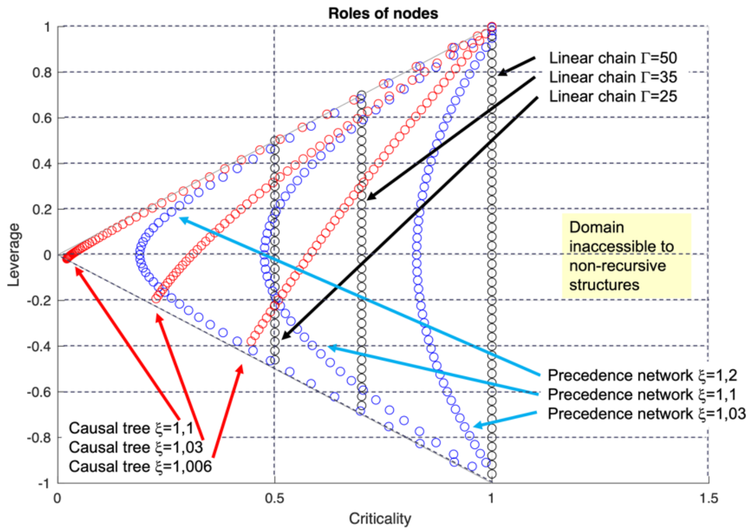

Fig. 5. Distribution of roles for independent causal structures.

6. Conclusion

Creating an appropriate and functioning organization is the major part of management. Though, besides numerous contracts to be designed and agreed on, quite many players are forming the circumstances of the project where their behaviour and impact is just a given. Hence, a substantial part of the task of managing is understanding the circumstances before attempting to shape the environment. Within a complex system, each element is capable of taking up more or less crucial roles, where activity and reactivity are the most visible characteristics, steering the system and indicating its course. Nevertheless, the newly derived parameters of criticality and leverage separated from recursiveness in total seem to improve and simplify the description of this part of the system. Their knowledge is expected to allow for creating sensible cooperation patterns which may help to bring the external stakeholders in as well as the internals based on contracts.

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