Management and Production Engineering Review
Volume 15 • Number 2 • June 2024 • pp. 150–159
DOI: 10.24425/mper.2024.151138

Selection of Optimal Technologies for Production of Goods: Space-System Approach

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Received: 21 February 2024
Accepted: 07 April 2024

Abstract
Despite the presence of a huge amount of research on various aspects related to the rationale for selection of optimal technologies, spatial aspects have traditionally remained unattended by scientists. Justification for selection of optimal technologies for the production and transportation of good and justification for selection of optimal location and capacity of the corresponding industries are interrelated tasks of the complex problem of optimizing the spatial and technological development of an economic sector within the relevant space. At first, based on the criterion of the availability of factors of production of the corresponding good, attractive production sites are identified and for each of them selection of place-based optimal production technology is justified. The developed systematic approach involves the stage of identifying locally optimal places and technologies of production and transportation for each sales market option according to the criterion of the minimum total costs of producing a good in the volume of demand of the corresponding sales market option and the costs of transporting this good to potential sales markets that form the evaluated market option sales in the amount of their demand. At the final stage, options for potential systemically optimal places and technologies, which are formed from locally optimal places and technologies, are compared. The option of potential systemically optimal locations and corresponding production and transportation technologies with minimal total costs for production and transportation is the best.

Keywords
Selection of optimal technologies; spatial approach; system approach; place-based optimal technology; locally optimal technology; systemically optimal technology.

Introduction

Any good can be produced using many interchangeable technologies. The ability to choose the optimal technology for producing a goot from them is an important factor in the competitive struggle of entrepreneurs. Of course, the calculation system does not necessarily have to lead to an unambiguous decision regarding the feasibility of a particular technology: the final decision is made taking into account not only the factors and characteristics reflected in formal calculations, but also relying on intuition, knowledge and experience, using analogies, etc. Although the passive use of the results of justification for the choice of the optimal technology for producing a good is unacceptable, the formal justification for the choice of the optimal technology for producing a good is a necessary component of the investment process both from the point of view of protecting the economic interests of the investor and from the point of view of providing information to potential sources of financing the project. Therefore, improving the justification for choosing the optimal technology for producing a good has always been, is and will always be an important scientific and practical task.

Literature review

Publications on the issues of justifying the selection of optimal options for technologies of the production of goods are extremely numerous. The selection of optimal technologies for the production of goods is traditionally made using the "net present value" (NPV) method (Chiesa & Gilardoni, 2005; Chiu & Garza Escalante, 2012; Elmaghraby & Herroelen, 1990; Grubbström, 1998; Magni, 2009; Proctor & Canada, 1992;

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Ross, 1995; Ruttan, 1997) with various modifications and improvements, which relate, first of all, to taking into account when justifying the selection of optimal technologies: the time factor (Costanza & Kubiszewski, 2021; Etgar & Shtub, 1997; Joaquin, 2001; Leyman & Van Driessche, 2019; Sunde & Lichtenberg, 1995; Vanhoucke & Debels, 2007), impact on the environment (Abdelhady, 2021; Dobrowolski & Drozdowski, 2022; Galli, 2018; Gladwin et al., 1995; Knoke et al., 2020) and impact on workers (Atanasoff & Venable, 2017; Bucci et al., 2019; Hope, 2008; Levenstein & Tuminaro, 1992), level of risk (Chapman, 2006; Chrysafis & Papadopoulos, 2021; Gaspars-Wieloch, 2019; Gradl & Youngblood, 2009; Kahneman & Tversky, 1979; Marchioni & Magni, 2018; McSweeney, 2006; Morris & Venkatesh, 2000; Nosratpour & Nazerib, 2012; Wiesemann et al., 2010), specifics of forecasting future indicators that influence the selection of optimal technology (Armstrong et al., 2015; Borucka, 2023; Green & Armstrong, 2015; Nia & Awasthiá 2021; Van Steenbergen & Mes, 2020; Wright & Stern, 2015). But constantly improving the NPV technique is like refining the shape of a car (to improve its aerodynamic properties) with a weak engine that cannot reach the speed at which these perfect aerodynamic properties could manifest themselves. The disadvantage of all NPV methods with various modifications and improvements is the lack of a spatial-system approach to justifying the selection of optimal technologies for the production of goods, since traditionally calculations are carried out in relation to only one place (the place where production is planned to be located), which is not always characterized by favorable production location factors valued good and in relation to only one sales market option.

In addition, calculations are traditionally performed for a given production capacity, which is fundamentally erroneous, since the optimal capacity is obtained in the course of substantiating the optimal location of production and substantiating optimal production technologies. That is, the optimal production capacity, as well as the optimal production technology, depend on the influence of the spatial factor and are thus the result of optimization of the spatial organization of the economy. Actual ignorance of the spatial-system approach when justifying optimal technologies for the production of goods can lead to the adoption of erroneous investment decisions and, as a result, a decrease in the efficiency of investments (at best, partial, at worst, complete).

Results and discussion

Justification of optimal technologies for the production of a good must be carried out simultaneously with justification of optimal placement and production capacity, since it ensures compliance with a systematic approach and thereby guarantees obtaining a high-quality result. This is exactly what we focused on in previous publications (Stadnicki & Terebukh, 2022; Stadnicki & Bashynska, 2023). In this article, we set out to consider the issue through the prism of justification for the selection of optimal technologies for the production and transportation of goods. In Table 1, a comparison is made of the spatial-system approach developed and proposed by us to justify the selection of optimal technologies for the production and transportation of goods with the traditional (generally accepted) approach.

Shown in Table 1, components of the sequence of actions are described in detail in previous publications. In this article we will limit ourselves to a brief description of the most important positions and move on to analyzing the differences between the spatial-system and traditional approaches to the problem of justifying optimal technologies for the production of goods.

Place-based optimal production technologies should be justified for each attractive production location (i.e. a place that is characterized by appropriate properties identified as production location factors) with reference to the sales market option (i.e. a separate potential sales market or a specific set of them) to take into account production capacity, on which unit and total production costs depend. Place-based optimal transportation technologies must also be justified for each attractive production location with reference to the potential sales markets of the corresponding sales market option to take into account the distance, direction and volume of transportation, which affects unit and total transportation costs.

Locally optimal production and transportation technologies must be justified for each sales market option (based on the place-based optimal technologies of this sales market option) according to the criterion of the minimum total costs of producing a good in the volume of demand of the sales market option and the costs of transporting this good from the corresponding attractive place of production to all potential sales markets of the corresponding sales market option in the volume of demand for each of these potential sales markets. A set of locally optimal production technologies, the total capacity of which is equal to system demand, forms options for potential systemically optimal production and transportation technologies. The option of potential system-optimal technologies with minimal production and transportation costs is the best.

As can be seen from Table 1, some positions of the spatial-systemic and traditional approaches are identical ("+", that is, presence in both approaches), some are completely different ("+" in the spatial-systemic

Table 1
Spatial-system (1) and traditional (2) approaches

Component sequence of actions	Approach	
	1	2
1.Decide on the good that we plan to produce;	+	+
2. Outline the space of possible production location;	+	+
3. Outline potential sales markets and assess the demand for each of them;	+	+
4. From potential sales markets, form variants of sales markets and calculate the demand for each of them;	+	–
5. Form a list of technologies for producing the good;	+	+
6. Within the space of possible placement, identify attractive production locations;	+	±
7. For each attractive production location, substantiate place-based optimal production technologies while oriented placement towards the appropriate market options;	+	±
8. Form a list of technologies for transporting good from each attractive place of production to all potential sales markets for the corresponding sales market option;	+	±
9. For each attractive place of production, justify place-based optimal technologies for transporting the good to all potential sales markets for the corresponding sales market option;	+	±
10. For each sales market option, from its many attractive production locations, determine the locally optimal production location and locally optimal technologies for the production and transportation of goods;	+	–
11. From locally optimal production sites, form options for potential systemically optimal production sites with potentially systemically optimal technologies for the production and transportation of goods;	+	–
12. From the options for potential systemically optimal production sites, justify the selection of the best one, that is, the option of systemically optimal sites with systemically optimal technologies for the production and transportation of goods.	+	–

approach and "–" in the traditional approach), some are ambiguous ("+" in the spatial-system approach and "±" in the traditional approach). Ambiguity means that the presence of the corresponding component in the traditional approach is possible, but not guaranteed, since this will be a random result and not a natural one.

Thus, for component of the sequence of actions 6 ("for each sales market option, identify attractive production locations") the ambiguity lies in the fact that the production location chosen with the traditional approach may turn out to be one of the attractive production locations. But this is not natural, since such a production location may not be one of the attractive production locations. Although, even if by chance this place turns out to be an attractive place of production, the situation will not fundamentally change, since other attractive places of production remain outside the analysis in the traditional approach.

For the component of the sequence of actions 7 ("for each attractive production location, justify a place-based optimal production technology"), the ambiguity lies in the fact that the production location chosen in the traditional approach may turn out to be one of the attractive production locations, and the rationale for the optimal production technology for it (for any one sales market option) will be the same under the traditional and spatial-system approaches. Here it should be emphasized once again that with the traditional approach, calculations are limited to only one location (which may turn out to be one of the attractive production locations), and with the spatial-system approach, calculations are performed for all attractive production locations, the number of which can be significant.

For component of the sequence of actions 8 ("form a list of technologies for transporting a good from each attractive production location to all potential sales markets for the corresponding sales market option"), the ambiguity, again, lies in the fact that the production location chosen with the traditional approach may turn out to be one of the attractive ones places of production, and the formation of a list of technologies for transporting good for it will be the same under the traditional and spatial-system approaches. However, in this situation, technologies for transporting goods from other attractive places of production of this sales market option remain without the attention of the traditional approach.

For component sequence of actions 9 ("justify place-based optimal technologies for transporting good from each attractive place of production to all potential markets for the corresponding sales market option"), the ambiguity lies in the fact that the location of production chosen in the traditional approach may turn out to be one of the attractive places of production, and the rationale for the optimal transportation technology for it will be the same for the traditional and spatial-system approaches. However, with the traditional approach, calculations of transportation costs (if they are nevertheless carried out and not ignored due to the uniformity of such costs for different technologies for producing a good in the same place) are limited to only one place (which may turn out to be one of the attractive places of production), and in the spatial-system approach, calculations are performed for all attractive production locations.

With the traditional approach, the costs of transporting a good to sales markets do not affect the selection of the optimal production technology, since they will be the same for the same place where, according to the decision made, production should be carried out, focused on one separate option for the sales market. With a spatial-system approach, the costs of transporting good to sales markets influence the selection of optimal production technology, since they will, as a rule, be different for each attractive production location for the corresponding sales market option. In general, despite the possibility of randomly obtaining individual correct results, the traditional approach to justifying the selection of optimal production technologies and transportation technologies has no chance of achieving the final correct result, which is only possible with a spatial-system approach.

Table 2 provides a description of the process of justifying the selection of optimal technologies for the production and transportation of goods.

The sequence of transition of technologies to a new quality in the process of implementing a spatial-system approach to substantiating optimal technologies for the production and transportation of goods is shown in Fig. 1.

As can be seen from the above, a list of all technologies that can be used to produce the valued good is initially formed. Later, these technologies compete with each other in each attractive production location with reference to a specific sales market option in order to take into account the production capacity equal to the demand of the corresponding sales market option. As a result, for each sales market option in each attractive production location, the place-based optimal technology for producing the good will be selected. That is, the number of optimal technologies in each attractive production location will be equal to the number of market options. Similarly, for each sales market option in each attractive production location, with reference to the potential sales markets of the corresponding sales market option, the selection of place-based optimal technology for transporting the good is justified, the number of which will also be equal to the number of sales market options.

The next step is for each sales market option to justify the selection of a locally optimal production technology and a locally optimal transportation technology (from place-based optimal technologies for attractive production sites for the corresponding sales market option) and at the same time a locally optimal place of production of the good. As a result, from a significant number of place-based optimal technologies for attractive production locations for each sales market option, there remains only one production technology (which becomes locally optimal) and only one transportation technology (which also becomes locally optimal), as well as only one attractive production location (which receives the status of locally optimal).

Later, locally optimal places, together with their locally optimal production technologies and locally optimal transportation technologies, form variants of potential systemically optimal places with corresponding potentially systemically optimal technologies for pro-

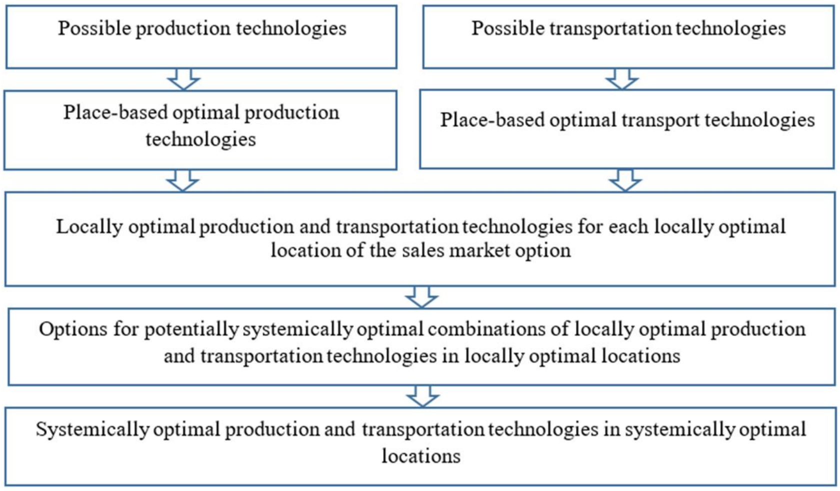

Fig. 1. Stages of selection of the optimal technologies for production and transportation of good

Table 2
Characteristics of the process of justifying the choice of optimal technologies

Technologies	Characteristic
Possible production technologies	Formation of a list of technologies for the production of goods
Place-based optimal production technologies in an attractive production location linked to market options	Justification for the selection of possible production technologies (spot competition of production technologies) taking into account the demand of sales market options, the value of which determines the production capacity
Possible transportation technologies	Formation of a list of transportation technologies
Place-based optimal transportation technologies from each attractive production site of a market option to all potential markets for that market option	Justification for the selection of possible transportation technologies (spot competition of transportation technologies) based on the criterion of minimum system costs for transportation from each attractive production site of a sales market option to all potential sales markets for this sales market option
Locally optimal technologies (production and transportation) for each locally optimal location of the sales market option	Justification for the selection of attractive production sites for the corresponding sales market options based on place-based optimal technologies (local spatial competition of production technologies and transportation technologies) based on the criterion of the minimum total production costs in the volume of demand of the corresponding sales market option and transportation costs from each attractive production location of the sales market option to all potential sales markets for this sales market option in the volume of their demand
Options for potentially systemically optimal combinations of locally optimal technologies (production and transportation) in locally optimal places	Options for combinations of locally optimal technologies of locally optimal places, the total production capacity of which is equal to system demand
Systemically optimal technologies (production and transportation) in systemically optimal locations	Justification for choosing from options for potentially systemically optimal combinations of locally optimal technologies in locally optimal places (systemic spatial competition of production technologies and transportation technologies) according to the criterion of minimum system costs for production and transportation

ducing and transporting the good. At the final stage, the best option for potential systemically optimal places becomes an option for systemically optimal places with corresponding systemically optimal technologies for the production and transportation of goods.

An example of a spatial-systemic approach

We demonstrate the application of the proposed spatial-system approach using a conditional example. Assume that there are three potential sales markets (M1, M2 and M3) with demand, respectively, 0.3; 0.6 and 3.0 million units. The demand of potential sales markets, as well as sales market options formed on their basis, are given in Table 3.

The conventional example also shows the geographical coordinates (X-horizontal coordinate, Y-vertical coordinate, in kilometers) of potential sales markets (Tab. 3) and attractive production sites (Tab. 4), which was the basis for calculating distances and transportation costs.

Potential unit production costs (UPC) for the optimal technology (the process of selecting the optimal production technology for each attractive production location is not considered in the example) in ten attractive production locations (A) are given in Table 4.

These costs depend on the production capacity Q and are calculated by adding an indicator calculated using the formula (1/Q) to the base value of unit production costs. For example, for a production capacity of 0.3 million units for an attractive production location A1, the potential unit costs will be 18.4 $(15.1 + (1/0.3) = 15.1 + 3.3 = 18.4)$, and for a production capacity of 3.9 the potential unit cost will be 15.35 $(15.1 + (1/3.9) = 15.1 + 0.25 = 15.35)$. In turn, for an attractive production location A10 for a production capacity of 0.3 million units potential

Table 3
Demand of potential markets and market options

Market options		Potential sales markets and their demand, million units			Demand of sales market options, million units
		$M_1/0.3$	$M_2/0.6$	$M_3/3.0$	
1		+	–	–	0.3
2		–	+	–	0.6
3		–	–	+	3.0
4		+	+	–	0.9
5		+	–	+	3.3
6		-	+	+	3.6
7		+	+	+	3.9
Coordinates, km	X	180	380	270	
	Y	11	150	250	

Table 4
Potential unit cost of production

A	Coordinates, km		UPC basic, units	UPC for production capacity Q, units						
	X	Y		$Q = 0.3$	$Q = 0.6$	$Q = 3.0$	$Q = 0.9$	$Q = 3.3$	$Q = 3.6$	$Q = 3.9$
A1	309	70	15.1	18.4	16.8	15.4	16.2	15.4	15.4	15.35
A2	111	301	3.1	6.4	4.8	3.4	4.2	3.4	3.4	3.35
A3	350	90	5.6	8.9	7.3	5.9	6.7	5.9	5.9	5.85
A4	140	370	3.1	6.4	4.8	3.4	4.2	3.4	3.4	3.35
A5	170	130	23.9	27.2	25.6	24.2	25	24.2	24.2	24.15
A6	230	60	9.1	12.4	10.8	9.4	10.2	9.4	9.4	9.35
A7	350	41	15	15.1	16.7	15.3	16.1	15.3	15.3	15.25
A8	280	100	10	13.3	11.7	10.3	11.1	10.3	10.3	10.25
A9	90	220	6.1	9.4	7.8	6.4	7.2	6.4	6.4	6.35
A10	40	171	6	9.3	7.7	6.3	7.1	6.3	6.3	6.25

unit costs will be 9.3 $(6 + (1/0.3) = 6 + 3.3 = 9.3)$, and for a production capacity of 3.9 these costs will be 6.25 $(6 + (1/3.9) = 6 + 0.25 = 6.25)$, etc.

Having calculated the distances between all attractive production sites and potential sales markets and assuming that the transport tariff is equal to 0.051, it is possible to calculate transportation costs (the process of selection of the optimal transportation technology is not considered in the example) from each attractive production site to all potential sales markets for the corresponding sales market option. At the next stage, the total costs of producing the good in each attractive place of production and transportation from each attractive place of production to all potential sales markets of the corresponding sales market option were calculated, which made it possible, based on the criterion of minimum total costs for each sales market option, to justify the selection of locally optimal locations and technology production of goods (Tab. 5).

So, for sales market option 1 with a demand of 0.3 million units the locally optimal location is the attractive location A6 (minimum total production and transportation costs – 4.944 million), for sales market option 2 with a demand of 0.6 million units – A3 (6.522 million), for sales market option 3 with a demand of 3.0 million units – A2 (34.68 million), for sales market option 4 with a demand of 0.9 million units (potential sales market 1 + potential sales market 2) – A3 (10.926 million), for sales market option 5 with a demand of 3.3 million units (potential sales

Table 5
Justification of locally optimal locations and production technology for each sales market options

A	Demand of the sales market option, million units						
	0.3	0.6	3.0	0.9	3.3	3.6	3.9
A1	7.58	13.44	80.62	20.01	87.31	93.23	99.72
A2	6.51	12.67	**34.68**	18.16	**40.29**	**46.51**	**51.92**
A3	5.42	**6.52**	45.24	**10.92**	49.76	50.92	55.25
A4	7.42	12.97	36.21	19.38	42.73	48.34	54.68
A5	9.99	22.09	98.45	31.06	107.55	119.70	128.61
A6	**4.94**	11.98	57.27	15.91	61.31	68.41	72.26
A7	6.97	13.69	81.09	20.61	88.12	93.94	100.78
A8	5.97	10.69	55.38	15.65	60.45	65.23	70.11
A9	6.33	13.86	46.74	19.17	52.17	59.76	65.00
A10	6.00	15.33	55.62	20.31	60.72	70.11	75.01

market š 1 + potential sales market 3) – A2 (40.29 million), for sales market option 6 with a demand of 3.6 million units (potential sales market 2 + potential sales market 3) – A2 (46.512 million), for sales market option 7 with a demand of 3.9 million units (potential sales market 1 + potential sales market 2 + potential sales market 3) – A2 (51.927 million).

From the obtained locally optimal locations and technologies, we form options for potential systemically optimal locations and technologies (characterized by a set of locally optimal locations and technologies, the total production capacity of which is equal to the total demand of potential markets), of which the preferred option is potential systemically optimal locations and technologies 2, the costs for which are 45.606 million, which is less than other options for potential systemically optimal locations and technologies (Tab. 6).

According to the result obtained, the best option for potential systemically optimal locations and technologies is option 2: for three sales markets (M_1, M_2 and M_3) it is advisable to produce in two attractive production locations (identified as systemically optimal locations) using appropriate technologies (identified as systemically optimal technologies):

- in location A_3 with a capacity of 0.9 million units – for potential sales markets M_1 and M_2 (this is sales market option 4)
- in location A_2 with a capacity of 3.0 million units – for potential sales market M_3 (this is sales market option 3)

Accordingly, the systemically optimal technologies will be: technology in the systemically optimal location A_2 for sales market option 3 and technology in the systemically optimal location A_3 for sales market option 4.

Table 6
Characteristics of options of potential systemically optimal places

Options for potential systemically optimal locations and technologies	Locally optimal locations and technology options	Option demand, million units	Expenses on production and transport, million
1	1+2+3	3.9	46.146
2	**4+3**	**3.9**	**45.606**
3	5+2	3.9	46.812
4	6+1	3.9	51.456
5	7	3.9	51.927

Conclusions

1. Place-based optimal technologies for producing a good for each attractive production location (linked to the corresponding sales market option to take into account production capacity) are justified from the list of possible technologies for producing the good based on the minimum production costs in the demand volume of the sales market option.
2. Place-based optimal technologies for transporting a good for each attractive place of production (linked to the corresponding sales market option to take into account the distance, transport tariffs and transportation volumes to all potential sales markets for this sales market option) are justified from the list of possible technologies for transporting the good according to the minimum system indicator calculating the total transport costs from an attractive production site to all potential sales markets for the corresponding sales market option;
3. Locally optimal production and transportation technologies are justified from the list of place-based optimal technologies of the corresponding sales market option according to the indicator, which takes into account the optimal production costs in the corresponding attractive production location and optimal system costs for transportation from this attractive production location to all potential sales markets for the corresponding sales market option.
4. The optimal system of technologies for systemically optimal places is justified from the list of possible options for potential systemically optimal places according to an indicator that takes into account the total production costs in the corresponding locally optimal places, and the optimal system costs of transportation from these locally optimal places to all potential markets for the corresponding sales market option.

The developed spatial-system approach to justifying the selection of optimal technologies for the production and transportation of goods systematically solves a long-standing problem and the correctness of this approach is beyond doubt. In the future, it is advisable to focus the study of the spatial dimension of the optimal system of production and transportation technologies on the problems of limiting the power of production technologies in some places, as well as on the problems of already functioning technologies for the production of goods in the corresponding attractive production places. The problem of the space of possible placement of production technologies requires careful attention.

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