Coordination Mechanisms in Multi Objective Setups: Results of an Agent-Based Simulation

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Abstract. This paper analyses how coordination modes and of multi objective decision making approaches interfere with performance and speed of performance improvement in hierarchical organizations. The investigation is based on an agent-based simulation. In particular, we employ a model based on the idea of NK-fitness landscapes, where we map multi objective decision making as adaptive walk on multiple performance landscapes. In our model, each landscape represents one objective. We find that the effect of coordination mode on performance and speed of performance improvement is critically shaped by the choice of multi objective decision making approach. In certain setups, the more complex approaches of multi objective decision making turn out to be less sensitive to the choice of coordination mode.

Keywords: Coordination Mechanism, Hierarchical Organizations, Multi Objective Decision Making, Simulation, NK-Model

1 Introduction and Research Question

During the last decades, changing environments have brought organization to revise their management approaches. In fact, today the major challenges are increased complexity and the need to consider multiple potentially conflicting objectives in decision making simultaneously, instead of focusing solely on one performance measure. For these developments, there are several lines of explanation. First, rapid technological change and growing globalization increase complexity and turbulence and lead to intensified competition [9]. Second, the consideration of different stakeholder interests in decision making has become critical to organizational success [7]. Third, the call for sustainability claims to balance economic, ecologic and social objectives [5, 33]. The literature on organizational theory recognizes goal conflicts that stem from divergent interests and preferences between organizational members [6], but widely ignores conflicts due to multiple competing objectives. Such goal conflicts stemming from organizations pursuing multiple objectives is what we particularly focus in this research paper. Developing innovative ideas and products as well as being very cost efficient at the same time might be an example for conflicting objectives. Hierarchies typically help in assuring cost efficiency via the improvement of (production) activities with respect to speed and quality. Being innovative, in contrast, often requires more space for creative and (sometimes) unconventional employees. However, space for creativity is not necessarily in line with the idea of hierarchies. Another illustrative example might be that maximizing the corporations' shareholder value as well as considering ecologic interests at the same time are potentially conflicting. However, such objectives are not conflicting in every case. Think, e.g., of BP and the oil platform 'Deep Horizon'. The ecologic consequences of this catastrophe were tremendous. At the same time, the catastrophe had an negative impact on BP's equity price (which, after the catastrophe, dropped drastically).

It is in the tradition of organizational science to develop efficient organizational structures, where particular focus is often put on how to design incentives and individual performance measures so that the corporate performance is maximized, given conflicting objectives (on the individual level, like, e.g., diverging time horizons between the decentral managers and the corporation as a whole) [10, 8, 25]. We hook up with this tradition. In particular, we focus on conflicting objectives not on the individual level but focus on conflicts between multiple organizational objectives and their consequences for the design of efficient organizational structures. This captures situations in which multiple corporate objectives are broken down to the individual level via multiple performance measures. Such multiple (and potentially conflicting) corporate goals evoke a higher need of coordination. Particular focus, here, is to align the involved individuals' varying behavior in a way which aligns their decisions to the overall strategy in the best possible way. What, however, makes coordination much more complex is that increasing complexity leads to more interdependencies among decisions. In order to illustrate such interdependencies think, e.g., of scarce (financial) resources: investments by one department decrease the available resources for the other departments. Investment into production capacity could, e.g., reduce the available financial resources for building up sophisticated distribution channels. Even though both aspects (capacity and sophisticated distribution channels) might be essential for a corporate objective, which, e.g., might be to fulfill the market's demand and, thereby, maximizing revenues. If multiple objectives are added on top of this complexity, coordination becomes even much more complex. However, in order to assure the efficiency of organizations, coordination is necessary across both objectives and individual decisions. Organizations can face this challenge with changes in their organizational design. In particular, the choices of coordination mode and method of multi objective decision making are promising regulating variables in order to increase the efficiency of the organizational structure.

The performance of multi objective decision making methods is widely investigated for the individual level, but rarely researched for the context of hierarchical organizations and different intensities of interdependencies among decisions. In addition, it is rarely investigated how suitable specific coordination modes are for certain setups of multi objective decision making approach and decision interdependence across objectives. We take account of this research gap and provide new insights into the suitability of a set of multi objective decision making policies and coordination mechanisms for multi objective setups. In order to do so, we utilize a variant of the NK-model [12, 13]. In particular, we map multi objective decision making as adaptive walk on multiple performance landscapes with each landscape representing one objective.[1]

With respect to multi objective decision making policies, we investigate the relatively simple, but widely utilized, methods of assigning (i) equal weights to each objective, and (ii) satisficing approaches (i.e., fixing aspiration levels). However, assigning equal weights, at least to some extent, can be interpreted as not taking particular care of the conflicting objectives and equally promoting their achievement without stating any preferences. With respect to the coordination mode, we investigate the extreme cases of (a) centralized decision making (with decentralized units proposing strategies for the future, where the central unit composes an overall strategy out of the proposals), and (b) autonomous decentral decision making (where corporate departments autonomously decide and operate their favored strategy). Please notice, we do not intend to develop very sophisticated methods of multi objective decision making or coordination mechanisms that promise a high performance. We do rather want to test the performance of deploying the set of investigated methods and mechanisms to particular setups. In particular, we aim at answering how the choice of coordination mechanisms and the choice of multi objective decision making policy interfere with each other (with respect to organizational performance). By doing so, we particularly address the following issues

– **How sensitive is the achieved performance to the choice of coordination mechanism given particular multi objective decision making policies?** In particular, in Sec. 3.1 we will investigate efficiency of the investigated coordination modes in the case of equally weighted objectives. We will show that in the case of equally weighted objectives, it does not make a significant difference whether departments can make their decisions autonomously or the central unit is in charge of making the final decision. In Sec. 3.2, we will focus on satisficing approaches and show that decentral coordination only brings very slight increases in performance. However, we will reveal that it is superior to fix aspiration levels for the less complex objective (with respect to interdependencies among decisions).
– **Which multi objective decision making policy appears to be appropriate with respect to the degree of interdependence among decisions?** In Sec. 3.3, we will evaluate across multi objective decision mak-

[1] In order to investigate the research question, we apply a simulation approach. In particular, simulation appears to be a powerful research method that allows mapping hierarchical organizations, different modes of coordination, interacting agents and different methods of multi objective decision making. Due to potential complexity and unpredictability of repeated simple patterns, formal modeling would lead to intractable dimensions [2]. Controlling the multitude of issues and disentangling effects of variables under research from other effects would find the boundaries of empirical research [29]. Simulation, on the contrary, appears to be a powerful method to face the complexity of the outlined research problem (cf. also [15, 17]).

ing policies and show that for equally complex objectives, equal weighting (or not caring particularly which objective to follow) leads to organizations being better off. For different complex objectives to be pursued concurrently, aspiration level approaches appear to be superior to weighting approaches. However, the efficiency of satisficing approaches critically hinges on the complexity of the objective the aspiration level is fixed for.

Organizations usually benefit from the actions and decisions taken by their (human) members. Here, both the organizational structure as well as the informal communication and interaction among agents play an important role with respect to the organization's success. It has already been recognized that enhancing multi agent systems with concepts stemming from organizational theory allows for investigating coordination and communication mechanisms as well as the structure of interactions (among agents and decisions) [19, 12, 18]. However, one central question is how to translate organizational structures and the structure of interactions into models of multi agent organizations. Typically, the global behavior (or the overall organizational objective) is captured by the organizational structure (e.g., in terms of coordination mechanisms or information flows) whereas the autonomous agents make their decisions in a local and autonomous process [31, 4]. By employing variants of the NK-model [12], different coordination mechanisms have been intensely investigated by Siggelkow and Rivkin [28]. In another line of research, they [23] also utilized the idea of the NK-model and focused on investigating interdependencies among different organizational design elements, like, e.g., hierarchies, information flows, incentive systems. In [24], the particular focus is put on patterns of interactions among decisions. Ethiraj and Levinthal [6] were among the first to investigate organizations pursuing multiple objectives, but, however, did not take into account organizational structures. We hook up with this tradition and design a model of a multi agent organization considering multiple objectives and hierarchical structures and, as, amongst others, it is in the core of this line of research [31], investigate the impact of organizational design elements (embodied in the organizational structure) on the corporations performance.[2]

2 Simulation Model

We employ a simulation model based on the NK-model, which was originally introduced by Kauffman et al. [12, 13, 35]. We decided for the NK-model because it has explicitly been designed in order to investigate interactions among its components. Based on the basic NK-model [12, 13, 35] and relevant extensions by Ethiraj and Levinthal [6], we map multi objective decision making as adaptive walk on multiple performance landscapes (cf. also [14, 16]). In our model, each decision affects performance on multiple performance landscapes, where each landscape represents one objective.

[2] A more extensive review of models of agent organizations, autonomous agents in organizations, and approaches to build agent organizations can be found at [31, 19, 3, 4].

In order to set up an appropriate computational model, three main features have to be elaborated more precisely: (1) the design of hierarchical organizations, (2) the representation of the performance landscapes, and (3) the mapped methods of multi objective decision making.

2.1 The Hierarchical Design

We map organizations as systems of interdependent choices [21], i.e. we conceptualize agents to search along a multi-dimensional decision space for optimal configurations rather than making decisions in a single-dimensional setup [22]. For each objective, the decision problems, which our organizations face, are represented by the respective performance landscapes. The number of decisions and the architecture of performance landscapes are constant along the observation period.

Our organizations face a ten-dimensional decision problem, where each decision can be solved in two ways, i.e. in each period $t \in \{1, ..., T\}$ agents make decisions $n^{i,t} \in N$ with $n^{i,t} \in \{0, 1\}$ and $i \in \{1, ..., |N|\}$. Due to the binarity of single decision-making alternatives, there exist $2^{|N|}$ different configurations for the overall decision problem, which are expressed by the vectors $C = \left(n^{i=1}, ..., n^{i=|N|}\right)$. The configuration of decisions for period t is denoted by $C^t = \left(n^{i=1,t}, ..., n^{i=|N|,t}\right)$. The starting configuration $C^{t=0}$ is chosen randomly.

Decisions $n^{i,t}$ affect performance of all objectives $g \in G$. In each period t and for each objective g, the decisions $n^{i,t}$ make a contribution $p_g^{i,t}$ to overall performance P_g^t. Due to interdependencies among decisions, performance contribution $p_g^{i,t}$ may additionally to decision $n^{i,t}$ be affected by K_g^i other decisions, which are denoted by $n_k^{j,t}$ where $i, j \in \{1, ..., |N|\}$, $k \in \left\{1, ..., K_g^i\right\}$ and $i \neq j$. Considering interdependencies, for each period t and each performance contribution $p_g^{i,t}$ the function f_g^i randomly draws a value from uniform distribution $U[0, 1]$, i.e.

$$p_g^{i,t} = f_g^i\left(n^{i,t}; n_{k=1}^{j,t}, ..., n_{k=K_g^i}^{j,t}\right) \tag{1}$$

where $i, j \in \{1, ..., |N|\}$, $i \neq j$ and $0 \leq p_g^{i,t} \leq 1$. Whenever any of the coupled decisions changes, the value for $p_g^{i,t}$ is redrawn. We map all $p_g^{i,t}$ to contribute to performance per objective equally. Hence, performance P_g^t results in the normalized sum of performance contributions $p_g^{i,t}$, i.e.

$$P_g^t = \frac{1}{|N|} \sum_{i=1}^{|N|} p_g^{i,t} \tag{2}$$

Our hierarchical organizations consist of decentralized units $d \in D$ and one central unit h. With respect to prior research (e.g. [6]), the mapping of hierarchical structures appears to be a novelty. We map organizations to consist of three decentral units where two units are in scope of three decisions and one unit is in scope of four decisions (cf. also Fig. 1, the solid lines represent our corporation's decentral structure). For each d, we denote the set of decisions within the area of responsibility as N^{own_d}, while the other units' decisions are given by N^{res_d}.

We map decentral decision makers as agents that seek to enhance their individual utility via incremental changes (for respective utility functions cf. Sec. 2.3). Efforts for stepwise improvement go along with literature on organizational learning [1] and prior modeling efforts (e.g. [24]), while the agents' selfishness is consistent with the economic literature [11]. Due to bounded rationality [26], agents do not envision all possible alternative configurations of departmental decisions N^{own_d}. They randomly discover two alternative configurations that differ in one respectively two decisions from the status quo (cf. also [32, 14, 16]).

Along with the status quo, decentral units d evaluate three alternative configurations of decisions. Each department is eligible to propose two alternative configurations of N^{own_d} for the next period. Departments d rank two of the alternative configurations under evaluation, in respect of which alternative is perceived to provide the highest improvement in individual utility. Depending on the limitation of proposals, one alternative (i.e., that configuration of decisions that promises the least performance) is discarded and, hence, not considered in the order of preference. The ranking for departmental decisions N^{own_d} is denoted by vectors $V_r^{own_d,t}$ with $r = \{1, 2\}$ indexing the assigned rank.

We analyze the effects of design options on overall performance. The computational model considers alternative choices in the mode of coordination of decisions and in the incentive scheme as options of organizational design. One further design-determinant considered in our research, is the structuring of the decentral units with respect to (cross-unit) interdependencies among decisions (cf. Sec. 2.2)

The mode of coordination of decisions determines, with respect to our hierarchical conceptualization of organizations, how the overall configuration of decisions for the following period $t + 1$ is selected. Hence, the mode of coordination is one of the major design options [36]. In our model we consider two different coordination modes: (1) fully decentralized coordination, and (2) a central mode of coordination. In case of *full decentralization*, decentral units decide and act autonomously in their areas of responsibility N^{own_d} [20]. The overall configuration of decisions C^{t+1} for period $t + 1$ results as concatenation of the top-ranked alternative configurations $V_1^{own_d,t}$. In case of the *central mode of coordination*, decentral units send proposals $V_i^{own_d,t}$ to the central unit where all proposals are evaluated with regard to overall performance (cf. Eq. 5). The central unit evaluates concatenations of all proposals $V_i^{own_d,t}$ and residual decisions according to the status quo $D^{res_d,t}$ and selects that proposal that promises the highest performance.

One further crucial design factor is the incentive scheme. The incentive scheme is reflected the subunits' utility functions (cf. Sec. 2.3) and, hence, affects the outcome of ranking of alternatives directly. We consider a linear incentive scheme where for every period t decentralized units d are rewarded on the basis of performance P_g^t of each objective g. In particular, incentives depend on performance of intra-unit decisions $N_g^{own_d,t}$ and residual decisions $N_g^{res_d,t}$ with different weights denoted as $w_g^{own_d}$ and $w_g^{res_d}$, respectively. For the current investigation we analyze incentive schemes that put more weight on intra-unit than on residual performance, what may cause a divergence of interest between the decentral d and the central units h. We set $w_g^{own_d} = 1$ and $w_g^{res_d} = 0.5$.

2.2 Representation of the Performance Landscapes

Complexity in hierarchical organizations critically depends on interdependencies among decisions [27]. In particular, complexity is a function of the choice of design options and the organizational environment. On the one hand, interdependencies among decisions are dictated by the decision problem itself [28]. On the other hand, organizations can face this given complexity by considering interdependencies among decisions in the structure of their decentralized units. Building units or assigning decision rights with respect to interdependencies among decisions might affect performance crucially.

According to Sec. 2.1, we describe interdependencies among decisions by parameter K_g^i. Increasing interdependencies K_g^i lead to performance landscapes to be more rugged [12]. With respect to the mapped search strategies (incremental improvement), a lower level of interdependencies leads to more starting configurations of decision $C^{t=0}$ to be in basin of attraction of the global maximum while increasing interdependencies K_g^i lead to a larger number local maxima [34], i.e., configurations of decisions where performance can not be further improved. Once an organization reaches such a trap, the status quo of configuration of decisions is likely to be constant for the remaining observation periods [6].

We follow the basic NK-framework [12, 13, 35] and use interdependence matrices in order to represent functional dependencies among decisions. Due to $|N|$-dimensionality of the decision problem, matrices M are of size $|N| * |N|$. The set of decisions N is assigned to the vertical axis while the horizontal axis represents payoff functions f_g^i (cf. Fig. 1). In our mapping, performance contribution p_g^i is functionally dependend on decision n^i in all cases. Additionally, a 'x' in cell m_{ij} with $i, j \in \{1, ..., |N|\}$ and $i \neq j$ shows that decision n^i additionally to performance contribution p_g^i affects performance contribution p_g^j. Consequentially, empty cells m_{ij} indicate that there is no functional dependency among decision n^i and performance contribution p_g^j.

We limit our research to three exemplary natures of interactions. In case of level of interdependencies *low* the decisions within a subunit are fully interdependent but there is no cross-unit interdependence. Hence, decisions N^{own_d} do not affect residual performance. For each decentralized unit d, K-values are constant along intra-unit decisions, i.e. $K_g^i = |N^{own_d}| - 1$ (cf. Fig. 1, panel 'low'). This pattern of interactions is comparable to the modular setup of organizations as investigated by Rivkin and Siggelkow [24]. With reference to small world networks, level of interdependencies *medium* are characterized by a high level of clustering [30]. Interdependencies among decisions are mainly clustered along the main diagonale of the matrix M, $K_g^i = 4$ along all decisions. This pattern of interactions results in intra-unit decisions N^{own_d} being partly interdependent but they are also partly interacting with other units' decisions. Unit-performance is reciprocally dependent on other units' decisions but intra-unit decisions also affect residual performance (cf. Fig. 1, panel 'medium'). We also map a (3) *high* level of interdependencies where all decisions are fully interdependent, i.e. $K_g^i = 9$ (cf. Fig. 1, panel 'high').

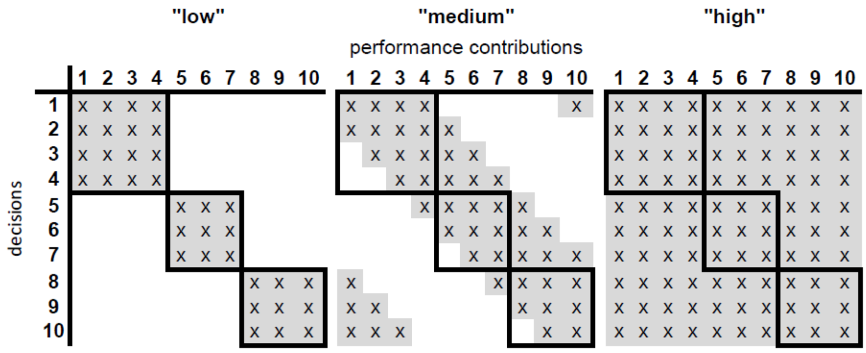

Fig. 1. Interdependence matrices

2.3 Methods of Multi Objective Decision Making

In our research we map different methods of multi objective decision making. On the one hand, we analyze effectivity of (1) a decision making policy where each objective is equally weighted. On the other hand, we map a (2) satisficing approach where for certain objectives aspiration levels are stated.

In the case of (1) *equal weighting*, decision makers do not have to explicitly articulate preferences for single objectives, they rather decide for all objectives to be pursued with the same importance. Consequently, with respect to multiple objectives and the linear incentive scheme (as stated in Sec. 2.1) in case of equal weighting, the decentralized units' utility function results in

$$U_d^t = \sum_{g=1}^{|G|} \left(w_g^{own_d} \frac{\sum_{i \in N^{own_d}} p_g^{i,t}}{|N^{own_d}|} + w_g^{res_d} \frac{\sum_{i \in N^{res_d}} p_g^{i,t}}{|N^{res_d}|} \right) . \qquad (3)$$

In order to operationalize the (2) *satisficing approach*, we introduce aspiration levels $s_g \in [0, 1]$ that are constant for the whole observation period. The function $f^g(s_g) = g$ defines the objective g the aspiration level s_g is applicable for. Decision makers seek to, at least, satisfy the aspiration levels before they consider the remaining objectives in the evaluation of alternatives (cf. Sec. 2.1). The period in which the aspiration level is achieved or exceeded is denoted by

t^{s_g}. In case of aspiration level approaches, for periods $t \leq t^{s_g}$ our agents solely pursue one objective, i.e. objective $f^g(s_g) = g$. Once performance $P^t_{f^g(s_g)}$ of that objective g the aspiration level is applicable for exceeds the stated level, no alternative configuration of decisions that lead to $P^t_{f^g(s_g)}$ falling below the aspiration level will be realized. Similar to method (1), for periods $t > t^{s_g}$ organizations assign equal importance to all objectives. The corresponding utility functions results in

$$U^t_d = \begin{cases} w^{own_d}_{f^g(s_g)} \frac{\sum_{i \in N^{own_d}} p^{i,t}_{f^g(s_g)}}{|N^{own_d}|} + w^{res_d}_{f^g(s_g)} \frac{\sum_{i \in N^{res_d}} p^{i,t}_{f^g(s_g)}}{|N^{res_d}|} & \text{for } t \leq t^{s_g} \\ \sum_{g=1}^{|G|} \left(w^{own_d}_g \frac{\sum_{i \in N^{own_d}} p^{i,t}_g}{|N^{own_d}|} + w^{res_d}_g \frac{\sum_{i \in N^{res_d}} p^{i,t}_g}{|N^{res_d}|} \right) & \text{for } t > t^{s_g} \ . \end{cases} \tag{4}$$

While decentralized units aim at maximizing their own utility functions (cf. Eqs. 3 and 4), the central unit seeks to maximize overall performance. With respect to the mapped methods of multi objective decision making, the central unit's utility functions result in

$$U^t_h = \begin{cases} \frac{1}{|G|} \sum_{g=1}^{|G|} P^t_g & \text{if equal weighting} \\ P^t_{f^g(s_g)} & \text{if satisficing approach, for } t \leq t^{s_g} \\ \frac{1}{|G|} \sum_{g=1}^{|G|} P^t_g & \text{if satisficing approach, for } t > t^{s_g} \ . \end{cases} \tag{5}$$

In the case of equal weighting and satisficing approaches (for periods $t > t^{s_g}$), the central unit aims at maximizing overall performance while considering all objectives simultaneously. If aspiration levels are applied, for periods $t \leq t^{s_g}$ also the central unit solely takes into account the objective the aspiration level is applicable for (cf. Eq. 5).

3 Results

In our simulation study each organization is in charge of taking ten decisions and pursuing two objectives simultaneously. Performance is observed for 100 periods. Thus, we set $|N| = 10$, $|G| = 2$ and $T = 100$. The hierarchical setup of the computational model corresponds to Sec. 2.1. All results are based on 450 landscapes per objective, each with 20 adaptive walks. The results for each combination of different levels of interdependencies are based on $9,000$ simulation runs. We report two performance measures. On the one hand, we report achieved performances after 100 periods $P^{t=100}_g$ as a snapshot of final performance (cf. Eq. 2). On the other hand, we report the average performance per objective g over the observation period T and all $9,000$ simulation runs as measure for performance over time P^{avg}_g, i.e.

$$P^{avg}_g = \frac{1}{9.000 \cdot T} \sum_{j=1}^{9.000} \sum_{t=1}^{T} P^{t,j}_g \tag{6}$$

with j indexing the simulation runs. P_g^{avg} can also be regarded as a condensed measure of the speed of performance improvement over all 100 periods [28]. Furthermore, the measures for overall performance are given by the averaged performance contributions of all objectives, i.e., $P_{all}^{t=100} = 1/|G| \sum_{g=1}^{|G|} P_g^{t=100}$ and $P_{all}^{avg} = 1/|G| \sum_{g=1}^{|G|} P_g^{avg}$.

We investigate effect of the choice of coordination mode on performance and effectivity of multi objective decision making methods in two steps. First, we analyze effects of design options on performance separately for each multi objective decision making method. This is to answer the question how sensitive performance in certain multi objective decision making approaches is to the choice of coordination mode. In a second step, we analyze performance across multi objective decision making methods. That allows for answering the question which decision making mode appears to be appropriate in given setups of interdependencies among decisions. Furthermore, implications on hierarchical design in case of a given decision making method can be derived from the presented results.

Table 1. Equal weighting.

interdependencies	final performances			average performances		
obj 1 / obj 2	$P_1^{t=100}$	$P_2^{t=100}$	$P_{all}^{t=100}$	P_1^{avg}	P_2^{avg}	P_{all}^{avg}
Panel A: coordination mode: central						
low/low	0.8984	0.8994	0.8989	0.8941	0.8949	0.8945
low/medium	0.8777	0.8737	0.8757	0.8734	0.8694	0.8714
medium/medium	0.8515	0.8475	0.8495	0.8479	0.8437	0.8458
low/high	0.8515	0.8508	0.8512	0.8478	0.8474	0.8476
medium/high	0.8215	0.8334	0.8274	0.8186	0.8303	0.8245
high/high	0.8089	0.8084	0.8087	0.8070	0.8063	0.8066
Panel B: coordination mode: decentral						
low/low	0.8987	0.8975	0.8981	0.8957	0.8945	0.8951
low/medium	0.9004	0.8705	0.8855	0.8967	0.8638	0.8803
medium/medium	0.8599	0.8596	0.8598	0.8530	0.8525	0.8527
low/high	0.8961	0.8415	0.8688	0.8909	0.8310	0.8609
medium/high	0.8457	0.8323	0.8390	0.8369	0.8198	0.8284
high/high	0.8121	0.8153	0.8137	0.7989	0.8023	0.8006

Incentivisation: $w_g^{own_d} = 1$ and $w_g^{res_d} = 0.5$. Results are based on 450 landscapes each with 20 adaptive walks. obj = objective, confidence intervals vary from 0.002 to 0.005 on the 99.9% level.

3.1 The Choice of Coordination Mode in Case of Equal Weighting

We find that in case of equal weighting in the central as well as in the decentral coordination mode increasing complexity leads to decreasing final and average overall performance. Not surprisingly, pursuing objectives with the same levels of interdependencies lead to the same levels of final and average overall performances (cf. Tab. 1).

For the choice of coordination mode, final performances indicate that in most cases the decentral coordination mode is superior to the central mode. This is also partly reflected in the average performances. In particular in case *low/medium*, the decentral coordination mode leads to a significantly higher speed of performance improvement while in the extreme cases (i.e. *low/low* and *high/high*) no sensitivity can be observed. So, in the majority of cases the decentral coordination mode leads to higher level of final overall performances although the concrete incentive scheme (cf. Sec. 2.1) causes a divergence of interest between central h and decentral units d,

On the single objective level, results suggest that with decentral coordination in mainly all combinations of objectives with different levels of complexity final and average performances increase for that objective with the less complex interactions and decrease for the other objective. Due to higher performances on the overall level in the decentral mode of coordination, the increasing effect appears to be higher than the decreasing effect.

Table 2. Satisficing approach, aspiration level for objective one: $s_1 = 0.8$.

interdependencies obj 1 / obj 2	final performances $P_1^{t=100}$	$P_2^{t=100}$	$P_{all}^{t=100}$	average performances P_1^{avg}	P_2^{avg}	P_{all}^{avg}
Panel A: coordination mode: central						
low/low	0.9090	0.8818	0.8954	0.9030	0.8700	0.8865
low/medium	0.9065	0.8503	0.8784	0.9005	0.8393	0.8699
medium/medium	0.8857	0.7849	0.8353	0.8794	0.7762	0.8278
low/high	0.8996	0.8293	0.8645	0.8938	0.8201	0.8570
medium/high	0.8784	0.7850	0.8317	0.8729	0.7768	0.8248
high/high	0.8568	0.7117	0.7842	0.8526	0.7073	0.7799
Panel B: coordination mode: decentral						
low/low	0.9122	0.8783	0.8952	0.9104	0.8715	0.8910
low/medium	0.9166	0.8505	0.8836	0.9146	0.8422	0.8784
medium/medium	0.8907	0.7983	0.8445	0.8851	0.7889	0.8370
low/high	0.9130	0.8259	0.8695	0.9110	0.8166	0.8638
medium/high	0.8871	0.7888	0.8379	0.8817	0.7795	0.8306
high/high	0.8573	0.7134	0.7853	0.8482	0.7074	0.7778

Incentivisation: $w_g^{own_d} = 1$ and $w_g^{res_d} = 0.5$. Results are based on 450 landscapes each with 20 adaptive walks. obj = objective, confidence intervals vary from 0.002 to 0.003 on the 99.9% level.

3.2 The Choice of Coordination Mode in Case of Satisficinig Approaches

Similar to the case of equal weighting, in case of satisficing approaches both performances decrease with increasing complexity of interdependencies among decisions. As expected, when our organizations pursue two objectives with the same complexity of interdependencies among decisions, final and average performances achieve the same level in the single objective as well as in the overall performance perspective and for both, the central and the decentral coordination mode. In cases of objectives with the same complexity of interdependencies, the choice of which objective the aspiration is applicable for does not affect performance measures. (cf. Tabs. 2 and 3).

In most cases, for final and average overall performances, at best, marginal increases with decentral coordination can be observed. However, in most scenarios performance does not appear to be significantly sensitive to coordination mode.

Conventional wisdom suggests to fix aspiration levels for that goal that is perceived to be more difficult to accomplish. Applying aspiration levels to the objective with the more complex interactions appears to be beneficial with respect to performance. Counterintuitively, for setups with different levels of complexity, we find that fixing aspiration levels for the less complex objective leads to significantly superior final overall performance and speed of performance improvement in the central as well as for the decentral coordination mode.

Table 3. Satisficing approach, aspiration level for objective two: $s_2 = 0.8$.

interdependencies obj 1 / obj 2	final performances $P_1^{t=100}$	$P_2^{t=100}$	$P_{all}^{t=100}$	average performances P_1^{avg}	P_2^{avg}	P_{all}^{avg}
Panel A: coordination mode: central						
low/low	0.8814	0.9076	0.8945	0.8967	0.9016	0.8856
low/medium	0.8197	0.8945	0.8571	0.8098	0.8877	0.8488
medium/medium	0.7918	0.8876	0.8397	0.7826	0.8815	0.8321
low/high	0.7338	0.8616	0.7977	0.7296	0.8569	0.7932
medium/high	0.7146	0.8606	0.7876	0.7103	0.8561	0.7832
high/high	0.7080	0.8568	0.7824	0.7037	0.8525	0.7781
Panel B: coordination mode: decentral						
low/low	0.8803	0.9089	0.8946	0.8734	0.9073	0.8903
low/medium	0.8324	0.8917	0.8620	0.8226	0.8860	0.8543
medium/medium	0.7980	0.8901	0.8441	0.7885	0.8848	0.8366
low/high	0.7389	0.8609	0.7999	0.7328	0.8517	0.7922
medium/high	0.7144	0.8588	0.7866	0.7084	0.8495	0.7789
high/high	0.7132	0.8587	0.7859	0.7070	0.8495	0.7783

Incentivisation: $w_g^{own_d} = 1$ and $w_g^{res_d} = 0.5$. Results are based on 450 landscapes each with 20 adaptive walks. obj = objective, confidence intervals vary from 0.001 to 0.004 on the 99.9% level.

3.3 Evaluation Across Multi Objective Decision Making Methods

After having outlined sensitivity of performance measures on organizational design elements separately for each policy of multi objective decision making, the following section analyses differences in performances between decision making approaches.

For scenarios with two objectives that show the same level of interdependencies among decisions, we find that the method of equal weighting appears to be superior with respect to final overall performance and average overall performance, in the central as well as in the decentral coordination mode. The difference between performances in case of equal weighting and performances in case of aspiration level approaches is the higher, the higher the level of interdependencies is. For both measures, final performance and speed of performance improvement, the difference reaches a slightly higher level in case of the decentral mode of coordination.

In setups with two objectives of different complexity, in most cases performance does not appear to be sensitive to the choice of multi objective decision making approach as long as the aspiration level is fixed for that objective with the less complex interactions. As a consequence of the results presented in Sec. 3.2, applying the aspiration level to that objective with the more complex interactions leads to a higher difference between performances. Hence, determining the objective the aspiration level is applicable for, affects overall performance crucially - besides the choices of coordination mode and multi objective decision making policy.

4 Implications and Conclusion

Our results indicate that final and average performances and speed of performance improvement subtly depend on the choice of design elements of hierarchical organizations. We find that building the decentral structure with respect to cross-unit interdependencies among decisions affects performance crucially. Increasing the level of overall complexity in general leads to a decreasing performance and a decreasing speed of performance improvement. Furthermore, advanced knowledge of the effects of the choices of coordination mode and multi objective decision making policy appears to be a critical factor of success for the design of hierarchical organizations.

In case of *equal weighting*, decentral coordination leads to significantly higher performances than central coordination as long as cross-unit decision interdependencies are not too complex. With respect to performance, for the design of hierarchical organizations this implies that the choice decentral coordination is superior to central coordination.

For the case of *satisficing approaches*, performance is de facto non-sensitive to the choice of coordination mode. Counterintuitively, our results suggest that fixing aspiration levels for that objective with the less complex cross-unit interdependencies affects performance and speed of performance improvement positively. For the building of a decentral structure and the assignment of decision rights to decentralized units this could mean that interactions of that objective the aspiration level is fixed for should be particularly considered.

The *evaluation across methods of multi objective decision making* indicates that equal weighting is superior in cases where all objectives are of the same level of interdependencies. In cases of objectives with different levels of cross-unit interdependencies, the favorable choice of multi objective decision making policy critically depends on the level of complexity of that objective the aspiration level is fixed for.

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