Synergies of the Economic Development of the Arctic Cluster System

E A Afonichkina[1], A I Afonichkin[2]

[1]Peter the Great St. Petersburg Polytechnic University, St.Petersburg, Russia
[2]Samara National Research University, Russia

ekaterinaafonichkina@gmail.com

Abstract. The paper discusses the problem of modelling the development policy of the Arctic Cluster of the Russian Federation. This economic development task takes into account the complex conditions and necessary requirements for the coordinated growth of all participants in the Arctic Cluster in the form of complex, spatially sectorial economic systems, including international. An important condition for such a policy is the possibility of generating synergy in the development process, from joint participation in the implementation of the development programme, especially in the face of significant constraints and balanced requirements. Failure to meet the conditions for the formation of synergy generates development risks. A network model of the Arctic Cluster is proposed, whose formula, describing the generalised strategy of system-wide development, is presented in the paper. Definitions of the formation of synergy of stage-by-stage development are also given. A formula combining the results of the development of the synergy effect at each stage to show cumulative systematic synergy is presented.

1. Introduction

One of the important strategic zones, which contains potentially broad opportunities for economic development, but also has very significant systematic risks, is the Arctic management zone. The effective use of the Arctic zone has long been a topic of consideration; however, the conditions and requirements for operating, managing and developing this segment are very high and require careful economic analysis. The attractiveness of this zone is that it disposes significant volumes of valuable natural resources and a high potential for the economic development of circumpolar countries. However, the level of risks is so great that full development of this zone is impossible without joint strategic activities of the countries concerned. In particular, the following Arctic segments are of economic interest: the waters of the Arctic ocean, the continental (land) territory of the zone and the continental shelf of the Arctic Territory. It is here that reserves of oil and gas, coal, gold and other valuable metals are concentrated. Opportunities for the formation of efficient transport and transit systems along the Northern Sea Route are also a topic of great current interest [1,2].

Despite the fact that almost all of the circumpolar countries of the Arctic zone have Arctic development strategies, their effectiveness depends both on the volume of investments as well as on a number of special conditions. The development of the Arctic zone is limited by the following factors [1,3,4]:

- Extreme climate, presenting particular management challenges;
- Weak resilience of the Arctic ecology to external and anthropogenic influences;
- Underdevelopment of transport and logistics as well as production and service networks;
- Spatial disunity of regions;
- Current lack of Arctic-specific life support technologies;
- Economic and legal inconsistency of participating countries.

Overcoming unfavourable conditions is only possible with the concerted interaction of the parties concerned in the implementation of Arctic projects. This requires both political will and a balancing of economic interests in the development of the global Arctic zone. In particular, the industrial development of the Arctic is written into Russia’s long-term development strategy [1,2]. Its effective development requires consideration of a number of specific spatial and sectorial factors, the formation of interconnected international industry and interindustry corporations, complementary industries and expansion of foreign economic activity, at least in this zone. However, the solution of such problems is connected to existing difficulties of the scientific and technical, economic, socio-environmental as well as international and legal aspects of the development of the Arctic zone.

The system of interactions of inter-branch economic systems within the spatial cluster of the Arctic leads to the formation of a specific Arctic spatial-sectorial economic system, in which not only interindustry systems, but also international alliances are involved. Typically, vast undeveloped spaces have considerable synergetic development potential; in this case, however, this would require cooperative adaptation of the entire Arctic infrastructure. All this necessitates the further expansion and deepening of research on problems in the development of economic activity in the Arctic zone for the effective management of changes in this economic space, taking into account the interests of all participating countries.

2. Network Model of the Arctic Cluster

The possible formation of a single Arctic economic zone in the form of a structured international cluster system can use the priorities of economic systems integrated into the spatial (Arctic) strategic economic zone in its development taking into account the interests of the participating circumpolar countries. Such systems allow the rational and purposeful management of processes of structural formation and development of the Arctic Cluster economy, its spatial organisation and the coordination of growth with the goals of sectoral development strategies, contributing to the creation and development of large territorial and sectorial economic complexes that serve as drivers for the economic growth of the Arctic Territories.

The affiliation of such systems to different international jurisdictions, while pursuing common development interests, has the potential to yield an effective result having the essential component of synergy. The international integration of the Arctic zone as a strategic economic zone for international and inter-industry corporations provides integration incentives leading to the formation of an economic system whose primary structure comprises a cluster network. Such a cluster network (*CN*) comprises an international entrepreneurship system within which economic entities having coinciding economic interests can enter into coordinated economic and managerial interactions on a contractual basis. Undoubtedly, in this case, it is necessary to clearly define the areas of responsibility, interests and goals of management, development resources, principles for coordinating the interests of cluster network participants in order to increase competitiveness and maximise synergies [5,6]. However, in such complex systems, which have strong economic convergence, a “backward wave” effect may appear, leading to a stronger and uneven concentration and zoning of the economic space, increasing not the synergy and development risks. Therefore, the policy of economic development of such cluster networks should be balanced and take into account the possibility of spatial and economic differentiation and risk alongside the pursuit of the multiplicative effect.

In many respects, development policy depends on the model of the system itself: for objects such as the economic cluster, the basic policy will be somewhat simplified, failing to reflect the complexity and effectiveness of cluster network agent interactions and the conditions for their implementation in the Arctic zone in international and inter-industry interactions. On the one hand, such integration of spatial and sectorial economic systems provides significant opportunities in supporting development processes due to synergies of integration, mutual influence of resources and opportunities, strengthening of investment attractiveness, growth of competitive advantages, etc. On the other hand, such integration generates a significant number of systemic risks associated with the generalisation of the management policy and the formation of a unified development strategy that takes into account the interests of all participants in this spatially sectorial economic system. The conditions for the formation of the synergistic effect of cluster development can be described as necessary and sufficient conditions for balancing and cohering activities of participants in the economic relations of the cluster network, as well as individual technological chains of the entire economic system of the Arctic zone.

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In accordance with the typologisation of clusters, let us supplement and structure the cluster network model with the following elements:

- Interacting elements of technological chains (*TC*) and, as per cluster network, participants in the technological chain, the total number of which comprises accounts *K*, $U_{TC}=\{u_1,u_2,u_3,\ldots,u_K\}$, $k=1–K$.

- Participant (an active element, a^0) of the cluster network (*CN*), defined as the cluster management centre (of different possible levels of management). Let this comprise index $k = 0$. Such a participant performs control and coordination functions for the remaining elements of a separate segment of the network CN_j and of the entire cluster network as a whole $\{CN\}$.

- Set of operations that require interactions $(\{a_i\}\{R_{CN}\}a_j)$ with other cluster members (a_i), the number of which for the j^{th} participant equals to N_k, $\{R_{Nk}\}$. Moreover, each type of interaction (R_{CN}) is determined by different types of relationships: – technological (R^T), – informational (R^I), organisational and managerial (R^U), – financial (R^F), etc., $\{R_{CN}\}\subseteq\{R^T,R^I,R^U,R^F,\ldots\}$.

The power (intensity, strength level) of interactions can be different and is determined by a function V_σ^R expressing the intensity dependence for specific types of interactions $(a_i \rightarrow a_j)$, or $(a_i)\bigcap_{j=1}^{n} R_j\,(a_j)$.

External organisations (b_i) (interacting with elements of the cluster system) that are not integrated into the cluster network structure, the number of which is equal to T_j, $\{R_{Tj}\}$, determine the types of interactions; the index *j* defines the element $a_j\subseteq\{CN\}$ with which the given external interaction takes place – $j=1,2,\ldots T_j$, $\{b_i\}\bigcap_{j=1}^{n} R_{Tj}\,(a_j)$ or $(\{b_i\}\{R_{Tj}\}a_j)$.

Let us determine that the model of the cluster network $\{CN\}$ is determined by the state of the economic potential, denoted as S_{NK} and referring to the value of the control vector U_{TC}, $\{CN\}$, a^0, $(\{a_i\}\{R_{CN}\}a_j)$, $(\{b_i\}\{R_{Tj}\}a_j)$, $u_k\subseteq U_{TC}$ $u=\{u_k, k=0\ldots.K\}$, $\{u_0,u_1,\ldots u_K\}\subseteq S_{CN}$, where each element $a_j\subseteq\{CN\}$ (within the framework of the *TC*) has its own target control vector z^k and additionally provides the system-wide goals z^O. Thus, the target vector of the element is defined in the form $z_k = z^O + z^k$. We believe that the target vector of the element a_j can be achieved following implementation of a system development strategy aimed at developing both the most active element (*TC* or $\{CN_j\}$) and the system-wide element $\{CN\}$).

We assume that z^k determines the strategy vector for the development of a particular segment of the cluster network $\{CN_j\}$,$\{p_1, p_2,\ldots,p_n\}\subseteq\{CN_j\}$, and z^O is the system-wide development vector $\{p^o{}_1, p^o{}_2,\ldots,p^o{}_k\}$, where the index *k* characterises part of the system-wide directions within the strategy of each element of the cluster network $\{a_j\}\subseteq\{CN_j\}$.

Then the generalised strategy formulated within the strategy of the elements $\{a_1,a_2,\ldots,a_k\}\subseteq\{CN\}$ for achieving system-wide development goals will be: $u = f(z)$, $U=\sum_{k=1}^{K}u_k+u^o$, $z_k = z^O + z^k$, $z^k = f(\{p_1, p_2,\ldots,p_n\})$, $z^O = f(\{p^o{}_1, p^o{}_2,\ldots,p^o{}_k\})$.

With this, we find that a system-wide development is determined by a generalised strategy of the form:

$$U=\sum_{k=1}^{K}z^k+u^o=\sum_{k=1}^{K}\sum_{n=1}^{N}p_{kn}+\bigcap_{k=0}^{K}p_k^o \qquad (1)$$

Thus, expression (1) establishes the priority directions for the development of the cluster network. The economic goal of the cluster network operation is the maximisation of the vector generalised criterion for the effectiveness of the cluster network, *Q*, taking into account the synergy of the system development ΔE

$$Q=\{\{a\},u^k,\{R\},U,p_k,p^o,E^k,\Delta E\} \qquad (2)$$

where the factors of the vector are particular criteria for the efficiency of E^k for each active element, technological chain or set of elements of the cluster network.

Thus, for the governing body of the cluster network (a^0), the problem of effective development is reduced to determining the control vector that maximises criterion (2), taking into account:

- Existing restrictions on resources, investment and the initial development potential of each element $\{a_1,a_2,...,a_k\} \subseteq \{CN\}$;
- The agreed development strategy, i.e. portfolio of cluster network development;
- Coordination of interests and results of activity between the participants in accordance with the rules of balance of interests.

3. Synergetic Effect of the Development Process

The overall economic effect represents the total result of the economic activity of the whole system, taking into account the result of each individual participant. The efficiency of each participant's activity (E_{sj}) entering the *CN* can be represented in the form $E_{sj} = (P/C)$, where *P* – is the economic result in the process of carrying out the changes; *C* – is the cost for carrying out the changes. The resource indicator can also be used in the form of the overall profitability of the participating enterprise. If the economic result is presented as the net profit *(Pr)* of the participant for the period and the costs of the changes are defined as the enterprise's investments for the period under study – that is, its assets *(A)* – then the participant's performance can be estimated by the following formula: $E_{Sj} = (Pr / A)_j$.

Conversely, the system synergy is defined as $E_S = \{E_{S1}, E_{S2}, \dots E_{Sn}, \Delta E_S\}$, where ΔE_S is the synergistic effect generated by the *CN* in the course of its development. Taking into account the distribution of the *CN* result among the participants in accordance with some rule *ρ*, we obtain $E^S = E_s + \Delta E_s = \prod_{j=1}^{n} (\rho_j * \frac{\Pr_j}{A_j}) + \Delta E_s$, where *n* – number of participating companies, *j = 1 – n*.

The synergistic effect – ΔE_S, can be manifested in the corporate development process for *CN* with a large number of structural elements of the system, with individual functions and tasks being implemented jointly. Synergy can be generated by each *CN* participant operating in *CN* value chains in the form of the additive function ΔE^E_S (synergy from mutual participation), $\Delta E^E_S = (\Delta^E E_{S1} + \Delta^E E_{S2} + \dots + \Delta^E E_{Sn}) = \sum_{i=1}^{n} \Delta^E E_{Si}$. In this case, synergy complements the level of efficiency of the development process through a variation of synergy factors along the development directions under certain conditions and constraints. Denoting ΔE_S as an incremental vector of the additional effect (synergy) in the directions of development, due to systematisation, coordination, economy, balance of resources and development potential in all directions of cluster network development, we obtain: $\Delta E_S = \sum_{k=1}^{m} \sum_{j=1}^{n} \Delta^k E_{Sj}$, where *k* – type of generated synergy, *k = 1…m* , *j* – corporate network member *(CN)*, *j – 1…n* .

Direct implementation of the coordination of such interactions, taking into account the level of synergy and implementation costs, is performed by the cluster management centre (a^0), which has the appropriate rights and powers.

To model the synergy factors in the sustainable development management process, let us outline the structural features of the cluster system as follows:

- Unity of the system goal;
- Joint activities of participants;
- System of interactions of participants in the cluster network;
- Consistency of interests of participants;
- Autonomy of the activities of individual participants;
- Collective and mutual responsibility for the results of joint activities;
- Specialisation and complementarity of functions and operations in value chains and networks;
- Stability of the structure of *CN*;

- Presence of synergy of the development of the *CN*.

In this connection, it is possible to outline the following range of tasks for the effective development of a cluster network with many conditions and limitations:
- Formation of a system of *agents* (*the composition of the CN participants*), distributed in the sectorial and spatial aspects of the economic system;
- Modelling the behaviour of economic agents of the spatial-sectorial economic system (cluster system);
- Modelling of coordinated interactions of *CN* agents.

The description of the dynamics of collective behaviour in the cluster network establishes the level of development dynamic synergy, where the behaviour of each of the network agents (cluster members) at the time t_0 is determined by its own state S^0 in the life cycle stage space, as well as by the states of other participants in the corporate network $\{S^1,S^2,\ldots,S^N\}$ at the preceding time (t_{0-j}) $\{S^0,S^1,S^2,\ldots,S^N\}/t_{(0+j)}$ and the interactions between them. These factors make it possible to distinguish the following components of the synergy of the cluster development process:
- Synergy of the coordinated interaction ($\Delta Э^S$) (sectorial elements ($\Delta Э_O$), spatial (ΔE_P), spatial-sectorial ($\Delta E_{P\text{-}O}$), provided that $\Delta E^S = \Delta E_O \bigcup \Delta E_P \bigcup \Delta E_{P-O}$;
- Synergy of adequate distribution of system results by participants (ΔE^{SR});
- Synergy of the phased coordinated development (by the stages of the life cycle) (ΔE^{LCS});
- Synergy of system development (multiplication for all previous components) (ΔE^{CN}), as a function: $\Delta E^{CN} = \Delta E^S \bigcup \Delta S^{SR} \bigcup \Delta E^{LCS}$.

From the position of control theory, the model (CN) can be described by the following parameters: A^j_K – the set of agents (j = 1 – sectorial, j =2 – spatial, j =3 – sectorial-spatial participants, j = 0 – cluster network control centre); index K – specifies the number of agents of the corresponding type, from which the cluster network is constructed $A^j_K = \{(a^1_1,a^1_2,\ldots a^1_n),(a^2_1,a^2_2,\ldots,a^2_d),\ldots,(a^0)\}$.When forming the CN structure, the participating agents form a $\{R_{ij}\}$ a system of interactions to solve operational problems and development problems, generating the E^S -function of the efficiency of the CN, $Ef(N) = F(\{P\},A^j_K,\{R_{ij}\})$. The system of relationships {R} can be defined in the general case by a matrix of interactions, which can also be asymmetric. $\{R_{ij}\} = R(T_{ij},X_{ij},V_{ij})$, $R_{ij} = f(a_i,a_j,\ldots,a_z)$, where: T – the matrix of typologies of interrelations between the elements of the network $(a_i,a_j,\ldots,a_z)$; X – the matrix of directions, resources (potential) of interactions and target parameters of interaction between network elements $(a_i,a_j,\ldots,a_z)$, determining the link function of the network vertex a_i, with vertex a_j; V – matrix on the levels of interaction strength for the participants in the cluster network. Thus, the vector of interactions R_{ij} is a set of independent matrix parameters characterising the interrelations and interactions between the members of the cluster network $(a_i,a_j,\ldots,a_z)$, i.e. those that cannot be further subdivided into constituent components. We will assume that these parameters will be conditional-constant for a certain time interval. Taking into account the multiplicity of relationships, multidimensional interactions R^k_{ij} – interconnections of power **k**, such as $R^k_{ij} \subseteq \{R_{ij}\}$ can be realised between the participants (a_i,a_j).

If the increment of efficiency due to synergy is determined through the function of synergy *F*, then E_S can be defined as the efficiency weighted by the effect of the synergistic lever $(1+\Delta)$, $E_S = E + \Delta E = E(1+\Delta) = Ef{*}F$, $F = 1+\Delta$. The set of local synergetic effects for each participant can be divided into synergies of coordination and interaction, synergies of cyclic (stage-by-stage) development, managerial synergies, etc. We will briefly consider some of the different types of development synergy in the next section.

4. Synergy of Coordination and Interaction of Participants

The coherence of interactions in the process of economic development determines the level of balance of interests and input resources of participants in the cluster network. It thus remains a necessary component for generating the maximum corporate development synergy [7,8,9]. Thus, we formulate a number of conditions for assessing the degree of balance and the level of development synergy:

- The leading role of consistency indicators should belong to the financial performance characteristics (profit, revenue, productivity, assets, etc.), which set possible 'growth points' and prospects for development;
- Interactions should describe various areas of activity of the cluster network and the state of participants in the dynamics;
- The level of consistency should be based on the use of a system of temporal and balanced indicators;
- The *SB* should take into account the various components of synergy in the processes, participants and stages of development of the cluster network;
- The synergy effect should provide the maximum system effect.

In this connection, a determination of the criterion of coherence of interests of participants in the cluster network (*CN*) (financial, material, efficient, informational, etc.) and the formation of its maximum value ensures the generation of a marginal synergistic effect. The balance of interests in the process of development management is an important condition for the formation of *CN* participant coherence during the period of growth and development since system efficiency can vary quite significantly as a consequence. In the literature, approaches for an assessment of the degree of balance between corporate interests and areas of activity are described. These tend to primarily feature financial performance indicators (ratings, performance indicators, temporal indicators, etc.) A growth index is used for assessing the current state of corporate governance and determining its level of consistency.

The degree of coherence is assessed through the level of conflict in the management system, for which purpose the index of the intensity of the corporate conflict of interests (including financial) of the *CN* participants:

$$CCI_i = \frac{\sum_{k=1}^{13} d_k w_k}{\sum_{k=1}^{13} w_k},$$

where CCI_i is the index of the intensity of the corporate conflict of the i^{th} participant of cluster interactions, d_k is the variable characterising the presence or absence of the k^{th} attribute, w_k is the weight of the k^{th} attribute.

However, the level of synergetic effect depends not only on the balance of interests, but also on the adequacy and accuracy of the interactions and mutual relations of participants with each other, reflecting the effect of the multicollinearity of the participants themselves, i.e. showing the change in the effectiveness of the participant S_j under the influence of the participant S_i. This can be reflected through the corrective indicator $RE_{Si,Sj}$, which increases or decreases the level of synergetic effect of the participants' interaction. The multiple correction index $RE_{S1,S2,\dots,Sm}$ can be used to assess the degree of interaction of several participants $\{S_1,S_2,\dots,S_{m-1}\}$ with the change in the share of the participant's synergy S_m.

Taking into account the additivity of the components of synergetic effects and possible adjustment thereof in terms of the interaction synergy of participants, let us define a generalised expression that specifies a quasi-separable function: $\Delta E_S = \sum_{k=1}^{m} \sum_{j=1}^{n} \Delta^k E_{Sj} + \sum_{k=1}^{m} \Delta^k E_{Sj} \prod_{i=1}^{n} RE^i{}_{S1,S2,\dots,Sn}$. Each of the corrective indicators RE^i can have both '+' and '-' signs; this depends on the conditions for reconciling interests, resources, growth potential and the level of contribution to the activity and effectiveness of the cluster system.

5. Synergy of Stage-By-Stage (Cyclic) Development

In accordance with the stages of the development life cycle, the synergy of development is determined by group laws, factors and conditions that variously affect the effectiveness of economic systems [10,11,12,13]. Let us formulate some definitions of the formation of synergy in the process of cluster network development.

Synergy of phased development. Analysing the formation process and the factors that generate synergy, we believe that the development synergy manifests itself in different forms with different intensity in different life cycles of the development of the cluster system. These differences establish the patterns, factors, conditions and constraints, as well as the impact of the level of synergy at each stage, and can be used to generate a multiplicative synergistic effect of the overall performance of the cluster system. For example, at the initial stage of development, a synergy can appear in the form of simplified components, e.g. in the form of reducing costs, saving time, etc.

Another stage in the formation of synergy is related to operational costs and investments, in particular, there can be distinguished: economies of scale, diversification of resources, growth directions, price elasticity of products, etc.

The next stage can be described in terms of 'qualitative' characteristics of synergetic advantages: mutual use of existing competencies and skills (the experience curve); strengthening of the brand and investment attractiveness; simplified access to strategic market segments, etc.

The accumulating stage can combine the results obtained at each stage and generate an overall synergistic effect. In this case, the cumulative systemic synergy combines the results of the development synergy effect at each stage and can be described by some function of the synergistic effect (for N stages): $F \supseteq \{(x^1{}_1,x^1{}_2,\ldots,x^1{}_n),(x^2{}_1,x^2{}_2,\ldots,x^2{}_k),\ldots,(x^N{}_1,x^N{}_2,\ldots x^N{}_m)\}$, where the parameters of the function F are the factors of synergy for a specific stage of the development cycle of the economic system: $(x^1{}_1,x^1{}_2,\ldots,x^1{}_n)$ – group of factors of synergy of the 1st stage of the life cycle of development of the economic system; $(x^2{}_1,x^2{}_2,\ldots,x^2{}_k)$ – group of factors in the 2nd stage of the life cycle; $(x^N{}_1,x^N{}_2,\ldots x^N{}_m)$ – group of factors in the nth stage of the life cycle.

In addition to taking into account the synergy of the different stages of the economic development life cycle, it is necessary to take into account the mutual influence of value chains (networks) operating within the framework of the economic system. At the same time, the interaction of participants in the value creation network requires the coordination and synchronisation of the management parameters in a unified development strategy, e.g.: management and operational technologies, allocated resources, interests of participants, procedure for harmonising tools and mechanisms of impact (activities, interests, resources, managerial influences).

The strategy for the sustainable development of the cluster network includes not only the active elements of the cluster system network representation that comprise the systemic development effect, but also mechanisms for generating development synergies in all possible directions of growth. The marginal value of the system effect will only appear if the components of development synergy meet the conditions and principles of development, ensuring consistency, balance and stability of strategic changes for managing the development of the cluster network.

6. Other Components of Development Synergy (Management Synergy)

Each basic synergetic component can in turn be structured into meaningful sub-components. Consider, for example, the component of the synergy of control functions ($\Delta^U E_S \subseteq \Delta E_S$), which can be decomposed into the following elements: planning $\Delta^U E_S^P$, forecasting $\Delta^U E_S^{\mathrm{Pr}}$, budgeting $\Delta^U E_S^B$, accounting $\Delta^U E_S^W$, analysis $\Delta^U E_S^A$, control $\Delta^U E_S^C$

$$\Delta^U E_S = \langle \Delta^U E_S^P + \Delta^U E_S^{\mathrm{Pr}} + \Delta^U E_S^B + \Delta^U E_S^W + \Delta^U E_S^A + \Delta^U E_S^C \rangle . \qquad (3)$$

Given that the synergistic effect changes in time, it is necessary to take into account the possible discounting of the synergy parameters using the discounting factors of the internal management processes (r_1) and the external environment (r_2); the synergy of management with discounting can be described by the following expression:

$$\Delta^U E_S^d = \Delta^U E_S \frac{(1+r_1)^n}{(1+r_2)^n} = \frac{(\Delta^U E_S^P + \Delta^U E_S^{\mathrm{Pr}} + \Delta^U E_S^B + \Delta^U E_S^W + \Delta^U E_S^A + \Delta^U E_S^C)\cdot(1+r_1)^n}{(1+r_2)^n} \quad (4).$$

Similarly, it is possible to calculate the contribution to the systemic synergetic effect taking into account the recoil for a certain period of time for each synergetic component.

7. Conclusion

Thus, a systematisation of the factors and components of the synergetic effect in the development of the Arctic Cluster network, in which all circumpolar countries can participate, has been carried out. The conditions, types and types of the generated synergy components and possibilities for their analysis and evaluation have been demonstrated.

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