

Forecasting the Future Development of Fiber Optic Access Networks Based on the CTE Model

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Abstract Telecom operators will play essential roles in the coming years and decades. At the same time, new satellite mobile operators will be competitors and partners of existing terrestrial telecom operators. Modern terrestrial telecom operators must adapt to new market conditions for the partnership to prevail. In principle, Telecom operators are becoming Telecom 4.0 service providers, and many business segments are changing significantly. Telecom 4.0 service providers will have to change their approach to product and service development (a complete reorganization of the approach will be required), a new approach to advertising, sales, and customer care, and will have to provide a very high-quality connection with users. All of this will be of key importance for every telecom business. This article will analyze the main characteristics of fiber-optic access networks to end users and the forecast of this type of network in the coming decades based on the CTE (Comprehensive Techno-Economic) model. The CTE model is a new original concept that quickly and qualitatively assesses the quality, advantages, and disadvantages of a telecom operator and indicates what needs to be changed and improved to improve the business of that telecom operator.	Article history Received: 09. 01. 2025. Revised: 15. 01. 2025. Accepted: 16. 01. 2025. Keywords Telecoms, Industry 4.0, Fiber Optic, CTE Model, Forecasting.
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1 Introduction

Access to customers will be one of the crucial issues for telecom operators in the coming years and decades. New services will require high-speed access speed and very low latency. Because of these reasons, fiber optic access networks will be significant as one of the key items for each telecom operator. Fiber optic access networks will have two essential parts:

- Access to customers for satisfying their needs and for offering new advanced services and;
- Support for mobile access to users at high speed and with little and insignificant signal delay.

In the Industry 4.0 era, telecom operators must be more ICT providers than classical ones. Telecom 4.0 will have to spread its business niches into information and communication levels and offer

more products and services to its customers than they have been offering until today.

This paper is an extension of the work "EKF Analysis for Positive Business Case: Telecom 4.0 and Modern Smart City", initially presented in the *2019 International Workshop on Fiber Optics in Access Networks (FOAN)* that was held in Sarajevo, Bosnia and Herzegovina in September 2019 [1]. This paper will provide a deeper and more precise explanation of the model for analyzing the potential of telecom operators. It will forecast fiber optic access network requests regarding new, improved, and advanced ICT services. It will briefly analyze telecommunication markets from 1990 to forecasts up to 2040 by using a Comprehensive techno-economic model. The results of fiber optic access networks forecasting for the following two decades will be shown.

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It is important to note that no similar model to the CTE Model has been found in the literature. Still, there are many models for the analysis of telecom operators, such as eTOM frameworks, TNA, TAM, TOE, or ITIL models, and different analysis models, such as SWOT or PESTLE models. All of them are often combined in analyses. The goal of creating the CTE Model was precisely to create a unique model for a quick and high-quality analysis of the potential of telecom operators. The CTE Model is quite complex, defined with three levels, eight areas composed of 14 segments, and items in each area. Therefore, it is not easy to describe it here if all the details can be found in the literature that precedes this paper. In the further part of the text, the basic facts and characteristics of the model will be briefly explained.

2 Methodology: main facts and figures of the CTE Model

2.1 Description of the CTE Model

A new comprehensive techno-economic model for analyzing telecom operator potentials (former EKF Analysis) is a new approach to telecom operator analysis. The development of this model has been going on for some time. The basics and its development can be found and monitored by analyzing papers published at SpliTech 2016 [1], SoftCOM 2016 [2], CIET 2018 [3], FOAN 2019 [4], ICETIS 2021[5] conferences and in Applied Sciences journal in 2023 [6].

This research aims to create a comprehensive model for analyzing the potential of telecom operators based on professional experience, knowledge, and previous scientific research. This model is easy for telecom operators to use to optimize their businesses. Such a comprehensive model enables and facilitates laying the basis for making particular business and strategic decisions.

A comprehensive techno-economic model for analyzing telecom operator potentials is defined by levels, areas (fields), segments, and the different items associated with each segment. There are three levels:

- Technical Level (TL);

- Business Level (BL);
- Environmental Level (EL).

The number of different segments defined in this model is fourteen. These fourteen areas are:

- Coverage and accessibility to users (TL);
- Technological development (TL);
- IT Development (TL);
- Products Development (BL);
- Services Development (BL);
- Sales (BL);
- Customer Care (BL);
- Human Resources – HR (BL);
- Political Environment (EL);
- Regulatory Environment (EL);
- Law Environment (EL);
- Finance Environment (EL);
- Quality of Brand (EL);
- Presence in public (EL).

The format of the model has been presented as "2 – 2 format". That means fourteen segments have been distributed into eight areas (fields). This distribution is presented in Table 1.

Table 1 Distribution of areas in the CTE Model

Distribution of areas in the CTE Model				
Technical Level	T.1. Coverage and Accessibility to Users		T.2. Technological Dev. and IT Development	
	B.3. Products Development	B.4. Services Development	B.5. Sales and Customer care	B.6. Human Resources (HR)
Business Level				
Environmental Level	E.7. Political, Financial, Regulatory and Law environment		E.8. Quality of Brand and Presence in publ	

Each area in this model will give individual results, but some areas will also have interconnections with other areas to get more precise results. The results will be presented as:

- Total Field Value (the maximum value is of each area 1 or 100%, and because of this reason, it is still not defined number of areas);

- Each item in each area will allow more detailed analysis of sub-segments and comparison with competitors;
- The results will be presented in tabular and graphical forms.

2.2 Description of T.1. area: list of items

The following ten (10) items have been defined in this area.

Mobile connectivity and availability:

- Quality of access to mobile data in urban areas (outdoors);
- Quality of access to mobile data in special parts of urban areas - areas of mass gatherings (e.g., shopping centers, stations, bus stations, railway stations, halls, and stadiums);
- Quality of access to mobile data in rural areas;
- Quality of access to mobile data on roads: highways and main state roads;
- Quality of access to mobile data on roads: regional roads and local roads.

Fixed availability and connectivity:

- The quality of transmission fiber optic systems at the state level, fiber optic systems at the level of connections between urban settlements, and the quality and value of the capacity of fiber optic systems;
- Percentage of connection of homes (houses, flats, apartments,...) with fiber optic cables - FTTH (Fiber to the Home);
- Percentage of connections of factories, business facilities, incubators, etc. with fiber optic cables - FTTBus;
- Local loop shortening - the percentage of the number of households (houses, flats, apartments, SME companies) that are less than 900 meters from the last telecom connection point (RSS) - Item related to the efficiency of the copper network;
- Quality of protection of the primary transmission system and all transmission systems to the endpoints in the event of failure of the entire system.

3 Forecasting of fiber optic access network development

Comprehensive Techno – Economic (CTE) model will continue to grow and develop. So, the CTE model is finished but will be changed in the future. How is it possible? For example, imagine this model in 1990, 2000, and 2010. And let's imagine what it will look like in 2030 and 2040. This presentation will explain in the most straightforward guidelines the potential dangers that telecom operators will face in the future in the Web3 environment.

3.1 Assumption of the appearance of the CTE Model in past decades

The CTE model did not exist in 1990. But it is interesting to analyze how it would have looked if it had existed then. The main items can be defined according to the analysis of telecommunications from that period. This period, based on the CTE model, can be briefly described as follows:

- Coverage and Accessibility (T.1.) to Users, Technological Dev. and IT Development (T.2.) joined together: Technology (and IT) development and accessibility to the customer will be based on fixed network: copper pair and coax network). There were no advanced ICT services yet.

This shows the assumed appearance of T.1. area of the CTE model in 1990 (what it would have looked like if it had existed then). An effort was made to present the appearance of this model based on the available information. What was the emphasis on telecommunications, and how developed were in general in that period? In this paper, due to the theme of the entire conference, the emphasis will be primarily on the area of T.1. Development of the telecommunications business segment was significantly low in the nineties of the last century. Accessibility to users was based on fixed access, and there were no services with added value. Primarily, everything was focused on voice calls via the fixed network and telegraphic traffic. As the commercialization of the first GSM mobile systems only started after 1991 (in the 1990s), it can be said that all items in the CTE model would be based on fixed access to users.

Already by the year 2000 and after that (in that decade), there were significant changes in the telecommunications segment. It shows the assumed appearance of T.1. area of the CTE model in the year 2000, according to the analyses of the telecom sector from those years. Area T.1. "Coverage and Accessibility to Users "will be briefly described as follows:

- Fixed access based on copper pairs and coax copper network;
- One to two items were based on optical network systems: connections among settlements;
- A mobile connection was based on GSM and GPRS;
- Approximately 7 fixed items and 3 mobile items.

This previous item gives a clear picture of the state of accessibility to users from that era. It is important to emphasize that, at that moment, there would be about 7 items defining the quality of fixed network accessibility to users and up to three items describing accessibility to users via the mobile network. A significant shift in the development of telecommunications towards mobile accessibility to users is noticeable, although fixed accessibility to users still prevails in the telecommunications segment. These fixed items brought significantly higher revenues than the mobile segment of telecommunications.

In 2010, the number of items from the mobile and fixed segments was almost the same. Area T.1. Coverage and Accessibility to Users is described as follows:

- Mobile Coverage: 4G already started in 2009;
- Fixed services based on copper pairs, coax, FTTH, and FTTHBus;
- Massive connections among settlements by fiber optic cables;
- Appx. 5-6 fixed and 4-5 mobile items.

Significant development of mobile systems and systems based on IP technologies is noticeable, and fixed systems are also developing. Still, the leading developments are in Internet access and TV and video

transmission. Basically, the ratio of fixed and mobile items is approximately equal, again pointing to the fact that the mobile segment of telecommunications takes precedence in service development and revenue. From 2010 until today, the telecommunications segment has experienced a big shift forward in terms of access to users and new advanced services. It is essential to point out that the beginning of the era called Industry 4.0 is connected with this decade, i.e., it is considered that Industry 4.0 begins in the middle of this century.

3.2 Assessing the outlook of the CTE Model over the next two decades

The current appearance of the CTE model is shown in Table 1, and more details about the model itself can be found in the literature listed in this paper. After the previous discussion, it is important to make assumptions about this model in 2030 and 2040 because, in this way, significant guidelines for strategic and business decisions can be obtained for telecom operators, the state, and society. The focus of this research was in the area of T.1. Considering the monitoring of the development curve of telecommunications concerning accessibility to users and monitoring the development of modern technologies, it can be concluded that the emphasis on accessibility to users will shift to the mobile segment and that as many as 7-8 items will be from this part of the area by 2030. All this is summarized in the items below (T.1. Coverage and Accessibility to Users area). There will be approximately 8 items from the mobile segment and 2 from the fixed segment: FTTO and fiber optic connections among settlements.

Using the same methodology of monitoring the development and changes in the CTE model and the development of new technologies, it was concluded that around (and even before) 2040, all items of accessibility to users will be based on the mobile segment. However, this does not mean that the fixed segment based on optical fibers will not be necessary. On the contrary, that segment will be mandatory, i.e., connecting all settlements, houses, apartments, buildings, and rooms in offices, homes, and flats must be coupled with optical fibers. Considering the demands of the new services, it is clear that the speed of downloading and sending data (upload) and the

delay in the network will be crucial for all these new services, and fiber optic technology is indispensable for them. Therefore, although all ten items will be based on the mobile sub-segment, the fixed segment based on optical cables and technology will be unavoidable in this period and later. It can be summarized that T.1. Coverage and Accessibility to Users area will be based on the following main items:

- All 10 items will be from the mobile segment;
- Fiber optical cable connections will be regular standard and;
- Optical connections to all rooms and offices will be a mandatory standard.

All this, briefly analyzed so far, clearly indicates that the telecommunications market is changing significantly and that telecom operators have a great chance to achieve significant results in that period with the conditions of recognizing opportunities and adapting to new changes. But also, in the case of delays in adjustments and changes, they can lose the market, customers, and money and eventually disappear from the market.

3.3 Conclusions on the development of the fiber optic access network in the following decades

Telecom 4.0 will be a crucial player in the following years and decades and will work in a digital environment and on mobile Internet. The CTE model shows directions for their development and gives a real picture of how, when, and why this issue is vital for Telecom 4.0. Our common future is a digital environment based on mobile Internet.

In addition to these analyses based on the CTE model, a short survey was conducted on the LinkedIn social network among professionals and scientists from the ICT segment. The question was: Do you think that FTTR (fiber to the (all) rooms) will be a binding standard until 2040? The answers offered were:

- Yes;
- No;
- Yes, but much later.

The obtained results were:

- Yes: 38%;

- No: 46%;
- Yes, but much later: 15%.

From the answers received, it is evident that half of the professionals and scientists agree with this thesis, and as many as 16% of them think that FTTR will be the standard, but sometime later.

Another short survey was conducted via the social network LinkedIn and concerns mobile systems' future. The question was: Which generation of mobile systems will include satellite communications. The answers offered were:

- 6G;
- 7G;
- 8G or later;
- None.

The obtained results are:

- 6G: 41%;
- 7G: 23%;
- 8G or later: 18%;
- None: 18%.

The results from both of these surveys show that experts and professionals from the ICT segment believe that the processes of development of modern technologies will be accelerated because some of these expectations were only planned for 2040 or later, while already now, many of them think that significant progress in telecommunications will take place in the next ten years.

According to the CTE model, the changes that have occurred in the telecommunications market since 1990 and will continue until 2040 (and beyond) can be summarized in a table and graphically. The focus is on the T.1 area of the CTE model.

Table 2 Development of T.1 is af CTE model from 1990. – 2040.

T.1. area	1990	2000	2010	2020	2030	2040
Fix items	10	7	6	5	3	0
Mob items	0	3	4	5	7	10

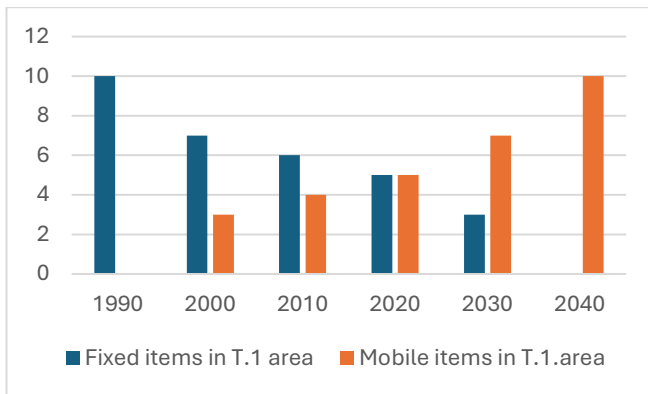


Figure 1 Development of T.1 area of CTE model from 1990. – 2040.

It is evident from Table 2 and Figure 1 that the market and the telecommunications segment are rapidly changing and that these changes will continue intensively until 2040 and beyond. The significance and size of these changes can best be seen through the analysis of the entire CTE model. Still, since the emphasis here is on the access network, the focus was on the area of T.1. What is important to emphasize is that in 2040, all services will be based on high-speed and low-latency mobile Internet access. For this, it is necessary to have the fiber-optic infrastructure "always and everywhere". This is precisely what the estimate indicates, there will be 10 mobile and 0 fixed items in the T.1 area of the CTE model in 2040.

4 Conclusion

The comprehensive techno-economic model (CTE) model was designed, created, and developed to help make key and strategic telecommunications decisions. The CTE Model is made up of 14 segments that are distributed in 8 areas. Each area consists of 10 items that are mathematically defined and provide exact results for these items. By analyzing the results for individual items and individual areas and analyzing the overall model assessment, guidelines are obtained for eliminating the shortcomings of the observed telecom and improving its business. Unlike almost all existing current analysis models, this model provides exact results based on input data obtained from measurements, data analysis, analysis of the offer for users, etc.

In addition, its use can be directed (as shown in the paper) to forecast the development of individual

telecommunications segments (this was done for the optical access network using the T.1 area). Therefore, its modular use is possible by analyzing individual areas or only individual items from the observed area. From this brief analysis of the model, or rather part of its scope, the assumption (forecast) that fiber optic access networks will be mandatory in telecommunications by 2040 at the latest, in the way that "fiber to the room" (FTTR) access will be a compulsory standard, is clearly indicated.

Two brief analyses conducted through surveys on LinkedIn clearly confirm this fact in the way that scientists and experts predict that perhaps even before 2040, this will be defined as a certain standard. Of course, some reject such an assumption. In addition, most respondents claim that satellite communications will become an integral part of mobile communications, which indicates that the focus will always be on signal coverage.

Covering every room and living space with fast internet access (for which FTTR access is necessary) will always enable mobile signal coverage everywhere, for which satellite coverage is required to support classic mobile terrestrial networks. As shown in T.1. In the CTE model area (forecast 2040), there will be 10 mobile and no fixed sites. In short, it can be concluded that fiber optic connections will be standard, and 10 mobile items mean that mobile coverage will be everywhere and always, which indicates that at least one or more satellite mobile sites for mobile coverage will be part of the T.1. area.

Conflicts of Interest: The author reports there are no competing interests to declare;

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