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COMPLEXITY OF CYBER-PHYSICAL DIGITAL MARKETING PRODUCT DEVELOPMENT PROJECTS

Е. Забарна, О. Тімчинский, О. Бондар, В. Овсійчук. **Складність проєктів розробки кіберфізичних продуктів цифрового маркетингу.** В статті показано, що актуальність дослідження зумовлена зростанням складності IT-проєктів, спрямованих на розробку кіберфізичних продуктів у сфері цифрового маркетингу, які поєднують апаратні компоненти, датчики, програмне забезпечення, аналітичні модулі та елементи штучного інтелекту. Обгрунтовано, що такі проєкти характеризуються високим рівнем інтеграції між фізичним і цифровим середовищами та мультикомандною структурою, що ускладнює процес управління. Виявлено, що ключовою проблемою є забезпечення ефективної міжкомандної комунікації та синхронізації дій між групами розробників, маркетологів і аналітиків, оскільки будь-які зміни у технічних чи програмних компонентах без своєчасного узгодження створюють ризики асинхронності, втрат даних, вимог та порушення строків завершення IT-проєкту. Сформульовано мету дослідження, яка полягає в обгрунтуванні підходів до вдосконалення управління комунікаціями в IT-проєктах розробки кіберфізичних систем цифрового маркетингу шляхом створення інтегрованої інтелектуальної моделі інформаційних взаємодій між командами. Для досягнення мети проаналізовано сучасні наукові підходи до управління складними мультидисциплінарними IT-проєктами, виділено особливості комунікацій у кіберфізичних системах. Запропоновано модель системи комунікацій, що включає три рівні – інфраструктурний, інформаційно-комунікаційний та аналітичний. Розроблено принцип побудови мережевої карти взаємодій між командами, у якій кожен зв'язок характеризується частотою, затримкою та якістю обміну. Побудовано математичну модель графа комунікацій G(V,E,W) з урахуванням вагових коефіцієнтів, що відображають інтенсивність інформаційних потоків. Запроваджено застосування методів інтелектуального аналізу даних та штучного інтелекту для автоматичного виявлення ризикових зв'язків, аналізу стану інформаційних потоків і формування управлінських рекомендацій. Проаналізовано можливості використання побудованої системи для автоматизації управління мультикомандними IT-проєктами, прогнозування ризиків асинхронності та підвищення ефективності прийняття рішень в процесі розробки складних кіберфізичних продуктів.
Ключові слова: кіберфізичний продукт проєкту, складний IT-проєкт, мультикомандна розробка, комунікації, цифровий маркетинг, міжкомандна взаємодія, штучний інтелект

E. Zabarna, O. Timchinsky, O. Bondar, V. Ovsiychuk. **Complexity of cyber-physical digital marketing product development projects.** The article shows that the relevance of the study is due to the increasing complexity of IT projects aimed at developing cyber-physical products in the field of digital marketing, which combine hardware components, sensors, software, analytical modules and elements of artificial intelligence. It is substantiated that such projects are characterised by a high level of integration between the physical and digital environments and a multi-team structure, which complicates the management process. It is revealed that the key problem is ensuring effective inter-team communication and synchronisation of actions between groups of developers, marketers and analysts, since any changes in technical or software components without timely coordination create risks of asynchrony, loss of data, requirements and violation of the deadlines for completing the IT project. The research objective is formulated, which is to substantiate approaches to improving communications management in IT projects for the development of cyber-physical digital marketing systems by creating an integrated intellectual model of information interactions between teams. To achieve the goal, modern scientific approaches to managing complex multidisciplinary IT projects are analysed, and the features of communications in cyber-physical systems are highlighted. A model of the communications system is proposed, which includes three levels: infrastructure, information-communication, and analytical. The principle of constructing a network map of interactions between teams is developed, in which each connection is characterised by the frequency, delay and quality of exchange. A mathematical model of the communications graph G (V, E, W) is constructed, taking into account weight coefficients reflecting the intensity of information flows. The application of methods of intelligent data analysis and artificial intelligence for automatic detection of risk relationships, analysis of the state of information flows and formation of management recommendations was introduced. The possibilities of using the constructed system for automating the management of multi-team IT projects, forecasting asynchrony risks and increasing the efficiency of decision-making in the process of developing complex cyber-physical products were analysed.
Keywords: cyber-physical product of the project, complex IT project, multi-team development, communications, digital marketing, inter-team interaction, artificial intelligence

Introduction

The product of digital marketing IT projects is often a cyber-physical system that combines physical devices, sensors, digital models, artificial intelligence algorithms, and network interaction. Examples include interactive AR shop windows and "smart mirrors". Such a system allows the user to interact with the product in real time – for example, to "try on" clothes or cosmetics using augmented reality, observing the integration of their own reflection with virtual models. A cyber-physical product consists of hardware, which includes a mirrored touchscreen display, RGB and depth cameras, lighting, motion sen-

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sors, controllers, and a microcomputer (e.g., NVIDIA Jetson or Raspberry Pi), and software, which includes computer vision modules, AR visualisation systems, product model databases, user behavior tracking and analytics algorithms, as well as APIs for integration with the brand's e-commerce platforms.

It is important to distinguish between the concepts of a hardware-software complex and a cyber-physical system. The first term refers to the technological integration of hardware and software that performs a specific function. A cyber-physical system, on the other hand, is a more complex entity with elements of AI, as it involves the interaction of physical processes with digital models in real time, state analytics, and the adaptation of system behaviour to external conditions, as shown in [1]. In the following discussion, the term *cyber-physical system* is used, as it more accurately reflects the intellectual nature of the product.

Three main teams are involved in the IT project to develop such a cyber-physical system: a hardware development team responsible for assembling the housing, sensors, electronic modules, connections, and creating prototypes; a software development team that implements computer vision, AR visualisation and analytics; and a brand marketing team that develops user interaction scenarios, visual product models and content strategy.

The complexity of such projects lies in the high level of integration between different technological domains – from electronics and brand marketing to artificial intelligence – and the need to ensure the synchronised work of several interdisciplinary teams. Any change in technical design or visualisation algorithm can affect the marketing concept or hardware interface requirements. An additional complexity is created by the need for continuous coordination between these teams, as all changes must be promptly recorded, agreed upon, and communicated to other project participants for the correct updating of decisions and continued development based on current data.

This is a complex and non-trivial task, as it requires simultaneous management of technical, communication and time dependencies. To solve this problem, it is advisable to develop a project communication management model that will ensure automated synchronisation of interaction between teams. Such a model should use intelligent data analysis methods and artificial intelligence systems to monitor information flows, identify critical messages, warn of inconsistencies, and support real-time decision-making.

Analysis of literature data and problem statement

Articles on the management of IT projects for the development of cyber-physical systems pay particular attention to the complexity of their organisation and team coordination. The paper "Enhancing Project Management for Cyber-Physical Systems Development" [2] identifies that the main problem with such projects is the combination of different domains – hardware, software, communication, and analytics – within a single life cycle. The authors note that classic IT project management methodologies, focused solely on software, do not take into account the physical part of the system, which leads to conflicts in planning, integration, and testing. The complexity is compounded by the different work rhythms of the teams: electronics engineers work with longer production cycles, while software developers use agile approaches. To address this imbalance, a hybrid management model has been proposed that combines elements of PMBOK [3] and Agile, creating a unified plan for integrating the hardware and digital parts of the system.

The same authors, in [4], emphasise that managing projects to create cyber-physical systems requires modifying classic PMI processes. The authors highlight the problem of communication between teams from different domains – software, hardware and analytical. Information barriers arise due to differences in terminology, testing methods, and reporting formats. To overcome this, a communication integration model is proposed in which all teams use a common management platform that synchronises changes in requirements and automatically updates project documentation. Such a platform effectively acts as the "digital core" of a CPS project, preventing information loss between teams and increasing process transparency.

The study [5] describes the practical difficulties that arise when creating complex cyber-physical products. The authors emphasise that the difference between such projects and conventional IT projects lies in the need for the synchronous development of three layers of the system – physical, software and network – each of which has its own dynamics of change. The main difficulty lies in ensuring the coherence of the architecture and managing the interdependencies between these layers. The paper describes the automation of management through the implementation of a "Digital Thread" – an end-to-end digital model that tracks changes at all stages of the CPS life cycle. The use of artificial intelligence elements, in particular machine learning methods, allows predicting integration risks and optimising the testing process of hardware and software components.

The analysed articles note that IT projects for the development of cyber-physical systems are characterised by increased complexity due to their multidisciplinary nature, the synchronisation of different types of teams, and the need to integrate physical and digital environments. The complexity of an IT project may be determined by the need for additional research to reduce uncertainty, as shown in [6]. At the same time, automation of management and the use of AI are considered key factors in improving the efficiency of such projects and reducing both risks and uncertainties in their implementation.

Therefore, the issue of communication management in complex IT projects was further considered. In article [7], communication is defined as a fundamental process that builds trust, mutual understanding, and motivation within a team. The authors emphasise that in the context of distributed and virtual IT teams, the complexity lies in maintaining a single information space when team members are in different time and cultural contexts. The main problem is identified as fragmented communication, which leads to information loss and destabilisation of processes. To overcome this, a two-component communication management model is proposed: interpersonal (human) and organisational, covering information flows, tools, exchange structure and feedback control. The authors analyse a number of communication management models, from the classic one based on communication planning to modern integration approaches that involve the use of Jira, Trello, Slack or Confluence platforms. It is important to emphasise the capabilities of artificial intelligence, which can automate the analysis of communication flows and identify information gaps to improve team coordination.

Another point of view is presented in the work of V. Bannikov [8], which focuses on the practical aspects of coordinating communications in complex projects. The author describes communication as a multi-level mechanism that includes the collection, systematisation, analysis, and transfer of information between all participants. The problem is identified as the lack of a systematic approach to communication management, where each team acts autonomously. The solution proposed is to develop a structured communication management plan covering the stages of initiation, planning, control, analysis, and closure. The plan involves the creation of an information and technology model of communication with a clear distribution of responsibilities. To avoid errors and data loss, it is recommended to use communication matrices and electronic message logs. The author believes that only on the basis of a detailed communication system is it possible to effectively coordinate complex IT projects.

In the article “The Role of Communication Management Within the Virtual Team in an International Projects-Based Organisation” [9], researchers analyse the problem of information asymmetry, which is particularly acute in international distributed teams. The complexity lies in uneven access to information due to time zones and cultural differences. To solve this problem, they propose the implementation of a “Communication Governance Framework” – a digital communication management system that includes a monitoring panel, automatic logging of discussions, and activity analytics. Such a system acts as a central hub that synchronises data exchange between teams and allows managers to identify information delays in real time.

Research [10] highlights the relationship between communications and risk management. The authors note that the lack of integrated channels between parallel teams creates hidden risks. To minimise them, they propose introducing a continuous data exchange mechanism between projects based on a centralised knowledge base. This allows for the synchronisation of management decisions and reduces task duplication.

In article [11], the authors focus on the cultural aspect of communications and the role of a manager’s “soft skills”. The authors emphasise that even with digital tools, communication remains primarily a human process, where emotional intelligence and the ability to build trust are critically important.

All of the articles analysed share the common idea that communication is a system-forming factor for complex IT projects. Their complexity lies not only in technical barriers, but also in interpersonal interaction. The authors point to the need for automation of communication management, development of integrated digital platforms, and use of intelligent message analysis algorithms to predict information gaps and improve team coordination. Such a solution is a necessary condition for the success of modern IT projects, especially in the context of multi-team interaction and a highly dynamic environment.

Purpose and objectives of the study

The purpose of the study is to justify communication measures in projects for the development of complex cyber-physical digital marketing products in order to ensure effective multi-team interaction. Achieving the stated goal will ensure the fulfilment of tasks related to the development of the structure

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and content of the communication system for IT projects for the development of complex cyber-physical products.

Justification of the approach to managing the information environment of IT projects for the development of cyber-physical digital marketing products

As revealed by the review and analysis of literature sources, the complexity of managing projects for the development of cyber-physical products lies in their multi-team nature, namely in the complexity and inefficiency of communication between all teams. Therefore, the effectiveness of managing such projects directly depends on a high-quality communication system [12].

The communication system for an IT project to develop a cyber-physical system in the field of digital marketing should be an integrated intelligent communication and analytical platform that not only ensures the transfer of information between teams, but also the automatic collection, structuring and analytical interpretation of data from the project environment. Its structure consists of three levels: infrastructure, information and communication, and analytical (intellectual).

At the infrastructure level, the system provides physical interaction between teams through a centralised data transfer environment. All teams – hardware, software, and marketing – connect to a single network infrastructure that supports both wired and cloud connections. This level is responsible for unifying data formats, synchronising file storage, maintaining change logs, and ensuring secure access to project information.

The information and communication level is the central part of the system, which performs the functions of collecting, filtering, and routing messages. All data generated in team environments (Jira, Git, Figma, Slack, Confluence, CAD systems) is automatically transferred to a centralised communication repository. Here, the system classifies content by type (technical changes, marketing decisions, graphic updates, defects, requirements, etc.) and establishes links between different types of messages [13].

A general view of such a network map is shown in Fig. 1. To ensure traceability, all communications are visualised in the form of a network map of interactions, showing the links between teams, the frequency of exchange, and the degree of information saturation of each node. The physical interaction between teams in the figure is graphically presented as directed lines. The direction indicates where and to whom the information is sent. The thickness of the lines indicates the intensity of such interactions; the thicker the line, the more intense the interaction. The dotted line indicates the discontinuity and instability of such interaction. The color indicates which department formed the corresponding communication. Additionally, on the network map of interactions, "alarmist" yellow or red marks may be provided near the lines of interaction between departments to signal a conflict of the information provided, or its critical delay. For a specific project, together with the network map, an appropriate dictionary of conventional symbols and images is created.

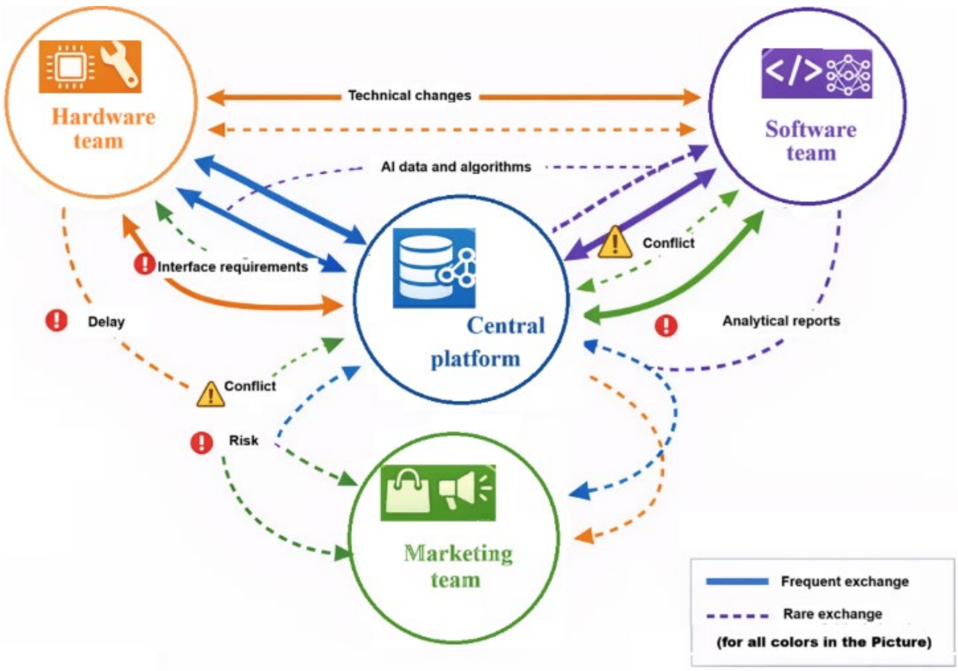

Fig. 1. General view of the network map of interactions between teams in a cyber-physical digital marketing product development project

Based on *the network map*, it is possible to calculate the necessary metrics of information interaction for a multi-team project, which are presented in Table 1.

Table 1

Key metrics of information interaction in a multi-team project

Metric	What it shows
Degree Centrality	Number of connections for each participant (how active they are in terms of communication)
Betweenness Centrality	how much a participant acts as an "intermediary" in communications between others
Closeness Centrality	how quickly information from a participant can reach others
Edge Weight	the intensity of communication between pairs
Density	overall level of interaction within the team (0–1)
Modularity / Clusters	how "sub-teams" or "interest clubs" are formed
Information Flow Index	speed of information transfer between teams (calculated based on time logs)

Based on this, the following management issues can be identified:

– find isolated nodes (teams that interact little);
– identify overloaded nodes (where there is too much communication and a risk of loss);
– reveal gaps in connections between key domains (e.g., Hardware ↔ Marketing);
– find time lags in communications (delays between a change and notification of it).

To build a network map of interactions in an IT project for the development of a cyber-physical digital marketing product, data on communications between teams and their members is required. This does not necessarily have to be correspondence; it can be any form of interaction that can be recorded as an event in the space "who ↔ *with whom* ↔ *about what* ↔ *when*". Such data is recorded in a communication table, an example of which is given in Table 2.

Table 2

Typical data from the "Project Communications Table"

Category	Source	Format	Example
Task	Jira / Trello	JSON / CSV	Task ID, Author, Assignee, Time, Comments
Code	GitLab / GitHub	Logs	Commit author, reviewers, merge requests
Documents	Confluence / Google Docs	API export	Co-authorship, comments, edit times
Communications	Slack / Teams / Email	Chat logs	From, To, Timestamp, Message text
Meetings	Google Meet / Zoom	Calendar logs	Participants, Duration, Agenda
Testing / analytics	CI/CD, QA logs	CSV	Pipeline triggers, responsible team

In a real IT project, such a table is filled from project management systems (Jira, GitLab, MS Teams, Confluence, Slack) [14].

Metadata collection plugins can be used that do not violate confidentiality and only record metrics: *who, when, with whom, through which channel, how often.*

For the study, a synthetic dataset was created based on simulation (simulation data for 3 teams, 15 participants, 500 communications). This made it possible to demonstrate the principle of the model without interfering with real processes.

As a result, the interaction graph is not just a "picture" but an analytical model in which each edge has a mathematical weight.

That is, graph *G* can be represented as:

$$G = (V, E, W)\,, \tag{1}$$

where:

V is a set of vertices, in our case, *teams or key project participants*, for example:
$V = \{HardwareTeam, SoftwareTeam, MarketingTeam\}$;

E is a set of *edges*, i.e. pairs of vertices between which there is communication, for example:
$E = \{(Hardware, Software), (Software, Marketing), (Hardware, Marketing)\}$;

W – a set of *weights* characterising the intensity, delay or quality of communication.

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Thus, each edge E_{ij} has its own weight W_{ij}, which can be one-dimensional or a vector depending on the complexity and depth of the analysis.

The graph can also be overlaid (as shown in Fig. 1) with:

– colors – type of communication (technical, managerial, marketing);

– line thickness – frequency or volume of exchange;

– node size – level of communication activity;

– centrality indices – importance in the network (who is the “bottleneck”).

In addition to visualisation, you can calculate:

–Communication Density – how integrated the team is;

– Information Delay Index – average response time between teams;

– Dependency Entropy – degree of uncertainty in connections (variation in exchange frequency);

– Centrality Index – who actually controls the information flow, even if they are not formally a manager.

Note that *a verbal description* of communications (for example, “the marketing team agrees on changes with the programmers”) only provides the logic of the process. It does not show:

– the actual intensity of the exchange;

– who is actually the center of influence (rather than the formal manager);

– where there are gaps or delays in the transmission of information;

– whether there is excessive communication that slows down work;

– which nodes become risk points for information overload.

In contrast, *a graph model* provides a quantitative picture that can be measured, compared, and predicted. It allows you to:

– see the “real state of interaction” rather than the one described in the documentation;

– predict the risks of communication gaps (based on a decrease in communication intensity);

– track team synchronisation;

– receive automatic recommendations from AI, for example:

“The intensity of communication between Hardware Team and Marketing Team has decreased by 40%. The probability of an asynchronous release has increased to 0.7”.

At the analytical (intellectual) level, artificial intelligence modules perform intelligent analysis of communication content. Using natural language processing (NLP) technologies and analytical models, the system automatically identifies potential conflicts between teams, task duplication, coordination delays, or conflicting requirements. To do this, it uses a multi-layer neural network that analyses text messages, code comments, documentation updates, and test reports. The result of the analysis is intelligent signals – automatically generated recommendations to the IT project manager on the need to coordinate, prioritise changes, or adjust the team interaction plan.

To implement this, the following system functionality was proposed:

– real-time communication monitoring with automatic identification of critical messages and risky exchange nodes;

– a system of notifications about detected inconsistencies or information gaps between teams;

– an intelligent assistant to the IT project manager, which generates recommendations based on statistical analysis and machine learning (for example, “the delay in synchronising the hardware design with the AR module exceeds the acceptable threshold – it is recommended to convene an inter-team session”);

– a communications control panel that displays the status of team interaction in the form of interactive graphs, data exchange dynamics, and consistency indicators.

This system eliminates the human factor in terms of losing or ignoring important messages and creates a closed loop of information management, where any change in one part of the project (team) is automatically reflected in all others. The use of artificial intelligence models allows us to go beyond passive data storage and ensure active communication management – to anticipate risks, identify inconsistencies, and support the IT project manager in making timely and informed project decisions.

Development of a network interaction map as an element of complex IT project management

As mentioned earlier, the information and communication level is the central part of the cyber-physical product development management system of a multi-team IT project. The project tasks involve the participation of three independent but interrelated teams: hardware, software, and marketing.

The main task of the analysis is to identify the effectiveness of communication between these teams and to formulate management recommendations to reduce the risks of asynchronous work [15].

A network communication map allows formalising relationships, measuring their intensity, identifying central nodes, and identifying weaknesses in interaction.

To build the interaction map, a mathematical model based on graph theory is used, where the project communication network is defined as (1).

The weight of each connection is determined by the formula:

$$W_{ij} = \alpha f_{ij} - \beta l_{ij} + \gamma q_{ij}, \tag{2}$$

where:

f_{ij} is the average frequency of communications between teams i and j (messages/day);

l_{ij} – average delay in responses (hours);

q_{ij} – interaction quality (0 – 1), and the coefficients α, β, γ are set experimentally: for example, $\alpha = 1.0$, $\beta = 0.5$, $\gamma = 2.0$.

Communication parameters taken into account in the model:

– frequency (f_{ij}) – reflects the intensity of exchange between teams;

– delay (l_{ij}) – average time between request and response;

– quality (q_{ij}) – subjective assessment of the completeness and accuracy of responses;

direction – oriented communication (from source to receiver).

Based on these parameters, a synthetic dataset (Table 3) was created for communication modelling.

Table 3

Synthetic dataset of project communications

Day	Sender	Recipient	Messages	Delay (hours)	Quality (0 – 1)
1	Hardware	Software	1	2.1	0.92
1	Software	Marketing	3	8.5	0.60
1	Hardware	Marketing	1	10.2	0.55
2	Software	Hardware	7	3.1	0.88
2	Marketing	Software	2	7.4	0.65

The data undergoes preliminary processing: cleaning, normalisation and aggregation to average the parameters over time intervals.

A relationship matrix is constructed based on the processed data:

Command →	HW	SW	MKT
HW	–	8.5	0.7
SW	7.9	–	3.5
MKT	0.9	1.2	–

Next, the weights of the connections between nodes are calculated using the above formula. For example, for the Hardware–Software connection, where $f_{ij} = 8.5$, $l_{ij} = 2.1$, $q_{ij} = 0.92$:

$$W_{\text{HW,SW}} = 1.0 \times 8.5 - 0.5 \times 2.1 + 2.0 \times 0.92 = 9.79.$$

Sets of nodes, edges, and weights are formed:

$$V = \{\text{HW, SW, MKT}\}, \tag{3}$$

$$E = \{(\text{HW, SW}), (\text{SW, MKT}), (\text{HW, MKT})\}, \tag{4}$$

$$W = \{9.79, 2.10, -1.85\}.$$

The analytical model of the graph allows network metrics to be calculated.

Centrality determines which team has the most connections.

Clustering coefficient shows the degree of node grouping in a subnetwork.

Density characterises the degree of network connectivity:

$$D = \frac{2\,|E\,|}{|V\,|(\,|V\,|-1)}, \quad (5)$$

where:

$|V|$ is the number of nodes (participants or project teams);

$|E|$ is the number of connections (actual channels of interaction between them).

The multiplier 2 in the numerator takes into account that the connections are bilateral (for example, “Hardware ↔ Software”).

Network density is one of the basic indicators in sociometry, organisational structure analysis, and project communications. It shows how fully all project participants actually interact with each other. In our case (an IT project for the development of a cyber-physical product), this metric measures: “*what proportion of possible connections between teams is actually used for communication*”. In other words, if three teams (hardware, software, marketing) could have three bilateral connections but actively communicate only through two, the density will be less than 1, meaning there is a “gap” in communications within the system.

The value of D always belongs to the interval from 0 to 1:

– $D \approx 1.0$ – the network is fully connected: all participants interact with each other regularly;

– $D \approx 0.5$ – partial communication: half of the possible connections actually work;

– $D < 0.3$ – weak connectivity: information circulates only through individual intermediaries;

For example: “The current communication density between IT project teams is 0.58. Recommendation: increase interaction between Software Team and Marketing Team through joint stand-ups or short synchronisation sessions”. Thus, D is a quantitative measure that transforms “invisible” communication problems into a measurable management indicator.

Centrality analysis may show that the marketing team has only weak inbound connections, and is therefore a peripheral node and a potential source of asynchrony.

Based on the metrics, critical ties are identified – those with a weight below the threshold value (e.g., $W < 2.0$). Such ties are subject to managerial intervention.

For clarity, the graph is visualised: the thickness of the edge is proportional to the weight value, the color indicates the status of the link (green – stable, yellow – risky, red – critical), and the direction of the arrow corresponds to the initiator of communication.

The critical state can be specified by the system by subtypes:

– unsatisfactory – the connection does not provide data exchange or distorts information;

– dysfunctional – formally exists but does not perform its functions (messages do not arrive, long delays);

– ineffective – communication is of low quality or frequency;

– faulty – communication is unstable over time.

Based on the simulated synthetic dataset, all the necessary indicators were calculated to build a network map of IT project interactions, which are summarised in Table 4.

Table 4

Calculated indicators of communication activity in the project environment

No. No.	Sender	Recipient	Number of messages	Average delay, hours	Communication quality rating (0–1)	Intensity
1	HardwareTeam	SoftwareTeam	36	1.2	0.9	0.82
2	HardwareTeam	MarketingTeam	15	4.5	0.6	0.41
3	SoftwareTeam	HardwareTeam	32	1.0	0.92	0.85
4	SoftwareTeam	MarketingTeam	48	2.8	0.8	0.67
5	MarketingTeam	SoftwareTeam	20	3.6	0.75	0.55
6	MarketingTeam	Hardware Team	12	5.0	0.5	0.3
7	ProductManager	Hardware Team	18	1.8	0.88	0.76
8	ProductManager	Software Team	25	2.0	0.9	0.78
9	ProductManager	Marketing Team	30	1.5	0.95	0.84

After that, based on Table 4, a network map of the project was formed, which is presented in Fig. 2.

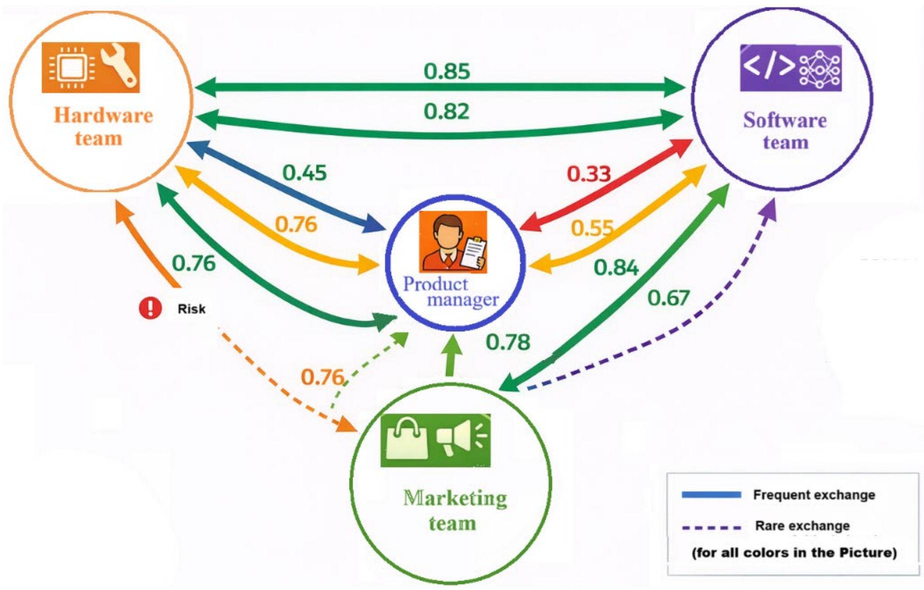

Fig. 2. Calculated network map of the IT project (the symbols and interaction lines shown correspond to Fig. 1**)**

The interaction network map (Fig. 2) was built for an IT project to develop a cyber-physical digital marketing product. It reflects the intensity and directions of information exchange between three teams: software and hardware development, marketing, and the Product Manager, who coordinates their interaction. The Product Manager is at the center of the map because this project is distinctly product-oriented, as the end result is not just a system but a commercial interactive product (AR showcase or "smart mirror") that integrates technology, design, marketing and user experience. Therefore, it is the Product Manager who is the link that coordinates the requirements of the market, the marketing team, and the hardware and software development teams. They define the product vision, functionality, usage scenarios, and priorities. The Project Manager is still present in such a system, but they manage deadlines, resources, risks, and plans, and in this case, they are not the center of communication between teams. Their role is organisational.

The number of arrows on the map corresponds to the number of fixed communication directions in Table 3. Each arrow shows the existence of real information exchange between two teams. Where the exchange is mutual, the arrows are bidirectional, indicating active two-way communication, for example between the hardware and software teams. If the arrow is unidirectional, this indicates asymmetry in the interaction, where one team initiates the exchange more often or transmits more information than it receives, which may be a sign of communication imbalance.

The color of the arrows reflects the status and quality of the connection. Green lines indicate stable connections with high-quality information exchange and minimal delays, such as between hardware and software teams. Yellow arrows indicate risky communications – delays in response, low frequency of contact, or partial loss of context, which is typical for communication between software and marketing teams. Red lines indicate unsatisfactory or failed communication, for example between the marketing and hardware teams, where the frequency of interactions is low and delays are significant. This color signals the need for project manager intervention to restore full communication.

The numbers on the arrows reflect the weight of the connection – a calculated communication intensity coefficient that combines message frequency, exchange quality, and average delay time. A value close to one indicates high intensity and stability of exchange, while low values signal weak or unstable interaction. These values are calculated automatically based on data from corporate communication platforms such as Jira, Slack or Teams.

For a project manager, such a map is an analytical tool that allows them to quickly identify bottlenecks in the interaction between teams. If, for example, the connections between the marketing and hardware teams have a low weight or are colored red, it means that changes in software logic or AR content are not synchronised with marketing scenarios. In this case, the manager can quickly schedule a short inter-team meeting or appoint a coordination specialist.

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It is advisable to calculate such a map regularly – at least once per sprint, and in intensive projects with parallel development of hardware and software – weekly, in order to record the dynamics of changes in communication links. It is not necessary to show the map directly to the teams, as it performs an analytical function for the manager. However, aggregated results, such as a decrease in intensity or an increase in delays, can be demonstrated at retrospectives as objective indicators of team interaction. Thus, the network map is not only a visualisation but also a tool for managing the quality of communication in a complex IT project.

The resulting graph allows the IT manager to immediately identify weak communication channels, assess the level of interaction between teams, and determine the need for synchronisation actions (additional meetings, clarification of technical requirements, or automatic notification via IS). Thus, the communication network map transforms subjective team interaction processes into a formalised analytical model suitable for monitoring, risk forecasting, and supporting management decisions in complex IT projects.

Conclusions

The study found that the complexity of IT projects for the development of cyber-physical digital marketing products is due to the high level of integration of various technological components, the multi-team development structure, and the need to maintain constant synchronisation between the physical, software, and marketing parts of the product. Unlike classic IT projects, which are dominated by software development, cyber-physical systems combine hardware devices, sensors, analytical modules, artificial intelligence algorithms, and elements of real-time user interaction. This creates fundamentally new requirements for information flow management, transforming communication between teams from a supporting process to a central element of the entire project's effectiveness.

The main factor complicating such IT projects is the need to ensure coherence between teams with different profiles that use different tools, methodologies, and languages to describe results. Any change in one of the subsystems, for example, in the design of a perception sensor block or in AR visualisation, instantly affects other components of the system, creating cascading risks for the entire project. Therefore, the key area for management optimisation is the development of an intelligent communication system that provides automated monitoring, analysis and visualisation of interactions between teams.

The practical implementation of the network communication map has demonstrated that the transition from descriptive management methods to analytical and visual ones allows complex communication processes to be transformed into an objectively measurable system. The constructed map reflects the actual intensity, frequency, delays, and quality of information exchange between teams, and also allows identifying central nodes and weak links that require intervention. In particular, the application of a formalised graph model $G(V, E, W)$ made it possible to calculate the weight coefficients of connections and network metrics such as communication density, centrality, and clustering coefficient. This provides the ability to quantitatively analyse interactions that were previously assessed only intuitively.

The system's intelligent modules, based on machine learning and natural language analysis technologies, provide automatic detection of risks of asynchrony, information gaps, and potential conflicts between teams. The analytical data obtained allows for the generation of management recommendations in real time — for example, on the need for urgent coordination of changes or a synchronisation session. Thus, the network map of interactions not only performs a visualisation function, but also becomes an integrated component of the management decision support system.

An important advantage of the developed approach is the transition to proactive communication management, where the system not only records the facts of communication, but also predicts possible failures and provides analytical signals to the manager about the need for intervention. This significantly increases the resilience of multi-team IT projects to dynamic changes in the environment and reduces the risks of asynchrony in development. Thus, the construction of a network communication map and the implementation of an intelligent analytical system become an effective tool for improving the manageability, coordination, and adaptability of IT projects for the development of cyber-physical digital marketing products, which is a necessary condition for their successful implementation in the digital economy.

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